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Market Acceptance of Animal Welfare-Improving Biotechnology: Gene Editing and Immunocastration in U.S. Pork

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Given general social resistance to agricultural biotechnology, viability of novel applications that improve animal welfare depends on market acceptance. Using a Becker–DeGroot–Marschak mechanism, we elicit willingness to pay (WTP) for pork produced using two animal welfare-improving biotechnologies. To evaluate U.S. consumer demand for these technologies, we model WTP premiums using a seemingly unrelated equations approach. Results indicate that negative attitudes toward biotechnology outweigh animal welfare benefits, though products still garner a premium due to heterogeneity in preferences. Findings support policies that balance the costs of regulatory approval with observed market acceptance and policies that accommodate animal welfare demands.

Key words: BDM mechanism, Certified Humane®, consumer demand, field experiment, seemingly unrelated equations

Introduction

Animal agriculture industries are responding to consumers' increasing interest in improving farm animal welfare conditions with innovative technologies and new methods of measuring animal well-being. In the pork industry, consumer interest in animal welfare is exemplified by recent legislative measures to eliminate confinement practices for breeding sows in Michigan, Florida, and California, among other campaigns (Videras, 2006; Tonsor, Wolf, and Olynk, 2009; Smithson et al., 2014; Ortega and Wolf, 2018). In addition to better living conditions, improvements in animal welfare include eliminating potentially painful routine procedures performed during the animal's lifetime. While often necessary for worker and animal safety or to ensure end-product quality, these procedures are increasingly addressed by novel biotechnologies. An example of this is the routine castration of male piglets in the U.S. pork industry. Castration, a surgical practice generally performed without anesthetic, prevents male sexual maturation. This eliminates the natural deposition and buildup of androstenone and skatole compounds in the meat, which affect pork product quality and are associated with a strong, unpleasant smell and off-flavor known as "boar

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taint" when the meat is cooked (Font-i Furnols, 2012). Castration also reduces male aggression (Guay et al., 2013).

Two novel biotechnologies that address painful castration in the pork industry are immunocastration and gene editing. Immunocastration uses a series of two vaccine injections to prevent the natural development of reproductive organs in boars. The vaccine stimulates an immune response (antibodies) to the boar's naturally produced gonadotropin-releasing hormone (GnRH), preventing puberty (Dunshea et al., 2001). Gene editing has various applications, including eliminating the need for castration by turning off the genes that control reproductive development. The most common gene-editing technologies currently used are CRISPR-Cas9 and TALENs, both of which allow for high-precision genome alterations (Bhat et al., 2017). Gene editing has already proven its potential for preventing boar taint in the meat of gene-edited male pigs, which remain in a prepubertal state, thus eliminating the need for castration (Menchaca et al., 2020). Both technologies prevent male pigs' sexual maturation without the need for painful castration procedures.

Biotechnologies, especially genetic biotechnologies in livestock, can carry a tremendous regulatory burden in terms of the time and financial costs necessary to receive approval. A prime example of this is the nearly 20-year approval journey that AquAdvantage genetically engineered salmon underwent in the United States prior to its approval in 2015, though further hurdles to commercial sale of the fish persisted even after approval (van Eenennaam, 2019). Given the possible risks in bringing these products to market, biotechnologies should have strong market viability to justify the costs of development and approval. To achieve this viability, sufficient consumer acceptance of the product, demonstrated by commensurate willingness to pay (WTP), must exist. Even when biotechnologies have received the necessary regulatory approvals for commercial availability, insufficient consumer acceptance of the product or—worse—outright rejection can nullify years of research and development and financial investments. A prime example of such marketing failures is recombinant bovine somatotropin (rbST) in the U.S. dairy industry, which received substantial consumer and retailer rejection (An, 2013). The Flavr Savr genetically modified tomato also experienced a short-lived market presence (Bruening and Lyons, 2000). Learning from these historical examples, this study investigates market acceptance and consumer WTP for gene editing and immunocastration in the context of their animal welfare benefits in the U.S. pork market.

These biotechnologies are poised to benefit both consumers and producers in the U.S. pork industry. For consumers, these technologies meet the demand for production methods that reduce painful procedures for animals by eliminating the procedures altogether. For producers, this elimination can reduce labor costs from the time and effort currently needed to deal with manual castration, may reduce input costs, reduce post-castration detriments to the animal, and may increase the level of care they can provide to the animals. While these novel technologies potentially offer enormous benefits to consumers, producers, and animals, their market evaluation using traditional research methods is complicated by their novelty and limited availability. Immunocastration is currently approved for use by veterinary prescription and available in the market, but its adoption is currently very low, with only 1.3 million pigs, approximately 0.13% of the live hog population, being immunocastrated worldwide in 2015 (Zamaratskaia and Rasmussen, 2015; Food and Agriculture Organization of the United Nations, 2021). Gene-editing technology is currently not approved for commercial agricultural use in the U.S. pork industry. Thus, the market viability of products produced using these technologies is subject to an accurate understanding of consumer acceptance.

We investigate market acceptance of novel products at the intersection of biotechnology and animal welfare in the U.S. pork industry. Several studies have previously explored consumer demand and WTP for each of these issues individually (see, e.g., Novoselova et al., 2005; Lagerkvist, Carlsson, and Viske, 2006; Meuwissen, Van Der Lans, and Huirne, 2007; Norwood and Lusk, 2011; Ortega and Wolf, 2018); however, the simultaneous evaluation of biotechnology and animal welfare has received less extensive treatment, particularly in U.S. pork. Negative consumer attitudes toward biotechnology can be ameliorated by direct consumer benefit from the technology (Lusk et al., 2004; Novoselova et al., 2005; Costa-Font, Gil, and Traill, 2008; Ribeiro, Barone, and

