MARKET OPPORTUNITIES FOR THE USE OF BIOTECHNOLOGY TO IMPROVE FARM ANIMAL WELFARE

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Agricultural, Food and Resource Economics – Doctor of Philosophy

2021

ABSTRACT

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Novel biotechnologies offer an avenue to improve farm animal welfare but face several potential challenges in the market. Consumers are demanding stricter animal welfare standards in livestock production but are wary of biotechnology applications in food and agriculture. This dissertation explores the market opportunities for biotechnology and animal welfare improvements in the pork and dairy industries. I take a comprehensive approach, employing experimental methods to investigate consumer receptivity to products with biotechnology and animal welfare traits; and producer intent to adopt such technologies into their operations.

The first chapter explores the economic foundations, challenges, and opportunities for consumer acceptance of biotechnology applications in animal welfare, especially gene editing techniques. I review the food economics literature on consumer acceptance of biotechnology to improve animal welfare and discuss the emerging opportunities for future improvements through gene editing. I also discuss industry and policy implications of consumer demand for animal welfare and biotechnology in livestock applications.

One of the first challenges at the nexus of biotechnology and animal welfare is effective communication between producer and consumer. Product labels communicate valuable traits to consumers but, when a single label represents multiple traits, communication can be hindered by consumer misinformation. The second chapter addresses the emerging phenomenon of redundant labels, which can address misinformation by explicitly indicating included qualities within a comprehensive label. I utilize data from a field experiment on willingness to pay for redundant

labels in the U.S. organic fluid milk market when consumers are either uninformed or informed of the redundancy. Market share simulations demonstrate the market impacts and effectiveness of introducing a redundant label as a response strategy to recapture market share lost to increasingly prevalent individual labels.

The third chapter also employs a field experiment and investigates the market viability of novel biotechnology applications that improve animal welfare. I evaluate U.S. consumer demand for pork produced using two animal welfare-improving biotechnologies – immunocastration and gene editing. Results indicate negative attitudes toward biotechnology outweigh animal welfare benefits, though products still garner a slight average premium due to heterogeneity in preferences. Findings support policies that balance regulatory approval costs with observed market acceptance and policies that provide for animal welfare demands.

Market opportunities are dictated by all decision-makers in the market, including both consumers and producers. The complexities of the decision to adopt gene-editing technology at the farm gate are likely to be greater than a simple matter of profitability. In the final chapter, I investigate *ex-ante* technology adoption intent to address how non-pecuniary motivations influence a dairy producer's decision to adopt gene-editing technology with animal welfare-improving benefits. This chapter extends random utility theory to account for situational influences on producer decision outcomes. I employ the experimental vignette methodology, and a random parameters ordered logit modeling approach. Findings point to a general resistance among dairy farmers towards gene-edited genetics, even with an animal welfare-improving application. Farmers can, however, become more amenable to the prospect of adopting gene-edited genetics through situational influences.

Dedicated to my grandparents,
for their humble legacy of hard work
and the gift of a love of the land
as my inheritance

ACKNOWLEDGMENTS

I cannot adequately express my gratitude to my advisor, Dr. David Ortega, for his guidance, support, and mentorship. This dissertation would have been twice as long and half as good without his help and encouragement. The greatest lessons I've learned in these four years were born from his tireless dedication and enduring patience. I will be forever grateful for the wisdom and knowledge he has imparted to me and the growth he fostered. I would also like to thank the other members of my committee, Drs. Chris Wolf, Melissa McKendree, and Janice Swanson, for their direction and advice, for keeping me continually improving, and for teaching me the power of collaboration.

I am grateful to the faculty in the AFRE and Economics departments at MSU for the education and skills they gave me. Thank you to my classmates and colleagues, without whom I wouldn't have made it far in this program, nor would I have enjoyed the ride as much as I did. I also gratefully acknowledge the USDA Agricultural Marketing Service, MSU College of Agriculture and Natural Resources, and MSU Department of Agricultural, Food and Resource Economics for their provision of funding and resources to make both this research and my education possible.

I'd like to acknowledge the Christian community in Lansing, who kept me connected to my faith through the challenging times of graduate school. And above all, I want to thank my family for their unwavering love and support. I have been blessed beyond measure by and through them and whatever I have achieved is because they were there for me through it all.

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KEY TO ABBREVIATIONS

GEn	Genetic Engineering
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
TALEN	Transcription Activator-Like Effector Nuclease
WTP	Willingness to Pay
rbST	Recombinant Bovine Somatotropin
bTB	Bovine Tuberculosis
GM	Genetic Modification/Genetically Modified
BDM	Becker-DeGroot-Marschak (mechanism)
GMO	Genetically Modified Organism
USDA	United States Department of Agriculture
OLS	Ordinary Least Squares
FDA	(U.S.) Food and Drug Administration
GE	Gene-Edited/Gene Editing
RPOL	Random Parameters Ordered Logit

CHAPTER 1

Economic Foundations for the Use of Biotechnology to Improve Farm Animal Welfare

This chapter was previously published in Trends in Food Science and Technology and is reproduced with the permission of the coauthors. DOI: https://doi.org/10.1016/j.tifs.2019.07.002

Ufer, D., Ortega, D. L., & Wolf, C. A. (2019). Economic foundations for the use of biotechnology to improve farm animal welfare. *Trends in Food Science & Technology*, *91*: 129-138.

Introduction

As standards of living increase, consumers are shifting their attention from the basic human need of simply acquiring food to making demands for food and the processes which produce it. These demands, which are often grounded in consumers' morals and ethics, range from sustainable production processes with reduced environmental impacts to natural or organic practices which appeal to consumers' sense of connection with nature. An additional example is fair trade or welfare certified foods, which are seen as produced with more integrity through higher standards for farm labor or livestock care. As these food credence attributes are perceived to exceed conventional standards of production, they often carry premiums through which consumers express their priorities by purchasing foods that represent the desired mix of credence benefits to suit their preferences. As such, producers are presented with both opportunities and challenges in meeting consumer demand for production traits. Opportunities exists for those who can adapt to consumer demands and provide the production traits consumers are demanding, potentially capitalizing on the premiums consumers are willing to pay. Challenges arise for those producers subject to increased costs to implement those production practices which are undercompensated by available market premiums. This is especially the case when consumer demands are expressed through legal measures rather than the market. A prime example of this opportunity-challenge dichotomy is revealed by consumer demand for farm animal welfare practices which are perceived to exceed conventional industry standards. In addition to the practices that consumers are demanding, producers may prefer to adopt a new technology or practice that is met with consumer opposition. The use of biotechnology in agriculture is just such an application. However, the rapid pace at which science is advancing in biotechnology has created something of a ‘perfect storm’ for these applications, as it becomes possible to meet those consumer demands with practices consumers may otherwise find objectionable.

The objective of this study is to explore the economic foundations for employing biotechnology to improve farm animal welfare and evaluate potential consumer response to such applications. The remainder of the paper is as follows: Section 2 explores consumer acceptance of biotechnology in animal agriculture, with a particular focus on genetic manipulation; Section 3 reviews consumer attitudes towards animal welfare, including differences in consumer and producer definitions of welfare; Section 4 explores the concepts identified in Section 3 in greater detail through the specific cases of the pork and dairy industries; Section 5 details the intersection of biotechnology and animal welfare in the science and policy arena. Section 6 concludes by discussing the future of biotechnology applications to improve farm animal welfare.

Consumer Acceptance of Biotechnology in Animal Agriculture

Biotechnology is a rapidly advancing field, with cutting-edge applications emerging in human medicine, biological research and agriculture. For these applications to be commercially viable, market demand must come from willing and accepting consumers. As such, understanding consumer attitudes towards biotechnology becomes essential before these technologies can be implemented and diffused through agricultural markets.

Biotechnology in agricultural applications refers to a range of biological tools that use living processes, organisms or systems to make or modify products or technology, improve plants or animals or develop microorganisms for agricultural use (USDA, 2019). Among the most prominent modern biotechnologies are genetic manipulation and the external production and use of exogenous hormones. Though similar in the goal of improving agricultural productivity through genetics, a wide variety of approaches exist for genetic manipulation, including genetic modification, genetic engineering and genome editing. While we discuss several biotechnological applications, the main focus of this paper is on genetic applications, specifically genetic engineering (GEn) and gene editing.[1]

Older studies indicated a majority of U.S. consumers found biotechnology to be quite acceptable in agriculture (Hoban, 1996). Some studies even found that between two-thirds and three-quarters of consumers had a positive perception of biotechnology, with those values being consistent with previous surveys (Cantley et al., 1999). However, these studies predate the widespread introduction of GEn foods, with the advent of such foods coinciding with a dramatic shift in consumer attitudes towards the food supply and production traits. Over the past two decades, consumers have become increasingly concerned about the origin of their food. Though U.S. consumers remain among the more accepting of GEn in the world, the general attitude has tended towards reluctance and negativity in recent years (Frewer et al., 2014).

Consumers now tend to hold an antagonistic view of GEn in agricultural applications (Novoselova, 2007; Ribeiro et al., 2016; Lin et al., 2019). This is exemplified in the preference for conventional production over that which employs GEn and is demonstrated in consumers discounting GEn foods in the marketplace. Consumers are consistently willing to pay more for conventionally-produced food than for food which was produced with GEn technology (Lusk et al., 2004; Novoselova et al., 2005; Costa-Font et al., 2008; Lusk et al., 2015). Costa-Font et al. (2008) noted that premiums for conventional foods relative to GEn foods could go as high as 110%, depending on the foodstuff. These negative attitudes were hypothesized to be driven by a variety of underlying factors, including moral and ethical concerns, a perception of unnaturalness

[1]For consistency, we use the terminology 'genetic engineering' though it should be noted that the literature discussed uses a wide variety of terms to identify foods which have been produced using genetic biotechnology.

or artificiality, and food safety concerns due to uncertainty regarding the long-term impacts of consuming engineered DNA (Verhoog, 2003; Frewer et al., 2014; Ribeiro et al., 2016). However, despite a general climate of negativity, there exists a fair amount of heterogeneity amongst consumers in terms of biotechnology acceptance. It has been hypothesized that the generally negative attitude may be heavily influenced by a small but obstinate subset of consumers who unconditionally reject genetically modified foods, aided by negative media influence, and that many consumers are uninformed or undecided (Kalaitzandonakes et al., 2004; Onyango & Nayga, 2004; Novoselova, 2007). For many, the perception of GEn as unnatural may not be sufficient cause to reject it, with many consumers instead adopting a rational risk-benefit approach (Hossain et al., 2004; Onyango et al., 2004; Frewer et al., 2011; Ribeiro et al., 2016). If an adequate case can be made for the benefits of the technology, particularly if they are tangible consumer benefits, GEn foods can become much more acceptable and even, in some cases, preferable to conventional products (Novoselova et al., 2005; Costa-Font et al., 2008; Ribeiro et al., 2016). This was observed by Costa-Font et al. (2008) in that, when foods were known to have a tangible consumer benefit, particularly relative to health or the environment, consumers were consistently willing to pay a premium, in some cases as high as 63% of the price of the conventional alternative. In addition, sociodemographic characteristics significantly influence willingness to accept GEn foods, with a 2004 study finding that young, white, college-educated males were the most likely to accept GEn biotechnology (Hossain et al., 2004). The degree to which consumers understand GEn biotechnology may also contribute to heterogeneity in attitudes, though studies have found inconsistent results as to whether more information and consumer knowledge actually increases acceptability of GEn biotechnology (Santerre & Machtmes, 2002; Scholderer & Frewer, 2003; Teisl et al., 2009). Sometimes consumer autonomy or the desire to be allowed to make informed decisions may be more important than understanding the technology itself. Kolodinsky and Lusk (2018) note that the Vermont mandatory labelling of GEn foods actually reduced consumer opposition to GEn foods by 19%.

While consumers have tended to express negative attitudes towards biotechnological applications in agriculture, they are not consistent across borders (Lin et al., 2019). A considerable amount of research has been conducted in the European Union, likely due to the E.U. policies restricting GEn agricultural products. However, these results should be cautiously interpreted and not applied to the U.S. For example, the number of U.S. consumers who consider food from operations which utilize GEn to be edible was double that of French consumers (Lusk & Rozan, 2006). This is consistent with the finding of Frewer et al. (2014) that European consumers were less willing to accept GEn animals than U.S. consumers. Furthermore, in Lusk et al.'s (2003) study on GEn corn-fed beef, European consumers placed a greater value on beef from animals which had not been fed with GEn feed than U.S. consumers. This is despite both European and U.S. livestock industries heavily utilizing GEn feeds, with the former importing GEn feedstuffs from countries which allow its cultivation.

Attitudes Towards Characteristics of Genetic Biotechnologies

Though the overall climate of consumer attitudes towards genetic biotechnology in agriculture is precarious at best, consumers have been less antagonistic towards some applications depending on the circumstances. Generally, consumers are more amenable to GEn in the context of plants than they are in animals (Cantley et al., 1999; Onyango et al., 2004; Frewer et al., 2013; Ribeiro et al., 2016). This is due to the perception that applications with animals may be harmful or dangerous, are unnatural and are subject to greater ethical concern (Frewer et al., 1997). This was evident in a 2004 Canadian study in which researchers concluded that, in the context of functional food development, consumers might be willing to increase acceptance of GEn plant foods but would likely continue to avoid GEn animal foods, regardless of potential personal benefit (Larue et al., 2004). This could lead to difficulties in genetic biotechnological applications in animal agriculture as consumer acceptance of GEn biotechnology has repeatedly been shown to be positively influenced by direct consumer or public benefit (Novoselova et al., 2005; Lusk et al., 2015; Ribeiro et al., 2016). These direct consumer or public benefits include healthier foods, more environmentally-friendly products, and increased animal welfare, among others. In one study of the benefits offered to consumers, which included quality improvements, environmental benefits and price discounts, animal welfare had the highest positive effect on consumer choice regarding GEn pork (Novoselova et al., 2005). In the particular application of genome editing, Shriver and McConnachie (2018), in a preliminary study, identified more favorable consumer responses to the technology when animal welfare improvements were the stated purpose of the modification.

Beyond the benefits of the application of genetic biotechnology in guiding consumer acceptance is the nature of the technology itself. Biotechnological techniques, even when narrowed to the field of genome editing and genetic engineering, are diversified and carry with them ethical and philosophical implications for consumers. In two studies focused on table grapes and apples, cisgenic applications, in which an organism’s own DNA or that of the same species is used for genetic improvements, were preferred to transgenic applications, which take DNA across species (Hudson et al., 2015; Edenbrandt et al., 2018). Edenbrandt et al. (2018) noted that traditional methods of grape production were preferred to any genetic biotechnological application, though they also observed that the disutility of the GEn grapes could be offset by the quality improvements from the technology such that consumer opposition was not an absolute impediment to the technology's use. Hudson et al. (2015) identified perceptions of naturalness as a factor in influencing overall approval, which is consistent with the cisgenic preference, as its applications tend to be naturally achievable through traditional methods, though the GEn biotechnology is more efficient and much quicker. This is corroborated by Lusk and Rozan's (2006) findings that consumers were more willing to accept ingenic plants, in which native DNA was re-introduced to the modified organism, than transgenic plants. Among the newest biotechnologies are CRISPR/Cas9 (clustered regulatory interspaced short palindromic repeats achieved using the Cas9 or 'CRISPR-associated 9' enzyme) and TALENs (transcription activator-like effector nucleases), which can edit genes within an organism without the introduction of foreign genetic material. The greater acceptability of alterations within a narrow family of genomes makes these new biotechnologies, excellent candidates for consumer acceptability in agricultural applications (Schultz-Bergin, 2018). The speed and cost with which animals produced using these technologies might become available relative to the traditional genetic engineering approval process will be subject to FDA requirements for approval. The FDA currently intends to regulate these intentionally edited organisms the same as new animal drugs (FDA, 2017). Genome editing using these technologies may further be more acceptable to consumers than more outdated methods as their precision may be perceived to decrease the risk profile of genetic modifications.

Examples from Dairy Production

Though there currently are no genetically engineered cattle approved for the dairy industry, biotechnologies have been employed for dairy and dairy product production with varying degrees of consumer acceptability. Among the most prominent cases of biotechnology in dairy was the use of recombinant bovine somatotropin (rbST) in cows for increased milk yield, GEn cultures in dairy products and GEn feeds in dairy rations. Consumers generally held negative attitudes towards the use of rbST in dairy production, owing to perceived food safety concerns and uncertainty regarding hormonal biotechnology (Aldrich & Blisard, 1998). Even so, rbST as a biotechnology was subject to the same ethical controversies as other biotechnologies. A 2002 survey in the UK found less than 10% of consumers found rbST use 'ethically acceptable' and nearly 60% believed it should not be licensed for use in the E.U. (Millar et al., 2002). The same study found that the more aware consumers were of the existence and use of rbST, the less acceptable it was. However, two studies on the effects of labeling of milk produced using rbST found that the availability of labeled milk itself improved consumer acceptance of rbST in milk production as it lowered their risk perceptions and allowed for informed consent to consume a hormonal biotechnological product (Zepeda et al., 2003). That consumers may simply want to be fully informed when making purchasing decisions regarding the use of any biotechnology in dairy products is important for potential applications to animal welfare and genome editing. The mass proliferation of negative attitudes towards rbST was sufficient to discontinue its use in the U.S. dairy industry in recent years, further highlighting the importance of understanding consumer acceptance of a hormonal biotechnology.

Though rbST represents perhaps the most widely understood biotechnology application in the dairy industry, the hypothetical use of genetic biotechnology in the dairy industry has been observed to exhibit a similarly negative response. In a study of Irish consumers' response to a hypothetical dairy spread produced using GEn to produce a direct consumer health benefit, the majority of participants rejected the product (O'Connor et al., 2005). This indicated that even when consumers are the intended beneficiary of the genetic biotechnology, negative attitudes may persist.

One further application of genetic biotechnology in the dairy industry with potential implications for consumers is the use of GEn crops for feeding dairy cattle. Despite the fact that between 70 and 90% of GEn crop biomass in the U.S. and worldwide is fed to livestock, most research on consumer attitudes towards GEn in dairy markets has been concentrated in European contexts (Young & Van Eenennaam, 2017). The research is particularly salient in this context as most milk in the E.U. is produced using GEn feeds but labeling milk products as such is not required. German consumers, in a study specifically looking at genetic modification (GM), have been found to exhibit positive willingness to pay (WTP) for ‘GM-free’ labels on dairy products and that they treat ‘GM-free’ labeled dairy products similar to organically produced dairy in terms of price shock protection (Punt et al., 2016; Dolgopolova & Roosen, 2018). Similarly, a 2009 report found that 76% of French consumers supported the ‘GM-free’ label and 93% thought it was wrong for farmers to feed their livestock GM feed without being obligated to explicitly inform the consumers of the product (Food Traceability Report, 2009). In a study across the E.U. on demand for U.S. beef, consumers had the highest WTP for beef labeled as not being treated with hormones and not fed GEn feeds and that the premium for those labels was greater than that of USDA Choice grade beef alone (Tonsor & Schroeder, 2003). This indicates that, at least amongst European consumers, negative attitudes towards GEn agricultural products extend beyond the animal itself, despite consistent evidence that biotechnologically-enhanced genetic materials do not pass through animals’ digestive systems into livestock products (Broll et al., 2005). The growing influence of similar domestic attitudes is evident in the dairy industry as some U.S. yogurt makers have begun to require that farmers certify their milk as being produced without GEn feeds (Geiger, 2016). Nevertheless, even in the face of considerable scientific evidence of negative consumer attitudes towards GEn food products, a 2014 social movement to eliminate GEn-fed dairy from a major coffee retailer was unsuccessful. This indicates that while consumers may not be completely comfortable with GEn feed or other GEn applications, their consumption priorities can overrule this discomfort (Robinson, 2014).

Consumer Preferences for Farm Animal Welfare

Defining Animal Welfare

One of the first difficulties in understanding consumer preferences for farm animal welfare is the definition of what constitutes animal welfare. Definitions across time and stakeholder groups vary considerably, with no single definition universally accepted (Cornish et al., 2016). Nevertheless, regarding consumer perceptions of animal welfare, several aspects are regularly observed as integral to acceptable animal welfare. These primarily include the animal's freedom to express natural behaviors and instincts; humane treatment, including a humane slaughter; access to the outdoors; and clean and hygienic living conditions (Harper & Henson, 2001; Napolitano et al., 2008; Clark et al., 2016; Wolf & Tonsor, 2017). These characteristics of animal welfare are not always given the same level of priority in consumers' definitions of animal welfare. For example, Napolitano et al. (2008) indicated that hygiene in production may in fact be more important to consumers than the state of naturalness. Additionally, consumers are not necessarily single-minded when approaching animal welfare, with a dual approach often employed. Frewer et al. (2005) identified animal health and the state of their living environment as the two main foundations for consumer definition of animal welfare while Swanson and Mench (2000) differentiated between a utilitarian versus a moral approach. This can become especially challenging for industry stakeholders when consumers adopt a zoocentric approach to animal welfare colored with anthropomorphism, where consumers project their own standards of human comfort and happiness onto animals (Clark et al., 2016).