Behrens, 2016). Simply combining market premiums for increased animal welfare with discounts for biotechnology to determine a net effect is insufficient to accurately evaluate the market viability of products with both traits. Instead, the two must be evaluated simultaneously to determine whether consumers actively trade off between the premium and discount mentality to a net increase or net decrease in WTP. Consumer acceptance of immunocastration in the pork industry has been studied previously, but it has primarily been studied in European markets with an emphasis on qualitative acceptance or sensory preferences rather than consumer demand (Lagerkvist, Carlsson, and Viske, 2006; Font-i Furnols et al., 2008; Huber-Eicher and Spring, 2008; Latacz-Lohmann and Schreiner, 2019). Consumer demand for immunocastration, a nongenetic biotechnology, has not been researched in the American market in the context of animal welfare-improving biotechnologies alongside gene editing, a genetic biotechnology. Additionally, while previous studies on preferences over biotechnology have studied genetic engineering in depth, finding a general distaste for such technologies in agricultural products, research has been primarily limited to older genetic applications that do not include gene-editing techniques, such as CRISPR-Cas9 and TALENs, which are at the current forefront of biotechnology. Thus, this study investigates whether the market can support a premium or whether consumers will require a discount for pork products derived from two distinct porcine-specific biotechnologies with animal welfare-improving applications. We employ a novel approach to evaluating products that are not yet commercially available. This approach combines the presentation of available and unavailable products within a Becker–DeGroot–Marschak (1964) (BDM) experiment to elicit incentive-compatible WTP values for those products which otherwise could not be evaluated with a real experiment. Moreover, since consumer choices over novel products do not occur in a vacuum, this study explores consumer WTP for other production traits in the pork industry alongside these biotechnologies. These traits include local, "no added hormones," and Certified Humane® pork, which represent production traits often observed in the current grocery environment. In addition, for some consumers, these traits could also represent individual facets of animal welfare or the absence of biotechnology.

This study's primary contributions are first to quantify the market viability of novel, animal welfare-improving biotechnologies in the U.S. pork industry from the demand side. That is, we evaluate consumer receptivity to biotechnologies with such benefits to determine whether they represent a potential avenue for producers to meet consumer demands for greater animal welfare. In addition, our results inform the potential benefits of a label like the "no added hormones" label that denotes an already-present characteristic of conventional pork production, as well as the potential market for production practices which require stricter than conventional animal welfare standards. Further, this investigation employs a novel approach to real preference elicitation with commercially and physically unavailable products using an approach developed by Chavez et al. (2020) in a BDM mechanism (Becker, DeGroot, and Marschak, 1964).

Methods

We designed and conducted a field experiment in October and November of 2019 in a local, nonspecialty grocery store in Okemos, Michigan. All pork-consuming customers over the age of 18 were invited to participate in a two-part process. Participation was elicited in the middle of the customer's shopping experience, within the store's meat department. The experiments, however, were conducted out of sight of the pork case to prevent any biasing effects of posted prices. The first part of the process was a questionnaire eliciting sociodemographic information, subjective and objective knowledge of biotechnology in agriculture, attitudes toward animal welfare and biotechnology regulations in agriculture, and pork consumption patterns. The second part was an economic experiment, consisting of seven steps, in which participant WTP for six different pork boneless top loin chops with varying designations was elicited: conventional, local, "no added hormones,"[1] Certified Humane®, gene-edited, and immunocastrated. Both the gene-edited and immunocastrated labels included a note stipulating that the use of biotechnology was specifically "for improved animal welfare."

While gene-edited and immunocastrated pork were the primary focus of the study, the local, "no added hormones," and Certified Humane® pork chops were also included to more fully simulate the wide selection of products presented to a consumer in the typical shopping environment. The local and "no added hormones" labels are prevalent in several grocery stores in the area in which the study was conducted and so were chosen to more closely simulate the pork-purchasing environment. The Certified Humane® label was chosen to represent the facet of animal welfare to individually identify the magnitude of that effect for consumers. Additionally, since synthetic hormone use in agriculture has historically been associated with biotechnology (Lemieux and Wohlgenant, 1989; Aldrich and Blisard, 1998), "no added hormones" may represent the absence of biotechnology for some consumers and so was used in the analysis as a proxy for that trait without a direct animal welfare component. To comply with federal law, the "no added hormones" pork included an additional statement: "Federal regulations prohibit the use of hormones." While it should be noted that no pork in the U.S. is produced using added hormones, consumers have often been demonstrated to be unaware of this fact and treat conventional products as having been produced using added hormones (Yang, Raper, and Lusk, 2020).

A BDM mechanism was used to elicit WTP for the six types of pork chops. The BDM mechanism allows for incentive-compatible elicitation of WTP from participants in an auction format without requiring the presence of multiple participants at the same time (Becker, DeGroot, and Marschak, 1964). A BDM experiment can be performed with individual participants, making it ideal for a grocery or field setting, where often only one participant is available at a time (Lusk and Shogren, 2007; Canavari et al., 2019). Despite the manifold benefits of the BDM mechanism for this study, the method's limitations must also be considered. One limitation is that participants can become confused by the second-price auction incentives of the mechanism, instead operating as though the BDM employs a first-price auction format and incentives (Cason and Plott, 2014). Additionally, the incentive-compatibility of the BDM can be compromised through bid dependence on the random price distribution (Horowitz, 2006). These limitations can be addressed through best practices for conducting field experiments (Canavari et al., 2019). For example, withholding the random price distribution from the participant can eliminate or reduce the issue of bid dependence without having any negative impacts on the experiment's outcome. Our study design employed these practices to minimize the impacts of the limitations of the BDM mechanism on our results.

Participants were informed prior to bidding that only half of the presented types of pork chops were available at the current time, though they were not informed of which types were available.[2] In accordance with the findings of Chavez et al. (2020),[3] this approach allows for incentive-compatible bids to be elicited for all products in an experiment, even if some products are not yet commercially available. Because this approach also requires the enumerator to be honest upfront about the availability of products, it avoids any experimental deception and its commonly associated pitfalls for economic experiments (Rousu et al., 2015). Chavez et al. demonstrated the principle in a real choice experiment. We extend their work by applying the approach in an experiment using a BDM mechanism.

The experiment was conducted in a seven-step procedure for each participant. First, participants who qualified under the selection criteria were informed of the nature of the study, including the

[1] We specifically use quotation marks to denote "no added hormones" throughout because the claim is technically true of all U.S.-produced pork; however, the claim is only made on some products.

[2] The available products were the conventional, local, and "no added hormones" pork chops. Both immunocastrated and Certified Humane® pork chops are commercially available, but a supply of them was not available for our experiment; gene-edited pork is not yet approved for commercial sale.

[3] Chavez et al. (2020) found that, when presenting both available and unavailable products in a choice experiment, informing participants of the partial availability of products but not which products were specifically unavailable led to bidding behavior that was identical to that observed when all products in the experiment were available

benefits and risks of participation. Second, consenting participants were given the questionnaire to fill out independently, though the enumerator was available for assistance if needed. Third, the BDM mechanism was introduced. Participants were informed that they would be bidding on six different 1-lb packages of pork chops. Participants were not assumed to have preexisting knowledge of the biotechnologies employed in immunocastration and gene editing, so a neutral informational card was provided. The card contained a brief description of each technology, including how they could be used to improve animal welfare in pigs, as well as how they differed from traditional genetic biotechnology. Participants were allowed to interpret the remaining labels as they would in the natural shopping environment, though clarification was provided for those participants who requested it. It was also made clear that conventional pork referred to conventional, unlabeled pork. The informational card was highlighted for participant use for any biotechnology products with which they were unfamiliar. Participants were made aware that the selection was limited to the available types, though they were not informed of which types were available until after bidding was completed. After explaining the BDM mechanism (described in Steps 5–7), participants were allowed to ask any clarifying questions about the process.

With the process fully explained and understood by the participant, the fourth step was for participants to submit their bids for each pork type. While a practice round is often employed to ensure participant understanding of the mechanism, we opted to assess each individual's understanding verbally in accordance with feedback received in earlier, similar studies. Any nonnegative value constituted a valid bid. In the fifth step, the participant rolled a multisided die to determine the binding type of pork chop from among the available types of pork. In the sixth step, a random market price was generated for the binding pork chops using a computer tablet, with prices uniformly distributed between $0/lb and $5/lb. As with previous studies, participants were not aware of the distribution of random market prices (Lusk et al., 2001; Noussair, Robin, and Ruffieux, 2004; Ortega and Wolf, 2018). In the seventh and final step, the random market price and the participant's bid for the selected pork were compared. If the bid exceeded the random price, the participant purchased the pound of pork chops at the random market price and received compensation for participating in the study. If the market price exceeded the bid, no transaction occurred, and the participant received only the participation fee ($10). After each session, subjects were thanked for their participation and any further questions were answered.

Participants were asked to formulate their WTP for a single pound (approximately 2–3 chops) of each of the six types of pork under the rules of the BDM mechanism. A sample package of unlabeled pork chops was available to contextualize the 1-lb quantity and the general quality of the products in the experiment. While the types of pork were presented simultaneously to participants for bidding, their arrangement was randomized across participants to prevent any ordering effects. The presentation of the experiment and materials carefully excluded any reference prices for pork chops in order to prevent anchoring behavior in bidding (Canavari et al., 2019). The experiment was conducted with one participant at a time.

Data

The data consist of 1,218 product bids from 203 individuals. The mean age of individuals in the sample was 55 years, and approximately 52% of the sample was female (Table 1). Most of the sample had some form of higher education, with less than 7% having only completed high school or less. Over 37% had a postgraduate or professional degree. A little less than 10% of the sample was considered low income, while approximately 46% were high income. Our sample was comparatively more female, educated, and of a higher income than the U.S. population; however, this is expected given that we targeted primary shoppers of meat products. Participants' average level of self-reported subjective knowledge of GMOs in agriculture was 4.3 on a scale from 1 ("not at all knowledgeable") to 10 ("very knowledgeable"). Objective knowledge was measured with a five-question true or false examination of basic statements regarding genetics and science. The average score was 3.3 correct

Table 1. Sample Summary Statistics

Variable	Sample Mean or Share	United States
Female (%)	51.7	50.8[a]
Age (years)	55.0 (14.4)	37.8 (median)[a]
College education (%)	55.7	27.4[b]
Postgraduate or professional degree (%)	37.4	11.8[b]
Low income (<$40,000/year) (%)	9.90	32.1[c]
High income (>$100,000/year) (%)	46.3	30.4[c]
Household size	2.6 (1.3)	2.6[a]
Subjective knowledge[d]	4.3 (2.4)[d]	
Objective knowledge[e]	3.3 (1.5)[d]	
Farm contact (%)	37.0	
Stricter AW legislation (1–10)	7.2 (2.3)	
Gene-editing ban legislation (1–10)	4.8 (2.6)	
Consumption[f]	2.50 (1.0)[f]	

Notes: Numbers in parentheses are standard deviations.
[a]*Source:* U.S. Census Bureau (2019c).
[b]*Source:* U.S. Census Bureau (2019a).
[c]*Source:* U.S. Census Bureau (2019b).
[d]On a scale from 1 (“Not at all knowledgeable”) to 10 (“Very knowledgeable”)
[e]A score of 0–5 correct answers in a short true/false examination
[f]Consumption values corresponded to 1 = “Less than once a month,” 2 = “A few times a month,” 3 = “Once a week,” 4 = “A few times a week,” 5 = “Once a day,” 6 = “Multiple times a day.”