Definitions of animal welfare also vary across stakeholder groups, with consumers and producers often holding very different ideas of what defines acceptable animal welfare. Where consumers tend to prioritize natural behaviors and access to the outdoors, producers tend to prioritize animal health, comfort and pain minimization (Bock & Van Huik, 2007; Ventura et al., 2015). Though producers must balance animal welfare needs with production performance, they have been shown to be motivated not just by economic incentives, but by reducing pain and suffering among other non-use values (Bock & Van Huik, 2007; Leach et al., 2010). In addition, consumers demonstrate a comprehensive understanding of the challenges of production in that, when asked to describe an ideal farm, while animal quality of life and cleanliness were important, consumers also recognized that profitability and efficiency in production were important (Cardoso et al., 2016). Consumers have historically been largely content with livestock welfare with 80% of consumers expressing their belief that livestock were treated humanely in 1998 (Swanson & Mench, 2000). Additionally, producers are generally satisfied with their animals' welfare and are already meeting many consumer demands for welfare practices (Wolf & Tonsor, 2017). Nevertheless, despite this, consumers have begun to increasingly express concern and dissatisfaction with the state of livestock operations on a welfare basis (Tawse, 2010; Wolf et al., 2016). This concern is exemplified by the increasing prevalence of animal welfare-based legislative proposals in recent years. With shifting consumer definitions of animal welfare, producers will be subject to consequential animal welfare standards, both by legal and market mechanisms. Thus, an understanding of the nature and determinants of consumer attitudes towards animal welfare is needed to address consumer demands.

Attitudes Towards Animal Welfare

On the whole, consumers are concerned about the welfare of the animals in the food system. For example, 63% of consumers expressed concern about the welfare of dairy cattle in the U.S. (Wolf et al., 2016). Some consumers have elected to reduce their consumption of animal products as a result of this concern, but other consumers use market solutions to acquire products which meet their demands for improved animal welfare (McKendree et al., 2013). Consumers' demand for improved animal welfare is most evident in their willingness to pay premiums for higher standards of welfare than those which are ubiquitous in conventional production. Consumer willingness to pay premiums for various welfare practices has been observed in general (Swanson & Mench 2000; Clark et al., 2017) as well as in individual industries including dairy (Napolitano et al., 2008; Wolf & Tonsor, 2017), eggs and poultry (Norwood & Lusk, 2011; Tonsor & Wolf, 2011; Ortega & Wolf, 2018), pork (Lagerkvist et al., 2006; Norwood & Lusk, 2011; Tonsor & Wolf, 2011; Ortega & Wolf, 2018) and fish (Olesen et al., 2010). These premiums, even when considered in the context of probable hypothetical bias and subsequent overestimation, have in some cases been estimated to exceed the costs of improving animal welfare such that they would represent a worthwhile economic opportunity for producers who can make welfare improvements in their operations (Liljenstolpe, 2008; Wolf & Tonsor, 2017; Ortega & Wolf, 2018). However, while premiums may be sufficient for improving producers' economic welfare, the widespread implementation of animal welfare improvements may not be so beneficial to consumers. Malone and Lusk (2016) found that despite consumers' reported WTP, demand for and subsequent increased production costs of an industry-wide switch to cage free egg production would result in a net loss of consumer surplus. Farmers have also expressed uncertainty as to the credibility of consumer WTP estimates and may distrust the actual market opportunities that exist to capitalize on welfare-friendly products (Bock & Van Huik, 2007). The ability of producers to capitalize on consumers' stated WTP is questionable due to potential hypothetical and social desirability bias in estimates. Additionally, producer distrust is further compounded by the small magnitude of WTP estimates found in some studies and even the complete absence of premiums observed in others (Liljenstolpe, 2008; Elbakidze & Nayga, 2012; Clark et al., 2017). Premiums are also subject to diminishing returns, with consumers only willingly paying more for a certain amount of a product before reverting to conventional pricing (Elbakidze & Nayga, 2012; Kehlbacher et al., 2012). Finally, premiums can be subject to the species in question. For example, some consumers have little or no willingness to pay for improved welfare in farmed fish, or at least having lower premiums relative to other animals like pigs (Frewer et al., 2005; Honkanen & Ottar Olsen, 2009). Despite these limitations on consumption behavior with regards to animal welfare, the literature is still generally conclusive that animal welfare is valued by consumers who are willing to pay more for improvements in farm animal welfare.

Heterogeneity in Preferences for Farm Animal Welfare

Though consumers generally value animal welfare, the literature has identified multiple sources of consumer heterogeneity in preferences (Liljenstolpe, 2008; McKendree et al., 2014; Clark et al., 2016; Cornish et al., 2016; Clark et al., 2017). The most consistent and significant sources of heterogeneity are age, gender, and education, though political leaning, religiosity and income have also been shown to have effects (Napolitano et al., 2008; Lagerkvist & Hess, 2010; McKendree et al., 2014; Clark et al., 2016). Women are considerably more concerned with animal welfare than men in general, as are younger individuals, with concern for animal welfare tending to decrease with age (Clark et al., 2016). The premiums individuals were willing to pay tended to increase with income and education (Lagerkvist & Hess, 2010; Clark et al., 2016). McKendree et al. (2014) also found that consumers who self-identified as members of the Democratic Party placed a higher priority on animal welfare. Clark et al. (2016) reported that individuals who considered themselves more religious were less likely to be concerned with animal welfare. With such a complex array of influences on consumer concern for animal welfare, producers must consider their primary markets and the coinciding consumer demand for improved welfare practices.

Finally, in the broad spectrum of animal welfare, it is important to note that consumer values for various aspects of food can be correlated with concern for animal welfare. One of the most important is the tendency for animal welfare labeled foods to carry a ‘halo effect’, in which consumers associate improved animal welfare with higher quality, safer, tastier or healthier products (Harper & Henson, 2001; Scholderer et al., 2004; Kehlbacher et al., 2012; Clark et al., 2016). Though this halo effect is an important influencer for many consumers, there are other consumers for whom animal welfare is superseded by food safety or health without the confounding association (Liljenstolpe, 2008; Clark et al., 2016; Grunert et al., 2018). In addition, sensory characteristics of a food could detract from the value of improved animal welfare, with consumers opting for products that meet sensory demands first and welfare demands second or the value of welfare traits being downgraded if the associated sensory traits of a product are poor (Napolitano et al., 2008; Olesen et al., 2010). Even so, behind those food characteristics which are immediately important to consumers, such as health, safety, and taste, animal welfare does take some priority over other credence attributes. For instance, animal welfare has been found to be more important to consumers than the environmental impacts of production (Cornish et al., 2016). In evaluating consumer demand for animal welfare, it is thus important to remember that it is not the primary driver in consumer decision making for food purchases but that its value is considered in conjunction with high quality, safe agricultural products. Thus, if producers aim to capitalize on animal welfare premiums, they must do so while maintaining product quality.

Farm Animal Welfare Regulation and Trade

Though consumer demand for animal welfare and the consequent market influence of that demand on producer practices is generally at the forefront of consideration in the literature, there are also several additional issues which impact animal welfare policies and consumer decisions. Multiple studies have pointed to consumer expectations that improved animal welfare be implemented through government policy as well as through the market (Uzea, 2009; Clark et al., 2017). Policy may also prove a useful tool for those stakeholders who are unable to exert market influence for welfare practices in livestock products because they do not consume animal products. Hence, while many state and federal statutes already provide basic protections to animals, consumers and other stakeholders have been increasingly turning to legal measures to effect change in animal welfare practices, with extensive impacts on producers and consumers alike. Recent examples include the 2008 California mandate phasing out gestation crates in the pork industry and battery cages in egg production, a similar measure in Michigan in 2009, and swine gestation crate bans in Arizona and Florida (Tonsor et al., 2009; Ortega & Wolf, 2018). Farm animal welfare remains a current issue with the recent passing of a 2018 ballot initiative in California to ban the same practices with stronger language and further-reaching implications for producers who market their products in California.

Though legal avenues are growing in importance, generally implemented on a state level, the movement of animal products across state and national lines presents a problem for consumers for whom animal welfare is of paramount importance. These consumers may be able to dictate welfare standards in their own backyard but cannot guarantee the same standards for products imported from other states or countries. This was the primary issue that the 2018 California law aimed to address. Differing welfare standards across borders have proven a difficulty for many European nations as increased costs of domestic production imposed by higher welfare standards create a comparative advantage for producers not subject to those standards but still able to supply their products in those markets (Grethe, 2007). Thus, animal welfare policies create far-reaching effects when they must not only be implemented in the domestic or local setting but must also be enforced for imported products (Mitchell, 2011). These can further increase the market cost of animal welfare policies, potentially creating a net negative effect on total consumer welfare (Malone & Lusk, 2016).

Consumer Trust and Claim Verification

As a credence trait, animal welfare is subject to information asymmetries between consumer and producer and so systems have been developed to deal with verification of labelled claims, including third party certifiers, government programs and industry certification. In addition to the potential for opportunism on the part of producers or marketers, the abundance of welfare-related claims and diversity of definitions of those claims can easily confuse consumers. For example, the Animal Welfare Institute (2018) identified three categories of labels: certified labels, unverified claims, and meaningless or misleading claims. Within each of these categories are between six and twelve different common claims on food which may or may not have animal welfare implications, though as the Animal Welfare Institute points out, those which fall under the certified labels are the ones that offer the greatest and most trustworthy verification of high animal welfare standards (Table 1.1). Among the labels listed are those which attempt to make no claim on animal welfare and are instead often easily misinterpreted by consumers as including welfare claims, such as the Kosher and Halal labels. Others, which may well imply animals were raised with the claimed welfare practices, are not subject to any verification process and therefore can be used by any producer, whether they engage in the practice or not, giving the consumer no guarantee of animal welfare standards. These labels include ‘pasture raised’ and ‘humanely handled’ claims. U.S. consumers have demonstrated a willingness to pay a premium for verified production practices in pork and dairy products (Olynk et al., 2010; McKendree et al., 2013; Olynk & Ortega, 2013). They favored a government certification with the highest premiums, indicating the highest level of trust rests with a government verified program (McKendree et al., 2013). Olynk et al. (2010) however, found in both pork and dairy that consumers’ most preferred verification method was dependent upon the practice in question. Similarly, Canadian consumers indicated government and third parties to be the most credible sources of verification of animal welfare in the pork industry (Uzea, 2009). These verification processes represent an additional cost owing to the need to account for higher animal welfare standards and, despite consumer willingness to pay a premium for verification or a greater assurance of trustworthiness, it is unclear if the combined premiums for the higher welfare standards themselves in addition to verification are adequate to justify the increased costs for producers.