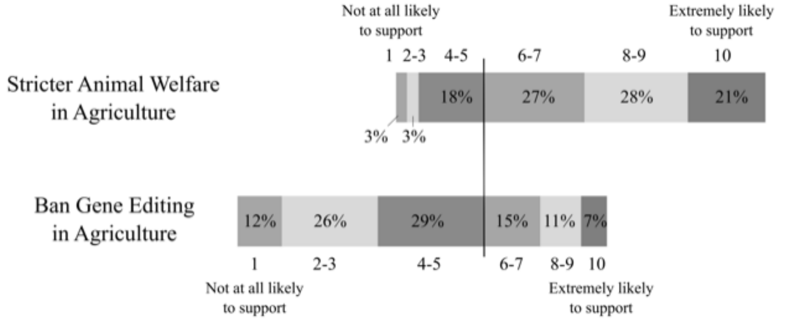

Figure 1. Distribution of Consumer Attitudes toward Stricter Animal Welfare and Gene-Editing Ban Legislation

responses out of 5. Approximately 37% of the sample had some form of agricultural or farm contact in the previous year. On a scale from 1 (“not at all likely”) to 10 (“extremely likely”), participants averaged a value of 7.2 in their self-reported likelihood to support legislation of stricter animal welfare standards and only a 4.8 in likelihood to support legislation banning the use of gene-editing technology in agriculture (Figure 1). In addition to knowledge and support for legislation, participant average pork consumption levels were elicited on a six-part scale ranging from “less than once a month” to “multiple times a day.” The average participant in the sample consumed pork between “a few times a month” and “once a week.”

Hypotheses and Empirical Model

Previous work on biotechnology and improved animal welfare provides a foundation for hypothesizing consumer response to products that combine them. We hypothesize that consumers will require a discount to accept gene-editing technology, despite the consumer benefit of increased animal welfare. Previous research has shown that biotechnology can become acceptable to a generally antagonistic consumer market if direct consumer benefits exist, but the opposition to the manipulation of genetics may exceed the potential gain from animal welfare benefits. In contrast, the immunocastration process has already been shown to be somewhat acceptable to consumers. Thus, in presenting immunocastration to consumers in light of its animal welfare benefits, we hypothesize that consumers will either be indifferent to immunocastration or willing to pay a premium due to the animal welfare benefits. Finally, for both gene-edited and immunocastrated pork, we expect that consumer attitudes toward biotechnology and animal welfare will significantly influence WTP. Given previous research, negative attitudes toward biotechnology should reduce WTP and positive animal welfare attitudes should increase WTP, though we do not necessarily expect the effects to be symmetric. Thus, we hypothesize that the reduction in WTP from negative biotechnology attitudes will outweigh the increase in WTP from positive animal welfare attitudes.

Premiums and discounts for each type of pork were calculated by subtracting the WTP for conventional pork from the WTP for each other type of pork for each individual. We modeled these deviations as a function of participant sociodemographic and consumption traits, subjective and objective knowledge of biotechnology and science relevant to agriculture, farm contact history, and attitudes toward possible legislation in agriculture. Individual regressions were specified for each type of pork but were estimated simultaneously using the seemingly unrelated estimation procedure (Weesie, 1999), which allows the error terms to be correlated across product equations for each individual while still allowing uncorrelated errors across individuals. This approach also allows for the estimation of robust standard errors to account for heteroskedasticity. A seemingly unrelated estimation approach has been used in the estimation of WTP models in studies which employed joint elicitation of WTP values for multiple goods or services because of this error-correlation structure (Bartels, 2006; Colson, Huffman, and Rousu, 2011; Shi, Gao, and Chen, 2014). The specification for the model is as follows:

$$\boldsymbol{PREM} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}, \tag{1}$$

where

$$\boldsymbol{PREM} = \begin{pmatrix} \boldsymbol{PREM}_1 \\ \boldsymbol{PREM}_2 \\ \boldsymbol{PREM}_3 \\ \boldsymbol{PREM}_4 \\ \boldsymbol{PREM}_5 \end{pmatrix} = \begin{pmatrix} \boldsymbol{X}_1 & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{X}_2 & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \boldsymbol{X}_3 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{X}_4 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{X}_5 \end{pmatrix} \cdot \begin{pmatrix} \boldsymbol{\beta}_1 \\ \boldsymbol{\beta}_2 \\ \boldsymbol{\beta}_3 \\ \boldsymbol{\beta}_4 \\ \boldsymbol{\beta}_5 \end{pmatrix} + \begin{pmatrix} \boldsymbol{\varepsilon}_1 \\ \boldsymbol{\varepsilon}_2 \\ \boldsymbol{\varepsilon}_3 \\ \boldsymbol{\varepsilon}_4 \\ \boldsymbol{\varepsilon}_5 \end{pmatrix} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}. \tag{2}$$

$\boldsymbol{PREM}_j$ are the vectors of dependent variables, measured as the deviation from the WTP for conventional pork of the bid for pork type j for each j in the set {local, "no added hormones," Certified Humane®, gene-edited, immunocastrated}, such that:

$$\mathrm{PREM}_{\mathrm{n,j}} = \mathrm{WTP}_{\mathrm{n,j}} - \mathrm{WTP}_{\mathrm{n,Conventional}}. \tag{3}$$

For each individual n, $\boldsymbol{X_1}$ to $\boldsymbol{X_5}$ are vectors of explanatory variables in each equation, such that $\boldsymbol{X}_j$ for equation j consists of explanatory variable vector $\boldsymbol{X}_{jn}$ for individual n, with corresponding coefficient vectors $\boldsymbol{\beta}_1$ to $\boldsymbol{\beta}_5$, which are to be estimated. The error terms are contained in the vectors $\boldsymbol{\varepsilon}_1$ to $\boldsymbol{\varepsilon}_5$ and are assumed to have an expected value of 0 and a constant variance and to be correlated within products but not across participants.