Consumer Knowledge and Inconsistent Purchasing Behavior

Compounding the difficulties of the credence trait is a generally poor understanding among consumers of production processes. Tawse (2010) found a high level of ignorance amongst UK consumers of pork production methods. Furthermore, Cornish et al. (2016) concluded that the general public had a poor understanding of animal welfare in food production in Australia. However, a recent study of Oklahoma consumers identified that as many as one-third of consumers may intentionally elect ignorance of the production processes for animal products, with guilt avoidance being a primary driver of this choice (Bell et al., 2017). Consumer ignorance can present substantial difficulties for producers, as consumers could potentially, and often do, demand practices that are counterproductive to improving animal welfare or may not understand that standards are already adequate under current systems.

Finally, one of the greatest challenges regarding farm animal welfare is that of inconsistency in behavior amongst consumers. That is, consumers may demand costly welfare improvements from producers but then reject the products due to increased costs, being unwilling to pay the premiums. This may be due to the dual view consumers may take toward animal products in which they may approach these products as either a consumer or a citizen. As a consumer, animal welfare can take a secondary role to other consumer priorities, while as a citizen aiming to influence societal standards, animal welfare can take a higher place in an individual's prioritization (Harper & Henson, 2001; Schröder & McEachern, 2004). This issue was empirically identified amongst European pork consumers who exhibited extremely low intention-behavior consistency in their demand for outdoor versus conventional pork production systems (Scholderer et al., 2004). With such inconsistency amongst consumers, the increased risk of uncertainty further increases the costs of welfare improvements for producers.

Animal Welfare Industry Case Studies

Animal Housing and Immunocastration in the Pork Industry

Though examining consumer attitudes toward animal welfare in the broad sense can help to draw conclusions about general consumer demands for animal welfare, it is worthwhile to view demands on an industry basis as well. In the literature focusing on animal welfare in the pork industry, two primary practices are targeted in consumer evaluations: the use of gestation crates (or stalls) and immunocastration as an alternative to castration without analgesics.

Housing procedures are among the most objectionable current practices to consumers in terms of animal welfare. Recent legal measures in the U.S. aimed at improving animal welfare have centered around improvements in housing in the poultry and pork industries (Ortega & Wolf, 2018). In addition to increasing production efficiency, the use of gestation crates in the pork industry is intended to improve welfare by protecting sow health by reducing disease spread and preventing fighting. However, the crates also reduce welfare by limiting the animals' ability to move freely, turn around and perform natural behaviors, factors critical to the consumer's definition of acceptable animal welfare (Ortega & Wolf, 2018). Consumer demand for these welfare traits in pork production has been clearly observed in the WTP studies by Norwood and Lusk (2011) which found consumers were willing to pay a $2.02 premium per two pounds of pork chops from a pasture system over a crate system. Ortega and Wolf (2018) found similar results for a premium for pork from a certified welfare operation which abandons the crate system. Ortega and Wolf (2018) also discussed the difficulty with which such premiums could be used to justify the increased costs of the production changes required to accommodate consumer demands, considering that premiums were heterogeneous across cuts of pork. Thus, care must be taken in determining if the premiums reported in the literature can cover the expenses of adopting costly welfare improvements (which are incurred by the whole animal), especially if those improvements also result in losses in production efficiency.

Immunocastration offers a unique perspective on animal welfare improvements as it employs hormonal biotechnology, which, as previously discussed, consumers have generally expressed opposition to in agricultural applications. The procedure offers producers a painless alternative to the industry standard of surgical castration which is generally performed without pain relief.[2] Immunocastration, in not using genetic manipulation, may appeal more to a consumer desire for naturalness in pork production while still employing a form of biotechnology to improve animal welfare. Though the European Union has changed policy to require analgesics in surgical procedures, immunocastration offers an animal welfare-improving application of hormonal biotechnology for which consumers might be willing to pay a premium. Multiple studies among European consumers have evaluated consumer WTP for immunocastration, generally finding immunocastration was preferred to surgical castration or no castration (Lagerkvist et al., 2006; Font-i-Furnols et al., 2008). These findings are especially important amongst a European population which already has considerable difficulty with many biotechnology applications in agriculture in that they show that animal welfare concerns have the potential to override hesitant attitudes towards hormonal biotechnology. This is corroborated by the findings of Novoselova et al. (2005) that consumers could even be willing to accept a genetically engineered pig if the benefits of the application serve the purposes of the consumer, such as demand for improved animal welfare. While the loss of gestation crates as a production method may reduce efficiency and hurt producer revenues if premiums for welfare improvements are inadequate, appropriate applications of hormonal biotechnology which offer both efficiency and welfare gains may help alleviate the uncertainty that surrounds potentially biased WTP estimates for producers, so long as prices are not discounted for the use of the biotechnology.

[2] Immunocastration is the immunization of young intact male pigs against gonadotropin-releasing hormone (GnRH), preventing the development of the genital tract and reducing plasma concentrations of gonadotropin and testosterone, effectively inhibiting boar taint in a painless manner.

Stockmanship and Animal Health in the Dairy Industry

Similar to the pork industry, the dairy industry faces a unique set of animal welfare challenges that invoke different consumer concerns. Among the key welfare issues facing dairy farmers and the industry at large today are tail docking, concerns about concentrated production and housing systems, animal health concerns like mastitis and laminitis, handling, castration and dehorning. Tail docking, while of great importance to animal rights advocates, is purported to be rarely practiced in the industry, with few empirically demonstrated benefits, and completely banned originally in California and later effectively nationally in the U.S. by the National Milk Producers Federation Board (Wilson, 2016; Wolf & Tonsor, 2017). Laminitis and mastitis are among farmers' top priorities in animal welfare as they also represent significant economic threats to dairy production (Leach et al., 2010; Ventura et al., 2015). Dehorning is a practice with the intended benefits of reducing injuries to handlers and cows, reducing aggressive behavior and improving production efficiency by reducing feed trough space requirements. Though a majority of farmers recognize that it is a painful procedure and yet do not use anesthetics due to high costs, farmers maintain the practice for these benefits and attempt to minimize the negative impacts on animal welfare by performing the procedure early in life using debudding techniques, with the intent that the one-time painful procedure is justified by future welfare gains to the animal (Gottardo et al., 2011; Kling Eveillard et al., 2015). With the challenging welfare dilemmas presented by efficient dairy production and as much as 87% of the population consuming dairy products, consumer attitudes toward livestock welfare in the dairy industry can exert profound market impacts (Widmar et al., 2017). Indeed, increasing welfare concerns caused 12% of dairy consumers to alter their consumption habits in the last three years, citing tail docking and dehorning among the most problematic of practices (Widmar et al., 2017). Many consumer studies regarding preferences for dairy welfare have taken a comprehensive approach, in which a large majority of consumers have indicated a willingness to pay a premium for dairy produced with generally improved or simply consumer-acceptable levels of welfare including appropriate feeding, good stocksmanship, space to move, a clean and hygienic environment, and access to clean water and comfort (Napolitano et al., 2008; Elbakidze & Nayga, 2012; Wolf & Tonsor, 2017). One study which evaluated specific practices was Wolf et al. (2016) who identified consumer opposition to superfluous antibiotic use and castration without the use of anesthetic, as a majority of the public supported the notion of a ban on antibiotics outside of disease treatment and required pain management for castration. Farmers, expressing awareness of consumer concerns, have begun industry-led initiatives to collectively improve welfare, such as the Farmers Assuring Responsible Management (FARM) program instituted in 2009. As such, producers are responsive to consumer demands for welfare and aim to meet these demands while maintaining profitability.

The Intersection of Animal Welfare and Biotechnology

Potential Applications of Biotechnology in Farm Animal Welfare

Despite potential consumer concerns, current biotechnological advances, particularly in the field of genetics and gene editing, have presented ample opportunities to improve farm animal welfare through genetic engineering. Technologies like CRISPR/Cas9 and TALEN have substantially simplified the gene-editing process relative to the advent of GEn technologies and have already been used in preliminary livestock applications. In pigs, perhaps the most promising application is dramatic improvement in disease resistance. At the forefront of this is the development of pigs which are resistant to porcine reproductive and respiratory syndrome (PRRS), a viral disease which causes spontaneous abortion in mature pigs and respiratory distress in neonatal pigs (Whitworth et al., 2016). This resistance can be achieved with a relatively simple gene edit, making it more likely to be acceptable to consumers than a transgenic process, and represents enormous potential for producers, for whom PRRS can be economically devastating. PRRS is also not the only disease for which gene editing can improve pig welfare, with researchers already using CRISPR/Cas9 to produce porcine endogenous retrovirus (PERV)-inactivated pigs as well (Niu et al., 2017). Furthermore, disease resistance is not the only welfare-improving application of biotechnology in pigs, with recent applications also including the development of cold adapted pigs by GEn and immunocastration by biochemical biotechnology. For example, Zheng et al. (2017) were able to use CRISPR to knock in a gene in pigs which improved their ability to maintain body temperature without losses in efficiency, resulting in reduced fat deposition and decreased susceptibility to the cold. These improvements again have both welfare and economic impacts, with resistance to cold having the capacity to reduce neonatal pig mortality and reduced fat deposition leading to higher lean carcass percentages. Future developments may even include gene-edited pigs which are prevented from reaching sexual maturity, effectively requiring no castration practices at all (Freese, 2018).

Similar to biotechnology applications in pigs, the primary potential welfare-improving applications in dairy cattle are in disease resistance and the elimination of the need for physical alterations which consumers may find objectionable. Though not specific to dairy cattle, the development of cattle with a resistance to bovine tuberculosis (bTB) represents a significant welfare and economic prospect (Wu et al., 2015). Though the cattle are produced using TALEN technology, they are transgenic and so may find less consumer acceptability than their gene knock-out porcine disease-resistant counterparts. Nevertheless, with bTB representing a considerable risk to dairy producers, bTB resistance could be both a dramatic welfare improvement for cattle as well as an economic safeguard.

Perhaps the most important welfare-improving disease-resistance application in dairy is the production of mastitis-resistant cattle. Though not immune to the disease, researchers were able to produce cattle which produced an antimicrobial in their milk against *S. aureus*, one of the primary agents of mastitis, significantly reducing the cows' risk of developing mastitis (Marshall 2005; Wall et al., 2005). Such a development could have massive economic impacts on the dairy industry, as mastitis is among the costliest dairy cow diseases, as well as enormous welfare-improving effects for cows, for whom mastitis is particularly painful. However, such a beneficial application of genetic biotechnology also draws some of the greatest challenges to consumer acceptance, as the cattle are transgenic in nature, the antimicrobial is present in the milk for an already antibiotic-weary consumer base and researchers have expressed uncertainty as to the sensory characteristics of the milk as a result (Marshall, 2005). Such uncertainty led scientists to abandon costly government approval efforts of the cows for fear of market rejection (Bloch, 2018). Even so, this application demonstrates the potential for genetic biotechnological advances to address pressing issues facing producers while simultaneously meeting the more important demands of consumers for the livestock industry.