Results

The mean bid for conventional pork was \$3.07/lb, with a standard deviation of \$1.54/lb and a maximum of \$9.00/lb (Table 2). The mean premium for gene-edited pork was \$0.06/lb, with a

Table 2. Summary Statistics of Bids and Premiums (in $/lb)

	Mean	St. Dev.	Min.	Max.	Parametric *p*-Value	Nonparametric *p*-Value
Direct bids ($N = 203$)						
Conventional	3.07	1.54	0	9		
Gene-edited	3.13	2.03	0	10	0.612	< 0.01
Immunocastrated	3.23	1.96	0	11	0.139	< 0.01
Local	3.85	1.96	0	11	< 0.01	< 0.01
Certified Humane®	4.01	2.07	0	10	< 0.01	< 0.01
"No added hormones"	3.68	1.94	0	12	< 0.01	< 0.01
Premiums						
Gene-edited	0.06	1.65	−9	3		
Immunocastrated	0.16	1.52	−9	5		
Local	0.78	1.39	−9	6		
Certified Humane®	0.94	1.37	−5	6		
"No added hormones"	0.62	1.31	−9	6		

Notes: Parametric and nonparametric tests compared the bids for each type of pork against conventional pork.

standard deviation of $1.65/lb. This result supports the finding by Yunes et al. (2019) that a majority of consumers (in the Brazilian market) accept pork from gene-edited pigs. The average premium for immunocastrated pork was $0.16/lb, with a standard deviation of $1.52/lb. In comparison, the mean premiums for Certified Humane®, local, and "no added hormones" pork were $0.94/lb, $0.78/lb, and $0.62/lb, respectively. The relatively large standard deviations of the premiums indicate that some individuals in the sample would demand a discount relative to conventional for all five types of pork or, rather, that some consumers prefer conventional pork. Between 3.4% (Certified Humane®) and 19.2% (gene-edited) of consumers required discounts to purchase nonconventional types of pork. Substantially more individuals, however, were willing to pay premiums, with between 47.8% (gene-edited and immunocastrated) and 68.0% (Certified Humane®) of participants bidding more for nonconventional types of pork over conventional. Additionally, the considerably higher mean premiums for the types of pork which do not employ biotechnology indicates that, on average, consumers are willing to pay more for nonconventional pork produced without biotechnology.

Boxplots of consumer WTP distributions indicate that most consumer premiums are small compared to a few discounts of considerably greater magnitude (Figure 2). Parametric two-sided *t*-tests of bids indicate no significant difference between conventional and gene-edited ($p = 0.61$) or immunocastrated ($p = 0.14$) pork, while Certified Humane® ($p < 0.01$), local ($p < 0.01$), and "no added hormones" ($p < 0.01$) pork all have statistically significant premiums over conventional pork. In contrast, nonparametric Wilcoxon sign rank tests of bids indicate statistically significant premiums for every labeled variety of pork over conventional pork. Therefore, we find evidence that consumers are on average either indifferent to or willing to pay a premium for gene-edited and immunocastrated pork. Plotting the distributions demonstrates an overarching similarity in distribution across product premiums. Notably, the distributions of premiums for gene-edited and immunocastrated pork are significantly different from those of Certified Humane®, local, and "no added hormones" pork.

Model Results

The seemingly unrelated estimation results show that age has a significant negative influence on the premiums consumers are willing to pay for all of the evaluated types of pork (Table 3). Despite being significant, the magnitude of this effect is relatively small and negative in all cases, indicating

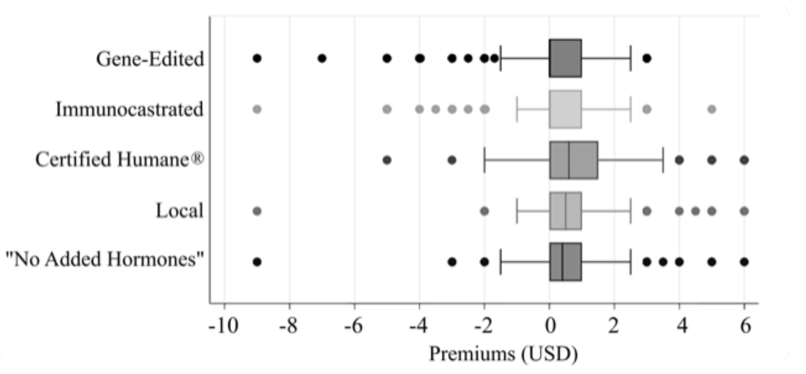

Figure 2. Boxplots of Premiums (in $/lb)

Table 3. Seemingly Unrelated Equation Model Results (*N* = 203)

Variable	Gene-Edited	Immuno-castrated	Certified Humane®	Local	"No Added Hormones"
Female	0.19	0.08	0.48***	0.26	0.23
	(0.21)	(0.19)	(0.17)	(0.18)	(0.17)
Age	−0.02***	−0.02**	−0.04***	−0.03***	−0.02***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
High school	−0.22	−0.39	−0.47	−0.68	−0.62
	(0.76)	(0.73)	(0.34)	(0.87)	(0.77)
Postgraduate	−0.30	−0.25	0.15	0.31	−0.05
	(0.22)	(0.20)	(0.19)	(0.19)	(0.18)
High income	−0.05	0.33*	−0.11	−0.07	0.05
	(0.22)	(0.19)	(0.16)	(0.19)	(0.17)
Consumption	−0.03	0.08	−0.16*	0.07	−0.05
	(0.10)	(0.11)	(0.09)	(0.09)	(0.08)
Household size	−0.01	−0.06	0.04	−0.05	0.02
	(0.10)	(0.10)	(0.07)	(0.07)	(0.07)
Objective knowledge	0.15*	0.05	0.06	−0.03	0.00
	(0.08)	(0.08)	(0.06)	(0.06)	(0.07)
Subjective knowledge	−0.09	−0.05	−0.03	0.00	0.03
	(0.06)	(0.05)	(0.03)	(0.05)	(0.04)
Farm contact	−0.20	−0.28	0.06	0.33*	−0.08
	(0.25)	(0.21)	(0.16)	(0.19)	(0.17)
Stricter animal welfare support	0.07*	0.08**	0.08**		
	(0.04)	(0.04)	(0.04)		
Gene-editing ban support	−0.15***	−0.16***			0.02
	(0.06)	(0.05)			(0.05)
Constant	1.69**	1.33*	2.46***	2.18***	1.72***
	(0.69)	(0.73)	(0.67)	(0.53)	(0.66)
R^2	0.15	0.14	0.26	0.14	0.09

Notes: Single, double, and triple asterisks indicate statistical significance at the 1% ($p < 0.01$), 5% ($p < 0.05$) and 10% ($p < 0.1$) level, respectively. Numbers in parentheses are robust standard errors.

that older individuals are willing to pay smaller premiums. Age is the only consistently significant variable across the five pork products under consideration.

Animal Welfare-Improving Biotechnologies

Results indicate that premiums for gene-edited and immunocastrated pork were not largely driven by sociodemographic variables, with the exception of age and, in the case of immunocastrated pork, high income. High-income individuals were significantly more likely to pay more for immunocastrated pork. Instead, WTP for these types of pork was most strongly influenced by attitudes toward animal welfare and biotechnology. The two variables that act as proxies for these attitudes are the likelihood of supporting stricter animal welfare regulations, a proxy for a positive attitude toward animal welfare in agriculture, and the likelihood of supporting a gene-editing technology ban in agriculture, a proxy for negative attitudes toward biotechnology. Both variables were significant in the gene-edited and immunocastrated cases. Support for a gene-editing ban had a negative effect, corresponding to an approximately $0.16/lb reduction in WTP for a 1-point increase over the mean on a 10-point scale. This indicates that individuals who were more likely to support a ban on biotechnology in agriculture were willing to pay less on average for pork produced using biotechnology, which is to be expected. In contrast, support for stricter animal welfare regulations had a positive effect (approximately $0.07–$0.08/lb) on both types of pork, indicating that individuals who were more likely to support stricter animal welfare standards were willing to pay more for both types of technology. This is evidence that consumers viewed both gene-edited and immunocastration in the context of eliminating conventional castration procedures as being potentially welfare-improving innovations. However, this finding may be influenced by the framing of the information provided about these technologies. Even so, these results present evidence of the stronger effect among these two attitudes, with the negative impact of a dislike for biotechnology having twice the magnitude of the positive impact for the animal welfare benefits. This is true for both technologies. Hence, our results suggest that consumer distaste for biotechnology in agriculture exceeded the consumer benefits of improved animal welfare such that there was a net negative impact on WTP from these attitudes at the mean. However, this net negative impact only occurred in individuals with strong opinions on both animal welfare and biotechnology in agriculture.

In addition to the attitude variables, objective knowledge of science relevant to biotechnology in agriculture significantly increases premiums for gene-edited pork. Interestingly, the objective knowledge coefficient was almost identical in magnitude to that of support for a gene-editing ban. However, it was positive and indicates that individuals who were more knowledgeable about genetics and the scientific basis for genetic biotechnology were more willing to pay for gene-edited pork. Within the sample, support for a gene-editing ban and objective knowledge had a correlation coefficient of −0.32. This suggests that increasing knowledge of genetics and biotechnology decreased opposition to their use in agriculture. This finding was consistent with those of other studies that determined a positive link between knowledge or level of information and acceptance of genetic biotechnology in agriculture (e.g., Baker and Burnham, 2001; Wolfe et al., 2018; Shew et al., 2018). On the other hand, this result contrasts those of Yunes et al. (2019), who found no significant relationship between gene-editing acceptance and objective knowledge. This discrepancy, however, could be attributed to differences between American and Brazilian consumers. Other studies have similarly found no link between objective knowledge and acceptance of genetic biotechnology (House et al., 2004).

Our findings may differ due to differences in traditional genetic biotechnology and gene-editing biotechnology. Gene editing may be more acceptable to consumers who are more knowledgeable about the underlying science due to gene editing being a less invasive technique than traditional methods. This is the case for the acceptability of medical gene-editing applications in humans (Scheufele et al., 2017). Additionally, because gene-editing applications have the potential for direct human health benefits through medical advances, it is also possible that greater acceptance of this technology at large could generate greater acceptance in agricultural applications. This is especially important given that the public has demonstrated that public engagement and discourse should be crucial precursors to the implementation of gene editing (Scheufele et al., 2017).

Animal Welfare Certified Pork

The results for Certified Humane® pork were consistent with previous findings of consumer value for animal welfare-certified products. In addition to age, gender was a significant determinant of WTP for Certified Humane® pork. The gender coefficient indicates that women were willing to pay an additional \$0.48/lb of Certified Humane® pork chops than men. This finding is in line with those of McKendree, Croney, and Widmar (2014) and Miranda-de la Lama et al. (2017), who observed that women tended to be more concerned with or give greater importance to animal welfare and consequently would value it more highly. Consumption was also statistically significant (at the 10% level) and negative, indicating that individuals who consumed greater amounts of pork were willing to pay less for welfare-certified pork chops. Finally, greater support for stricter animal welfare regulations positively and significantly affected WTP for pork produced with stricter voluntary animal welfare standards. Though these standards were subject to an individual's interpretation of an often-vague label, they technically included, among other things, minimum space and facilities requirements and limitations on painful procedures such as castration. The magnitude of the coefficient on support for stricter animal welfare was approximately \$0.08/lb, similar to those of gene-edited and immunocastrated pork. This indicates that animal welfare support had a similar influence on WTP for pork with biotechnology-improved animal welfare and pork labeled with stricter animal welfare standards. Nevertheless, the Certified Humane® production standards carry stricter requirements than conventional agriculture, without the inherent detraction of biotechnology. Thus, Certified Humane® pork commands a larger overall premium, on average, than the two biotechnologies. This finding was reflected in the average premium for Certified Humane® pork of \$0.94/lb relative to the \$0.06/lb average premiums for gene-edited pork and \$0.16/lb average premium for immunocastrated pork (Table 2). Ultimately, the results for Certified Humane® pork chops demonstrate the value consumers had for animal welfare in the pork industry and provide a stark contrast to the relatively lower value for improved welfare achieved through biotechnological means.