Improved disease-resistance is not the only potential opportunity for genetic biotechnology in dairy cattle which can improve welfare. The development of polled cattle, that is cattle which naturally have no horns, in major milk-producing breeds could result in the elimination of dehorning practices in the industry. Though dehorning serves quality and welfare purposes for a cow's life later in the production process, the practice itself is painful if performed without anesthetic. Using an allele of the polled gene from breeds which are naturally hornless, TALENs were used to produce a cow the researchers claim could have been achieved through natural mating but without the attendant genetic losses and complications that come with natural breeding for polled cattle (Carlson et al., 2016). As dehorning is a priority welfare practice to be dealt with for many retailers and animal advocacy groups, and as the practice is extensively employed throughout the dairy industry, with 80% of dairy calves estimated to undergo the procedure annually, the widespread proliferation of polled dairy cattle in the industry would represent a substantial improvement in animal welfare through genetic biotechnological means (Carlson et al., 2016). Additionally, there is already preliminary evidence to suggest consumers may be willing to accept the use of gene editing to produce polled cattle (Shriver & McConnachie, 2018).

The Regulatory Environments of Animal Welfare and Biotechnology

The use of legal measures has become an effective way for consumers to ensure that the higher animal welfare standards they demand are implemented in the industry. This approach has been increasingly popular, given the growing number of measures passed in recent years, including the most recent passage of California's Proposition 12, limiting the use of confinement practices like cages and gestation crates in hen and hog production, as well as a similar Michigan legislation passed in 2009 (Ortega & Wolf, 2018). Such public policy interventions in animal welfare have the benefit of enforcing universal producer compliance through financial penalties for failure to comply as well as even criminal charges for the most severe cases of noncompliance (McCluskey, 2000). Wolf et al.'s (2016) observations of public support for a ban on antibiotics for purposes besides disease treatment and a mandate for the use of anesthesia in castration procedures demonstrate this. In addition to mandating the practices themselves, Tonsor and Wolf (2011) found consumers were also largely in support of mandatory labeling measures indicating production practices such as gestation crate use and cages for laying hens. Despite their perceived potential to universally improve animal welfare in an industry, additional legislative measures are liable to increase production costs for all producers due to the required industry-wide implementation. This was observed in the case of California's cage free egg production mandate, which unilaterally increased egg prices for all consumers, not just those who derive disutility from confinement practices for laying hens (Malone & Lusk, 2016). The potential negative impact on consumers of these policies was further demonstrated by Lusk (2019) where the demands of a small fraction of consumers for cage-free eggs drove a substantial price increase in eggs across multiple retailers to the detriment of those consumers who were unwilling to pay such premiums. Additionally, these animal welfare demands affected retailers' decisions to stock more affordable, conventional eggs, decreasing their availability and disproportionately impacting the economic welfare of poorer consumers (Lusk, 2019). Among the greatest pitfalls of legal approaches is the inflexibility of public policy, which can both restrict development in the changing environment of agricultural production and, if not carefully specified and evaluated prior to implementation, can also impose unintended consequences which are neither of benefit to producers nor consumers (McCluskey, 2000). As consumers gain greater control of the agricultural production environment through legislation, their preferences over animal welfare and the potential applications of various biotechnologies in that respect will become increasingly important. In addition, as consumers demand higher standards of animal welfare through regulation, producers may find themselves turning to biotechnological solutions, genetic, hormonal and otherwise, to decrease costs and meet consumer demands, making it imperative to determine consumer acceptability of such biotechnologies in the context of animal welfare improvement.

The available gene-editing biotechnologies present regulatory challenges of their own. As previously mentioned, technologies like CRISPR/Cas9 and TALENs represent a direct alteration of the genetic material of an organism. In 2018, the U.S. Department of Agriculture (USDA) announced that it had no plans to place additional regulations on gene-edited plants that could otherwise have been developed through traditional breeding prior to commercialization. Under this ruling, genetic deletions, single base-pair substitutions, and the insertion of nucleotide sequences from related plants that could have come about through crossbreeding do not trigger additional regulatory scrutiny (Van Eenennaam et al., 2019). Despite the current state of affairs, concern over the misuse of these technologies has led to calls for tighter monitoring of their use and greater scrutiny. Current regulations, overseen by the FDA, the USDA and the EPA, for GEn organisms for human consumption require that they meet the same food safety standards as traditionally bred organisms. A voluntary consultation process is followed prior to the approval of foods from GEn plants, with the burden of proof resting on the manufacturer to show the foods are safe (FDA, 2018). GEn animals, on the other hand, are treated as new animal drugs by the FDA and must undergo an intensive approval process as such. Subjecting gene-edited animals that could otherwise have been developed through traditional breeding to a mandatory, multigenerational, new animal drug approval process prior to commercialization has been meet by opposition in the scientific breeding community (Van Eenennaam et al., 2019). To date, only one GEn food animal product, the AquAdvantage salmon, has successfully gone through the FDA's mandatory, premarket new animal drug approval process. This founder GEn fish was originally produced in 1989, and it was finally approved in 2017 following years of regulatory delays and uncertainty. The FDA held an open request for comments in 2016 and 2017 as to their recommendation on the application of the same approval process specifically for genome-edited animals. Following the request for comment, the FDA has so far issued recommendations that genome-edited animals remain subject to a similar approval process as GEn animals, characterizing them completely as GMO's in the legal sense and in the public mind (FDA, 2017).

An important consideration for producers and scientists in pursuing gene-editing technology in agriculture is the potential cost of FDA approval, or approval by foreign governing bodies, and its impact on the economic viability of the products which result from the technology. Costs accrue from, among other things, the intensive data collection and record keeping necessary to provide multigenerational data demonstrating that a new animal drug is effective and safe for consumers, animals, and the environment. As mentioned earlier, excessive costs for approval have already prevented some GEn animal products with substantial potential benefits from reaching the consumer market (Bloch, 2018). Not all countries are regulating gene-edited animals as GEn. Several South American countries are not requiring additional regulatory evaluation for gene-edited products that do not introduce a new combination of genetic material. For example, Brazil has ruled that gene-edited polled cattle carrying a naturally-occurring allele of the polled gene will not be treated differently to conventional polled cattle (MCTIC, 2018). One potential means of reducing costs for producers and scientists on a global scale would be to consolidate the approval process to a single international approving body, eliminating redundancy in approvals across borders and reducing costs of marketing gene-edited animal products globally.

The Future of Biotechnology in Animal Welfare Applications

Consumer values for the production traits of their food clearly influence the price they are willing to pay for animal-based products. Strong consumer opinions in favor of or against production process traits can quickly determine the success or failure of developments in agricultural production. Consumers are already wielding this influence in the realm of GEn foods, other agricultural biotechnologies and animal welfare practices, significantly impacting market outcomes as well as food policy. These effects are particularly evident in the pork and dairy industries, which offer substantial opportunities for both biotechnological advancement and improved animal welfare. The intersection of biotechnology and animal welfare creates a unique situation for consumers as they evaluate tradeoffs. On one hand, consumers demonstrate a clear dislike towards genetic and hormonal biotechnology applications in agriculture, resulting in significant discounting of products produced using GEn technologies among other biotechnologies. On the other hand, consumers are demanding ever-increasing levels of animal welfare and are willing to pay premiums to assure the livestock responsible for their food were raised in accordance with acceptable welfare standards. These counteracting effects may represent an opportunity for a compromise amongst consumers and producers.

If the benefits of biotechnological applications in agriculture are both welfare- and profit-increasing, producers may be able to capitalize on profitable biotechnologies while meeting consumer demands for improved welfare. However, it is yet unknown whether the welfare benefits will be communicated effectively to offset consumer objections to biotechnology or if consumer aversion to biotechnology is stronger than preferences for improved animal welfare. Previous research suggests the potential for such a counterbalancing effect and consumer willingness to accept biotechnological applications if their use is motivated by concerns for animal welfare. With biotechnologies eliminating the need for painful procedures and increasing disease resistance to reduce antibiotic use and mortality, breakthroughs in biotechnology are already poised to begin meeting consumer demands for improved animal welfare. It remains to be seen how industry stakeholders will market and convey the benefits of these products and if consumers will willingly accept them without significant reservation.

APPENDIX

Table 1.1: Common Animal Welfare Labels by AWI Category

Animal Welfare Institute Category	**Labels**
Certified Labels Formally defined with a set of publicly available standards. Third party audit verification.	American Grassfed Certified American Humane Certified Certified Humane® Certified Organic Food Alliance Certified Global Animal Partnership
Unverified Claims No legal definition. Standards are vague or weak. Compliance with the USDA definition is unverified.	Cage Free (eggs) Free Range Free Roaming Pastured Fed/Grown Meadow Raised Grass Fed Humanely Raised/Handled Naturally Raised No Added Hormones (dairy, beef, lamb) Raised without Antibiotics Pasture Raised Sustainably Farmed
Meaningless or Misleading Claims Meaningless or misleading with regard to animal welfare (though may be meaningful in other contexts)	Cage Free (broiler chicken or turkey) Halal Kosher Natural No Added Hormones (poultry or pork) United Egg Producers Certified USDA Process Verified Vegetarian Fed

Source: Animal Welfare Institute (2018).

REFERENCES

REFERENCES

Aldrich, L. M., & Blisard, N. (1998). *Consumer acceptance of biotechnology: Lessons from the rBST experience* (No. 33663). United States Department of Agriculture, Economic Research Service.

Animal Welfare Institute. (2018). *A Consumer's Guide to Food Labels and Animal Welfare*. Animal Welfare Institute. Retrieved May 14, 2019 from: https://web.archive.org/web/20190406184956/https://awionline.org/content/consumers-guide-food-labels-and-animal-welfare.

Bell, E., Norwood, F. B., & Lusk, J. L. (2017). Are consumers willfully ignorant about animal welfare?. *Animal Welfare*, *26*(4): 399-402.

Bloch, S. (2018). Hornless Holsteins and Enviropigs: the genetically engineered animals we never knew. *The New Food Economy*. May 1, 2018. Retrieved May 14, 2019 from: https://web.archive.org/web20190401163301/http://newfoodeconomy.org/web/20190401163301oe_/https://newfoodeconomy.org/transgenesis-gene-editing-fda-aquabounty/.

Bock, B. B., & Van Huik, M. M. (2007). Animal welfare: the attitudes and behaviour of European pig farmers. *British Food Journal*, *109*(11): 931-944.

Broll, H., Zagon, J., Butschke, A., Leffke, A., Spiegelberg, A., Bohme, H., & Flachowsky, G. (2005). The fate of DNA of transgenic inulin synthesizing potatoes in pigs. *Journal of Animal and Feed Sciences*, *14*: 337.

Cantley, M., Hoban, T., & Sasson, A. (1999). Regulations and consumer attitudes toward biotechnology. *Nature Biotechnology*, *17*(2s): BV37.

Cardoso, C. S., Hötzel, M. J., Weary, D. M., Robbins, J. A., & von Keyserlingk, M. A. (2016). Imagining the ideal dairy farm. *Journal of Dairy Science*, *99*(2): 1663-1671.

Carlson, D. F., Lancto, C. A., Zang, B., Kim, E. S., Walton, M., Oldeschulte, D., Seabury, C., Sonstegard, T. S., & Fahrenkrug, S. C. (2016). Production of hornless dairy cattle from genome-edited cell lines. *Nature Biotechnology*, *34*(5): 479.

Clark, B., Stewart, G. B., Panzone, L. A., Kyriazakis, I., & Frewer, L. J. (2016). A systematic review of public attitudes, perceptions and behaviours towards production diseases associated with farm animal welfare. *Journal of Agricultural and Environmental Ethics*, *29*(3): 455-478.

Clark, B., Stewart, G. B., Panzone, L. A., Kyriazakis, I., & Frewer, L. J. (2017). Citizens, consumers and farm animal welfare: A meta-analysis of willingness-to-pay studies. *Food Policy*, *68*: 112-127.

Cornish, A., Raubenheimer, D., & McGreevy, P. (2016). What we know about the public's level of concern for farm animal welfare in food production in developed countries. *Animals*, *6*(11): 74.

Costa-Font, M., Gil, J. M., & Traill, W. B. (2008). Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy. *Food Policy*, *33*(2): 99-111.

Dolgopolova, I., & Roosen, J. (2018). Competitive niche in milk pricing: Analyzing price dynamics of GMO-free, organic, and conventional milk in Germany during 2009–2010. *Food Policy*, *78*: 51-57.

Edenbrandt, A. K., House, L. A., Gao, Z., Olmstead, M., & Gray, D. (2018). Consumer acceptance of cisgenic food and the impact of information and status quo. *Food Quality and Preference*, *69*: 44-52.

Elbakidze, L., & Nayga Jr, R. M. (2012). The effects of information on willingness to pay for animal welfare in dairy production: Application of nonhypothetical valuation mechanisms. *Journal of Dairy Science*, *95*(3): 1099-1107.

FDA (U.S. Food and Drug Administration). (2017). *Guidance for Industry: Regulation of Intentionally Altered Genomic DNA in Animals (No. 187)*. U.S. Department of Health and Human Services. Retrieved May 14, 2019 from: https://web.archive.org/web/20190514145855/https://www.fda.gov/media/74614/download.

FDA (U.S. Food and Drug Administration). (2018). *How FDA Regulates Food from Genetically Engineered Plants*. U.S. Department of Health and Human Services. Retrieved May 14, 2019 from: https://web.archive.org/web/20190423024612/https://www.fda.gov/Food/IngredientsPackagingLabeling/GEPlants/ucm461831.htm.

Font-i-Furnols, M., Gispert, M., Guerrero, L., Velarde, A., Tibau, J., Soler, J., Hortós, M., García-Regueiro, J.A., Pérez, J., Suárez, P., & Oliver, M. A. (2008). Consumers' sensory acceptability of pork from immunocastrated male pigs. *Meat Science*, *80*(4): 1013-1018.

Food Traceability Report. (2009). France adopts 'Fed without GMOs' label. *Agra Informa, Inc*. May, 2009. Retrieved May 14, 2019 from: https://web.archive.org/web/20190509021127/https://www.gmwatch.org/en/news/archive/2009/10889-france-adopts-gm-free-labelling-for-meat-poultry-and-dairy-products.

Freese, B. (2018). Gene Editing Aims to End Pig Castration. *Successful Farming*. January 3, 2018. Retrieved May 14, 2019 from: https://web.archive.org/web/20180104003420/https://www.agriculture.com/livestock/hogs/gene-editing-aims-to-end-pig-castration.

Frewer, L. J., Bergmann, K., Meertens, R., Rowe, G., Siegrist, M., & Vereijken, C. (2011). Consumer response to novel agri-food technologies: Implications for predicting consumer acceptance of emerging food technologies. *Trends in Food Science & Technology*, *22*(8): 442-456.

Frewer, L. J., Coles, D., Houdebine, L.M., & Kleter, G. A. (2014). Attitudes towards genetically modified animals in food production. *British Food Journal*, *116*(8): 1291-1313.

Frewer, L. J., Howard, C., & Shepherd, R. (1997). Public concerns in the United Kingdom about general and specific applications of genetic engineering: Risk, benefit, and ethics. *Science, Technology, & Human Values*, *22*(1): 98-124.

Frewer, L. J., Kole, A., Van De Kroon, S. M. A., & De Lauwere, C. (2005). Consumer attitudes towards the development of animal-friendly husbandry systems. *Journal of Agricultural and Environmental Ethics*, *18*(4): 345-367.

Frewer, L. J., van der Lans, I. A., Fischer, A. R., Reinders, M. J., Menozzi, D., Zhang, X., van den Berg, I. & Zimmermann, K. L. (2013). Public perceptions of agri-food applications of genetic modification–a systematic review and meta-analysis. *Trends in Food Science & Technology*, *30*(2): 142-152.

Geiger, C. (2016). Is yogurt from GMO-free feed a possibility? *Hoard's Dairyman*. May 2, 2016. Retrieved May 14, 2019 from: https://hoards.com/print-article-18583-permanent.html.

Gottardo, F., Nalon, E., Contiero, B., Normando, S., Dalvit, P., & Cozzi, G. (2011). The dehorning of dairy calves: practices and opinions of 639 farmers. *Journal of Dairy Science*, *94*(11): 5724-5734.

Grethe, H. (2007). High animal welfare standards in the EU and international trade–How to prevent potential 'low animal welfare havens'?. *Food Policy*, *32*(3): 315-333.

Grunert, K. G., Sonntag, W. I., Glanz-Chanos, V., & Forum, S. (2018). Consumer interest in environmental impact, safety, health and animal welfare aspects of modern pig production: Results of a cross-national choice experiment. *Meat Science*, *137*: 123-129.

Harper, G., & Henson, S. (2001). Consumer concerns about animal welfare and the impact on food choice. *EU FAIR CT98-3678, Centre for Food Economics Research, The University of Reading*.

Hoban, T. J. (1996). Trends in consumer acceptance and awareness of biotechnology. *Journal of Food Distribution Research*, *27*(1): 1-10.

Honkanen, P., & Ottar Olsen, S. (2009). Environmental and animal welfare issues in food choice: the case of farmed fish. *British Food Journal*, *111*(3): 293-309.

Hossain, F., Onyango, B., Adelaja, A., Schilling, B., & Hallman, W. (2004). Consumer acceptance of food biotechnology: Willingness to buy genetically modified food products. *Journal of International Food & Agribusiness Marketing*, *15*(1-2): 53-76.

Hudson, J., Caplanova, A., & Novak, M. (2015). Public attitudes to GM foods. The balancing of risks and gains. *Appetite*, *92*: 303-313.

Kalaitzandonakes, N., Marks, L. A., & Vickner, S. S. (2004). Media coverage of biotech foods and influence on consumer choice. *American Journal of Agricultural Economics*, *86*(5): 1238-1246.

Kehlbacher, A., Bennett, R., & Balcombe, K. (2012). Measuring the consumer benefits of improving farm animal welfare to inform welfare labelling. *Food Policy*, *37*(6): 627-633.

Kling-Eveillard, F., Knierim, U., Irrgang, N., Gottardo, F., Ricci, R., & Dockès, A. C. (2015). Attitudes of farmers towards cattle dehorning. *Livestock Science*, *179*: 12-21.

Kolodinsky, J., & Lusk, J. L. (2018). Mandatory labels can improve attitudes toward genetically engineered food. *Science Advances*, *4*(6): eaaq1413.

Lagerkvist, C. J., & Hess, S. (2010). A meta-analysis of consumer willingness to pay for farm animal welfare. *European Review of Agricultural Economics*, *38*(1): 55-78.

Lagerkvist, C. J., Carlsson, F., & Viske, D. (2006). Swedish Consumer Preferences for Animal Welfare and Biotech: A Choice Experiment. *AgBioForum*, *9*(1): 51-58.

Larue, B., West, G. E., Gendron, C., & Lambert, R. (2004). Consumer response to functional foods produced by conventional, organic, or genetic manipulation. *Agribusiness: An International Journal*, *20*(2): 155-166.

Leach, K. A., Whay, H. R., Maggs, C. M., Barker, Z. E., Paul, E. S., Bell, A. K., & Main, D. C. J. (2010). Working towards a reduction in cattle lameness: 2. Understanding dairy farmers' motivations. *Research in Veterinary Science*, *89*(2): 318-323.

Liljenstolpe, C. (2008). Evaluating animal welfare with choice experiments: an application to Swedish pig production. *Agribusiness: An International Journal*, *24*(1): 67-84.

Lin, W., Ortega, D. L., Caputo, V., & Lusk, J. L. (2019). Personality traits and consumer acceptance of controversial food technology: a cross-country investigation of genetically modified animal products. *Food Quality and Preference, 76*: 10-19.

Lusk, J. L. (2019). Consumer preferences for cage-free eggs and impacts of retailer pledges. *Agribusiness*, *35*: 129-148.

Lusk, J. L., & Rozan, A. (2006). Consumer acceptance of ingenic foods. *Biotechnology Journal: Healthcare Nutrition Technology*, *1*(12): 1433-1434.

Lusk, J. L., House, L. O., Valli, C., Jaeger, S. R., Moore, M., Morrow, J. L., & Traill, W. B. (2004). Effect of information about benefits of biotechnology on consumer acceptance of genetically modified food: evidence from experimental auctions in the United States, England, and France. *European Review of Agricultural Economics*, *31*(2): 179-204.

Lusk, J. L., McFadden, B. R., & Rickard, B. J. (2015). Which biotech foods are most acceptable to the public?. *Biotechnology Journal*, *10*(1): 13-16.

Lusk, J. L., Roosen, J., & Fox, J. A. (2003). Demand for beef from cattle administered growth hormones or fed genetically modified corn: A comparison of consumers in France, Germany, the United Kingdom, and the United States. *American Journal of Agricultural Economics*, *85*(1): 16-29.

Malone, T., & Lusk, J. L. (2016). Putting the Chicken Before the Egg Price: An Ex Post Analysis of California's Battery Cage Ban. *Journal of Agricultural & Resource Economics*, *41*(3): 518-532.

Marshall, J. (2005). Averting an Udder Disaster. *Science*. April 4, 2005. Retrieved May 14, 2019 from: https://web.archive.org/web/20190514145130/https://www.sciencemag.org/news/2005/04/averting-udder-disaster.

McCluskey, J. J. (2000). A game theoretic approach to organic foods: An analysis of asymmetric information and policy. *Agricultural and Resource Economics Review*, *29*(1): 1-9.