Local and "No Added Hormones" Labels

In addition to evaluating biotechnologies' market viability with animal welfare-improving applications, we investigated other products and marketing strategies in the pork industry. The "no added hormones" and "local" labels could speak to consumer demand for production methods that eschew conventional practices. Individuals who spoke with a farmer about agriculture in the last year or visited a farm were willing to pay significantly (at the 10% level) higher premiums for local pork. This is to be expected: Individuals who have had a personal connection with farmers in the past year would arguably be more likely to directly support those or similar farmers, assuming that contact occurred near an individual's place of purchase.

For pork labeled as produced with "no added hormones," there were no statistically significant explanatory variables aside from age. On average, though, consumers were willing to pay a premium for this type of pork. Support for banning gene editing in agriculture for "no added hormones"-labeled pork was statistically insignificant. This shows that individuals who dislike biotechnology were not necessarily opposed to all production practices that might employ scientific advances. In that case, we would expect a significant positive effect on WTP for pork explicitly labeled as produced without additive biochemical agents. Instead, this attitude had a significant effect only on those technologies that are specifically engineered.[4]

Policy Implications and Market Considerations

Our results have implications for both policy considerations and pork marketing strategies. Addressing the founding premise of this study, we find that both gene editing and immunocastration are viable options in a Midwestern market when used to improve animal welfare. Consumer indifference—or even a willingness to pay a slight premium for these practices relative to conventional pork—indicates that, under conditions where additional costs do not exceed revenues, these technologies could be profitably applied to improve animal welfare. Producers and industry stakeholders should carefully consider the benefits of using these technologies to improve the pork industry's sustainability and public image, given our observed market acceptance levels. Further, policy makers should be mindful of the degree of regulatory oversight for these technologies (particularly gene editing) to ensure that achieving commercial approval is both economical and scientifically validated. Our findings of market viability for gene-edited pork products, at least in the Midwest, also demonstrate the potential for other future gene-editing applications in animal agriculture. There is no evidence of outright rejection of gene-edited animal products in our results, though the acceptance we observe is likely due to the attendant benefit of animal welfare improvement.

Among the most salient of our findings for the broader animal agriculture industry is the relative importance of consumer distaste for biotechnology, a net negative even when accounting for biotechnology's benefits in improving animal welfare. It is apparent from our results that a consumer benefit of these technologies, such as animal welfare improvement, should be a clear aspect of their use if they are to gain adequate consumer acceptance. In this respect, our findings corroborate those of others (Lusk et al., 2004; Novoselova et al., 2005; Costa-Font, Gil, and Traill, 2008; Ribeiro, Barone, and Behrens, 2016). Producers who choose to adopt them should be mindful of the importance of the consumer benefit in marketing their products to minimize discounting behavior and maximize acceptance. However, it is also important to note that the complexities of the pork industry's organization make the decisions that influence marketing crucial to all stakeholders. While pork producers may directly influence pork marketing through initiatives such as the Pork Checkoff, other major players—such as processors and food retailers—should be similarly conscientious of their marketing efforts and shared objectives of maximized consumer acceptance. The demonstration of a greater impact of rejection of biotechnology than demand for stricter animal welfare suggests that industry participants and producers should be mindful of which biotechnologies they advocate for approval because these could potentially lead to negative consumer attitudes toward the industry as a whole.

In addition to recognizing the dynamic between consumer attitudes against biotechnology and for stricter animal welfare, our results point to the role of consumer knowledge in defining these attitudes. Our results indicate that consumers who are more knowledgeable about the biotechnology science are more accepting of the technology's use in production and willing to pay more. This indicates a counterbalancing effect of objective scientific knowledge on negative biotechnology attitudes. Thus, the introduction of such technologies should be accompanied by aggressive educational campaigns that aim to increase consumer knowledge of what the biotechnology does and how it achieves the desired outcomes.

The value we observe for Certified Humane® pork illustrates the market potential for animal welfare-certified products in the market, with the highest average premium among the evaluated products of \$0.94/lb. These premiums are substantial enough to merit consideration by producers in

[4] It is possible, however, that this absence of effect is due to the federally mandated explanation beneath any "no added hormones" label in pork, which points out that no pork is produced with added hormones; however, very few individuals in our sample indicated their awareness of this standard or their attendance of this information.

the potential trade-offs of increased revenues from premiums and increased costs to meet third-party certifiers' stringent welfare standards (e.g., the Certified Humane® program). However, it should be noted that these premiums cannot be assumed constant across the entire animal since premiums for pork produced with stricter welfare standards vary by the cut of meat (Ortega and Wolf, 2018). Even so, in the case of boneless top loin chops, a premium of $0.94/lb is substantial and deserves consideration in a market that has thus far been hesitant to offer credence trait-differentiated products, which are otherwise ubiquitous in livestock products (Shanker, 2018). The potential for consumers to support legislation that requires stricter industry-wide animal welfare standards may be ameliorated by an increasing proportion of producers providing products such as Certified Humane® pork. Thus, a policy that supports and incentivizes animal welfare-centric production by reducing costs for those certified by a Certified Humane® program may be the optimal means for reaching a market offering that caters to consumers of all persuasions. Alternatively, as a means of protecting conventional producers, a federally organized animal welfare certifying program, similar in structure to the USDA National Organic Program, might benefit consumers who desire stricter animal welfare standards while helping to consolidate and standardize the premiums received by producers. Such a program might be more consistent with the recommendation of Harvey and Hubbard (2013) to avoid producer subsidization and instead facilitate consumer subsidies for animal welfare-friendly products. Though not identical in nature to the USDA organic marketing program, an alternative might be to establish a federal livestock welfare committee to help develop a distinction between required animal welfare practices and recommended practices. The USDA's Agricultural Marketing Service (AMS) currently offers a version of this, though it currently lacks widespread consumer awareness or a clear delineation between recommended practices and federally required practices. Strengthening the AMS program or developing a new, more focused program could preserve conventional practices that meet the broader demands of the market while also providing a venue to build niches in the industry to cater to demands of consumers more focused on strict animal welfare. A similar strategy has already been employed by the Canadian National Farm Animal Care Council and their Codes of Practice, with some success with industry and consumer engagement (National Farm Animal Care Council, 2021).

Producers may benefit from highlighting their pork traits that are of interest to consumers, such as using no added hormones, as this clearly has value to consumers. This is already happening on pork products in some stores, but there should be an industry-wide push for improving consumer knowledge of these standard practices to prevent some producers from being misrepresented by deceptive marketing or labels by not putting forward a unified front. This strategy, however, depends on the distribution of benefits. If the sale of a portion of pork products at a premium under "no added hormones" labels increases the overall market price received by producers, then this strategy, as currently implemented, is beneficial to all actors in the pork supply chain. If, however, the labeling of some pork products as "no added hormones" reduces consumer value for conventional pork and, consequently, the market price received by producers, then this strategy is detrimental to producers. In that case, a new policy may be warranted in addition to the already required fine print of the "no added hormones" label to ensure no pork producers are misrepresented by competing products. Additionally, the existence of labels that point out that "no added hormones" were used may contribute to a broader consumer misperception of animal agriculture industries, which is already characterized by views of unnecessary or gratuitous use of hormones, antibiotics, and other additives (Lusk, Roosen, and Fox, 2003; Bowman et al., 2016). This appears to be the case given the premiums we observe in this study for pork labeled "no added hormones" relative to conventional pork, which are effectively identical. Our results are consistent with those of Yang, Raper, and Lusk (2020). In this case, the reduction in confidence and potential loss of some consumers may outweigh the benefits of this labeling strategy, and an industry-wide campaign to accurately represent producers at large may instead be warranted. These dynamics are subject to the highly vertically integrated pork industry's inherent complexities and merit further research of their own.

Conclusion

This study explored consumer acceptance and preference for animal welfare-improving biotechnologies in the pork industry. In addition, it investigated demand for other types of pork in the context of consumer attitudes toward biotechnology and animal welfare in agriculture. Using results from a field experiment, we observed that a Midwestern market can support a small premium, on average, for pork produced using animal welfare-improving biotechnologies. Consumers were willing to pay substantially higher premiums at the mean for local and Certified Humane® pork and pork labeled as produced using no added hormones. Further, we found that negative attitudes toward biotechnology had a stronger influence on WTP than positive attitudes toward animal welfare for pork produced using biotechnology with animal welfare-improving applications. The animal welfare-improving benefits did not appear to substantially outweigh consumers' propensity to reject biotechnology in agriculture, resulting in a net reduction of WTP for these technologies for consumers who both value animal welfare and the absence of biotechnology. As with other studies, however, we also found that objective knowledge of the basic science underlying these technologies can mediate these negative attitudes and increase the acceptability of these technologies in pork production.

This study provides essential insight into the interactions of consumer attitudes regarding animal welfare and biotechnology, but it is limited in some respects. Because our field experiment required a very concise format, we use attitudes toward potential legislation as a proxy for attitudes toward animal welfare and biotechnology. While not unrepresentative of those attitudes, future research will ideally include more comprehensive inventories of these attitudes to determine their influence on consumer acceptance of biotechnologies of varying benefits. Future studies that focus on other regions of the United States will also be useful for determining the generalizability of our results. Additionally, the animal welfare benefits of the evaluated biotechnologies are an improvement over practices many consumers are already unaware of in the pork industry; however, we chose castration alternatives due to their ability to evaluate both a genetic and a nongenetic biotechnology with similar welfare outcomes. Future research should identify animal welfare outcomes that are more salient to prominent consumer concerns to determine whether consumer awareness of current practices influences their acceptance of biotechnologies that mitigate the need for such practices. Finally, while our study evaluates preferences over these technologies with no assumed prior knowledge of immunocastration or gene editing among consumers, future work may measure consumer information and understanding of these technologies to determine impacts on WTP and consumer acceptance.

Our findings have important implications for future market strategies in the pork industry and livestock industries' policies at large. Producers and marketers are already sensitive to consumer acceptance of various technologies in agriculture, but our findings indicate that emphasizing the direct consumer benefits of those technologies—such as improved animal welfare—can increase consumer acceptance and WTP. Similarly, policy makers and researchers must be mindful of consumer acceptance of and benefit from biotechnological advances in evaluating these advances' development and approval. Our results indicate that increasing consumers' objective understanding of the basic science underlying agricultural biotechnology may be a worthwhile endeavor as such knowledge reduces rejection of the technology. Policies can encourage consumer awareness of this science by including a minimum informational provision requirement for these products upon approval, like the federally required note on the industry-wide restriction on the use of hormones in pork when labeled as produced with no added hormones. Finally, the high premiums consumers are willing to pay for pork with a welfare certification combined with an increased WTP associated with individuals who would support stricter animal welfare regulation in agriculture indicates there may be a market for a federally operated animal welfare certifying program, similar to the USDA organic program.

Future endeavors to improve animal agriculture practices through biotechnological advances hold great potential for progress in these industries, but they must be cautiously approached with the consumer's perspective as a priority. Ignoring consumer rejection of these technologies could lead to inefficient use of resources, while focusing too much on consumer appeal could hinder progress. It is essential to continue pursuing an understanding of how consumer attitudes toward various issues in animal agriculture play into their overall evaluation of a production technique or technology, as these dynamics can easily dictate the future of conventional livestock production and industries.

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