McKendree, M. G. S., Croney, C. C., & Widmar, N. O. (2014). Effects of demographic factors and information sources on United States consumer perceptions of animal welfare. *Journal of Animal Science*, *92*(7): 3161-3173.

McKendree, M. G., Widmar, N. O., Ortega, D. L., & Foster, K. A. (2013). Consumer preferences for verified pork-rearing practices in the production of ham products. *Journal of Agricultural and Resource Economics*, *38*(3): 397-417.

MCTIC (Ministry of Science, Technology, Innovations and Communications Brazil). (2018). *Technical Opinion 6125/2018: Consultation on the application of Normative Resolution 16 in animal products developed with innovative precision improvement techniques – TIMP*. Retrieved May 8, 2019 from: http://sei.mctic.gov.br/verifica.html.

Millar, K. M., Tomkins, S. M., White, R. P., & Mepham, T. B. (2002). Consumer attitudes to the use of two dairy technologies. *British Food Journal*, *104*(1): 31-44.

Mitchell, L. (2001). Impact of consumer demand for animal welfare on global trade. *Changing Structure of Global Food Consumption and Trade*, *80*: 83-85.

Napolitano, F., Pacelli, C., Girolami, A., & Braghieri, A. (2008). Effect of information about animal welfare on consumer willingness to pay for yogurt. *Journal of Dairy Science*, *91*(3): 910-917.

Niu, D., Wei, H. J., Lin, L., George, H., Wang, T., Lee, I. H., Zhao, H., Wang, Y., Kan, Y., Shrock, E., Lesha, E., Wang, G., Luo, Y., Qing, Y., Jiao, D., Zhao, H., Zhou, X., Wang, S., Wei, H., Güell, M., Church, G. M., & Yang, L. (2017). Inactivation of porcine endogenous retrovirus in pigs using CRISPR-Cas9. *Science*, *357*(6357): 1303-1307.

Norwood, F. B. & Lusk, J. L. (2011). A calibrated auction-conjoint valuation method: Valuing pork and eggs produced under differing animal welfare conditions. *Journal of Environmental Economics and Management*, *62*(1): 80-94.

Novoselova, T. (2007). *Analysis of adoption of genetic modification in pork production chains*. (Doctoral Dissertation) Wageningen Universiteit.

Novoselova, T. A., van der Lans, I. A., Meuwissen, M. P., & Huirne, R. (2005). *Consumer Acceptance of GM Applications in the Pork Production Chain: A Choice Modelling Approach*, (2005 European Association of Agricultural Economists International Congress, August 23-27, 2005, Copenhagen, Denmark: No. 24527).

O'Connor, E., Cowan, C., Williams, G., O'Connell, J., & Boland, M. (2005). Acceptance by Irish consumers of a hypothetical GM dairy spread that reduces cholesterol. *British Food Journal*, *107*(6): 361-380.

Olesen, I., Alfnes, F., Røra, M. B., & Kolstad, K. (2010). Eliciting consumers' willingness to pay for organic and welfare-labelled salmon in a non-hypothetical choice experiment. *Livestock Science*, *127*(2-3): 218-226.

Olynk, N. J., & Ortega, D. L. (2013). Consumer preferences for verified dairy cattle management practices in processed dairy products. *Food Control*, *30*(1): 298-305.

Olynk, N. J., Tonsor, G. T., & Wolf, C. A. (2010). Consumer willingness to pay for livestock credence attribute claim verification. *Journal of Agricultural and Resource Economics*, *35*(2): 261-280.

Onyango, B. M., & Nayga Jr, R. M. (2004). Consumer acceptance of nutritionally enhanced genetically modified food: relevance of gene transfer technology. *Journal of Agricultural and Resource Economics*, *29*(3): 567-583.

Onyango, B. M., Govindasamy, R., & Nayga, R. (2004). *Measuring US Consumer Preferences for Genetically Modified Foods Using Choice Modeling Experiments: The Role of Price, Product Benefits and Technology* (No. 18181). Rutgers University, Food Policy Institute.

Ortega, D. L., & Wolf, C. A. (2018). Demand for farm animal welfare and producer implications: Results from a field experiment in Michigan. *Food Policy*, *74*: 74-81.

Punt, M., Venus, T., & Wesseler, J. (2016). Labelling GM-free Products. A Case Study of Dairy Companies in Germany. *EuroChoices*, *15*(1): 45-51.

Ribeiro, T. G., Barone, B., & Behrens, J. H. (2016). Genetically modified foods and their social representation. *Food Research International*, *84*: 120-127.

Robinson, E. (2014). Anti-GMO Social Media Campaign Fails to Percolate at Starbucks. *Delta Farm Press*. October 24, 2014.

Santerre, C. R., & Machtmes, K. L. (2002). The impact of consumer food biotechnology training on knowledge and attitude. *Journal of the American College of Nutrition*, *21*(sup3): 174S-177S.

Scholderer, J., & Frewer, L. J. (2003). The biotechnology communication paradox: Experimental evidence and the need for a new strategy. *Journal of Consumer Policy*, *26*(2): 125-157.

Scholderer, J., Bredahl, L., & Magnussen, M. (2004). *Consumer expectations of the quality of pork produced in sustainable outdoor systems.* Aarhus School of Business, Aarhus University, MAPP Centre.

Schröder, M. J., & McEachern, M. G. (2004). Consumer value conflicts surrounding ethical food purchase decisions: a focus on animal welfare. *International Journal of Consumer Studies*, *28*(2): 168-177.

Schultz-Bergin, M. (2018). Is CRISPR an Ethical Game Changer?. *Journal of Agricultural and Environmental Ethics*, *31*(2): 219-238.

Shriver, A., & McConnachie, E. (2018). Genetically modifying livestock for improved welfare: A path forward. *Journal of Agricultural and Environmental Ethics*, *31*(2): 161-180.

Swanson, J. C., & Mench, J. A. (2000). Animal welfare: Consumer viewpoints. In *2000 Poultry Symposium and Egg Processing Workshop, University of California, Davis*.

Tawse, J. (2010). Consumer attitudes towards farm animals and their welfare: a pig production case study. *Bioscience Horizons*, *3*(2): 156-165.

Teisl, M. F., Fein, S. B., & Levy, A. S. (2009). Information effects on consumer attitudes toward three food technologies: Organic production, biotechnology, and irradiation. *Food Quality and Preference*, *20*(8): 586-596.

Tonsor, G. T., & Schroeder, T. C. (2003). European consumer preferences for US and domestic beef: willingness to pay for source verification, hormone-free, and genetically modified organism-free beef. In *American Agricultural Economics Association Annual Meeting, Montreal, Canada* (pp. 27-30).

Tonsor, G. T., & Wolf, C. A. (2011). On mandatory labeling of animal welfare attributes. *Food Policy*, *36*(3): 430-437.

Tonsor, G. T., Wolf, C., & Olynk, N. (2009). Consumer voting and demand behavior regarding swine gestation crates. *Food Policy*, *34*(6): 492-498.

USDA (U.S. Department of Agriculture). (2019). *Biotechnology Frequently Asked Questions*. U. S. Department of Agriculture. Retrieved May 14, 2019 from: https://web.archive.org/web/20190130104808/https://www.usda.gov/topics/biotechnology/biotechnology-frequently-asked-questions-faqs.

Uzea, A. D. (2009). *Canadian Consumer Valuation of Farm Animal Welfare and Quality Verification The Case of Pork* (Doctoral Dissertation) University of Saskatchewan.

Van Eenennaam, A. L., Wells, K. D., & Murray, J. D. (2019). Proposed US regulation of gene-edited food animals is not fit for purpose. *npj Science of Food*, *3*: 3.

Ventura, B. A., von Keyserlingk, M. A., & Weary, D. M. (2015). Animal welfare concerns and values of stakeholders within the dairy industry. *Journal of Agricultural and Environmental Ethics*, *28*(1): 109-126.

Verhoog, H. (2003). Naturalness and the genetic modification of animals. *Trends in Biotechnology*, *21*(7): 294-297.

Wall, R. J., Powell, A. M., Paape, M. J., Kerr, D. E., Bannerman, D. D., Pursel, V. G., Wells, K. D., Talbot, N., & Hawk, H. W. (2005). Genetically enhanced cows resist intramammary Staphylococcus aureus infection. *Nature Biotechnology*, *23*(4): 445.

Whitworth, K. M., Rowland, R. R., Ewen, C. L., Trible, B. R., Kerrigan, M. A., Cino-Ozuna, A. G., Samuel, M.S., Lightner, J. E., McLaren, D. G., Mileham, A. J., Wells, K. D. & Prather, R. S. (2016). Gene-edited pigs are protected from porcine reproductive and respiratory syndrome virus. *Nature Biotechnology*, *34*(1): 20-22.

Widmar, N. O., Morgan, C. J., Wolf, C. A., Yeager, E. A., Dominick, S. R., & Croney, C. C. (2017). US Resident Perceptions of Dairy Cattle Management Practices. *Agricultural Sciences*, *8*(07): 645.

Wilson, D. (2016). Dairy Veterinary Newsletter. *Utah State Extension*. Retrieved May 14, 2019 from: https://web.archive.org/web/20190514150436/https://extension.usu.edu/dairy/files/UtahStateDairyVetNewsletterMar2016.pdf

Wolf, C. A., & Tonsor, G. T. (2017). Cow Welfare in the US Dairy Industry: Willingness-to-Pay and Willingness-to-Supply. *Journal of Agricultural and Resource Economics*, *42*(2): 164-179.

Wolf, C. A., Tonsor, G. T., McKendree, M. G. S., Thomson, D. U., & Swanson, J. C. (2016). Public and farmer perceptions of dairy cattle welfare in the United States. *Journal of Dairy Science*, *99*(7): 5892-5903.

Wu, H., Wang, Y., Zhang, Y., Yang, M., Lü, J., Liu, J., & Zhang, Y. (2015). TALE nickase-mediated SP110 knockin endows cattle with increased resistance to tuberculosis. *Proceedings of the National Academy of Sciences*, 201421587.

Young, A. E., & Van Eenennaam, A. L. (2017). 733 Genetically engineered feed: Impact on animal performance, health and products. *Journal of Animal Science*, *95* (supplement4): 357-357.

Zepeda, L., Douthitt, R., & You, S. Y. (2003). Consumer risk perceptions toward agricultural biotechnology, self-protection, and food demand: the case of milk in the United States. *Risk Analysis: An International Journal*, *23*(5): 973-984.

Zheng, Q., Lin, J., Huang, J., Zhang, H., Zhang, R., Zhang, X., Cao, C., Hambly, C., Qin, G., Yao, J., Song, R., Jia, Q., Wang, X., Li, Y., Zhang, N., Piao, Z., Ye, R., Speakman, J. R., Wang, H., Zhou, Q., Wang, Y., Jin, W., & Zhao , J. (2017). Reconstitution of UCP1 using CRISPR/Cas9 in the white adipose tissue of pigs decreases fat deposition and improves thermogenic capacity. *Proceedings of the National Academy of Sciences*, 201707853.

CHAPTER 2

Information and Consumer Demand for Milk Attributes: Are Redundant Labels an Effective Marketing Strategy?

This chapter was previously published in Applied Economic Perspectives and Policy and is reproduced with the permission of the coauthors. DOI: https://doi.org/10.1002/aepp.13155

Ufer, D., Ortega, D. L., & Wolf, C. A. (2021). Information and consumer demand for milk attributes: Are redundant labels an effective marketing strategy? *Applied Economic Perspectives and Policy*, *2021*:1-22.

Introduction

Producers are continuously working to find more efficient and effective means of communicating with consumers about their products. Consumers are regularly exposed to product information. This exposure is often warranted by an increasing demand for more information regarding the production, quality, and impact of the products they purchase. Of particular importance is the information which consumers cannot discern for themselves by inspecting the product. These invisible product traits, or 'credence attributes,' thus require a trustworthy certifier and consistent labels to effectively impart this information to the consumer (Caswell & Mojduszka, 1996; McCluskey, 2000). With an ever-changing landscape of consumer demands for these traits, it falls on producers to determine not only what consumers want from the production of their food but also how to most effectively communicate those traits to consumers.

In working to deliver the myriad of traits demanded by consumers, the consolidation of information into a single label can unintentionally reduce the effectiveness of communication. A prime example is the USDA organic label. Without explicit knowledge of the label's provisions, the label alone may fail to communicate organic's requirements to the consumer (Conner & Christy, 2004; Hemmerling et al., 2015). As consumers seek out specific credence traits, they may overlook their provision in organic products in favor of more explicitly labeled products. These explicit labels can be more important to consumers than organic labels (Ellison et al., 2017). More stringent animal welfare requirements and the absence of genetically modified organisms (GMOs) exemplify this issue (Ellison et al., 2017; Ufer et al., 2019). Comprehensive labels may fail to inform the consumer of what the product truly offers or enable the consumer to assume a trait exists when it does not (Hemmerling et al., 2015). Furthermore, consumers may shorten their decision-making time and effort through decision heuristics, making the meaning and use of a label subject to its capacity for rapid interpretation and self-explanation (Chen & Chaiken 1999 as cited in Janßen & Langen, 2017; Grunert et al., 2014). Additionally, there may be a preference to impart to the label the meaning they desire of it rather than what it actually means. If this is the case, it raises the possibility that the existence of the label itself provides value to the consumer. To ensure consumers are receiving the traits they demand and producers are capitalizing on the traits they offer, finding the optimal means of communication through labels is imperative.

One approach to ensuring consumers realize the full implications of comprehensive labels is the increasingly prominent phenomenon of redundant labeling. Even with the availability of organic products, which have always been non-GMO, consumers have demonstrated a preference for products explicitly labeled as non-GMO (McFadden & Huffman, 2017). This desire for an explicit label has led many organic marketers to include an explicit non-GMO label alongside the organic label. One industry where this practice is increasingly prevalent is the U.S. dairy industry, in which many organic dairy products are beginning to bear labels like the Organic is Always non-GMO label presented in Figure 2.1. Animal welfare claims are also increasingly prominent on dairy products, despite the animal welfare requirements of organic production. The U.S. dairy industry has long been subject to high costs and price volatility, making the marketing of dairy products of utmost importance. The fluid milk supply chain has one of the closest price spreads of all commodities from farm gate to consumer. In 2018, over 50% of the retail price of fluid milk went directly to farmers, more than three times the sector-wide average of approximately 15% (ERS, 2018; ERS, 2020). As such, dairy farmers are highly susceptible to the success or failure of marketing efforts in the grocery dairy case. The rise of explicit labels that offer subsets of organic traits brings the risk of organic market share loss to products that provide fewer traits. Thus, strategies such as redundant labels become very appealing.

Redundant labels have not been studied extensively. A few notable studies have looked at consumer preferences when presented with labels that provide no new or useful information, particularly explicit non-GMO labels on organic products. Some have found little to no premium for the organic and non-GMO label over the non-GMO label alone (Bernard et al., 2006; McFadden & Lusk, 2017). In contrast, Conner and Christy (2004) found that, despite participant awareness, average willingness to pay (WTP) for a label which denoted both traits was higher than for the organic label alone. Further, Drugova (2019) found that WTP for the organic/non-GMO label was higher than organic alone for some products but not others, suggesting a product-dependent effect. Bernard et al. (2019) found that the presence of a label providing minimal additional information increased WTP and could induce participants to believe the food would be tastier, safer, and more likely to meet the consumer's definition of local. Heng et al. (2016) found that the addition of redundant or superfluous labels to organic eggs increased WTP, even after informing consumers of the redundancy or superfluity. Wilson and Lusk (2020) similarly found consumers valued labels that were redundant in providing no differentiating information about a product, such as non-GMO salt, and the value persisted for many consumers even when they were informed of the redundancy. Janßen and Langen (2017) found certain classes of consumers were more likely to find a redundant labeling approach in German organic dairy products helpful and appealing.

The USDA organic label is a federally regulated program. As such, the policy implications of a redundant labeling strategy on informational and marketing efforts are important to consider. Should the comprehensive USDA organic label prove ineffective in communicating the desired traits, the proliferation of redundant labels in the marketplace may be the first warning sign that a reevaluation of the USDA organic label's design is needed.

This study evaluates the effects of information and redundant labels on consumer purchase decisions and simulates market shares to inform policy and producer decision-making. One contribution of this study is to assess consumer preferences for redundant labels in a market that offers them alongside a comprehensive label and an explicit singular label. We determine whether informing consumers of a label's redundancy eliminates any benefits consumers derive from it. To do so, we use a novel application of a Becker-DeGroot-Marschak (BDM) experiment in a supermarket setting. With the preferences elicited by this experiment, we investigate if redundant labels can recapture lost market share through market share simulations. Our simulations allow for identification of whether the value for redundant labels is driven by a lack of consumer knowledge of the comprehensive label's provision or by value for explicit designation of the included traits.

Field Experiment Design and Data

We designed and executed a field experiment in a local grocery store in Okemos, Michigan, in May and June of 2019.[3] All customers over 18 years of age who consumed fluid milk were invited to participate.[4,5] A half-gallon size of milk was used for all experiments. The seven types of milk used were labeled 'conventional,' USDA organic, 'Animal-friendly,' 'Non-

[3] A local, independent, non-specialty grocery store location was used to ensure no selection bias towards specialty consumption in the sample.
[4] Days and times for data collection were varied to preserve variation in participant characteristics.
[5] Consumers who exclusively consume lactose-free or plant-based milks were excluded.

GMO,' and all pairwise combinations of the latter three. The 'Animal-friendly' term was chosen for animal welfare labeling for several reasons. Animal welfare claims and labels are considerably less consistent than non-GMO or organic labels, and claims are often made with varying terms without attendant certification. Thus, the animal-friendly label captures the notion of animal welfare in the broad sense that is most commonly experienced in the current market. Additionally, our study was limited by the availability of animal welfare certified fluid milk products, while the more general 'animal-friendly' claim is more readily available. Furthermore, to ensure that the redundant labeling strategies would not impose substantial additional costs on organic marketing, generic non-GMO and animal welfare labels were used. These labels were also selected to avoid any artificial inflation of bids due to the sheer presence of multiple labels. The presentation of the traits through plain text labeling was designed to highlight the content of the label rather than the graphical appeal of additional labels. The milk products presented to consumers for evaluation did not differ aside from the labels.[6] Individuals were each compensated $10 for participation after their session.[7]

Willingness to pay for the seven differently labeled types of milk was elicited using a BDM mechanism (Becker et al., 1964). The BDM mechanism was used since it is theoretically incentive-compatible and can be performed with individual participants, capturing any decision heuristics they may employ in the decision process. The mechanism operates by eliciting a subject's bid, which is then compared to a randomly drawn "market price" from a pre-specified distribution. If the bid exceeds the market price, the subject purchases the product at the market price. If the market price is higher than the bid, it indicates the subject would be unwilling to

[6] All products used in the experiment were available for consumers to purchase.
[7] Emphasis on the amount and timing of compensation were minimized to reduce 'windfall' bidding behavior.

purchase the product in the "market," and no transaction occurs. The BDM mechanism is more easily administered in a real-world setting than experimental auction mechanisms as it can be performed with participants individually (Lusk & Shogren, 2007; Canavari et al., 2019). While these benefits make the BDM the optimal WTP elicitation method for our study, it is also important to consider the limitations of the mechanism. One limitation is the potential for the incentive-compatibility of the mechanism to be compromised by bid dependence on the random price distribution (Horowitz, 2006). Another is the possibility of participant confusion over the second-price auction incentives of the BDM, with participants instead acting as though the BDM operates with first-price auction incentives (Cason & Plott, 2014). These limitations were considered in our study design, which also employed best practices for conducting field experiments (Canavari et al., 2019).

The BDM experiments were conducted by two trained enumerators in a grocery store setting. The field experiment was designed to test the effects of information. Willingness to pay was elicited before and after information on the relationship between USDA organic, non-GMO, and animal-friendly dairy production practices. Participants had the option to purchase all seven products, but no additional information as to the full meaning of labels was used. Consumers' initial bids were recorded. Participants were then provided with a short paragraph (Appendix B) informing them of the relationship between USDA organic and non-GMO and animal-friendly traits, making it clear that the latter two are subsets of the former. After reading the provided information, participants submitted bids for the same products, allowing them to make any adjustments relative to their initial bids. The same nine steps were used by each enumerator for each participant. The full experimental procedures are described in detail in Appendix C.

Data

Descriptive statistics for our sample (n=203) are presented in Table 2.1 alongside national averages and median values. The sample was approximately 60% female. The average age was 54, with 45.3% having some postgraduate education and only around 19% not having a college degree. Additionally, 59.1% fell into a high household income bracket of over $80,000 per year. The average household size was 2.7. The sample is disproportionately female, older, wealthier, and more educated than the U.S. population at large. To account for this discrepancy with the population at large, we use an importance weighting approach where weights are calculated using the iterative proportional fitting process developed by Bergmann (2011). Population proportions for age and gender were drawn from the 2010 census (Howden & Meyer, 2011), and education and income from the U.S. Census Bureau's 2019 estimates (Table 2.1).

In addition to basic sociodemographic questions, our survey also included consumption variables, animal welfare attitudes, and food knowledge relevant to GMOs in agriculture. Questions regarding personal political and moral beliefs related to food choices were also included, as political beliefs have been shown to coincide with specific animal welfare and organic preferences and moral beliefs may dictate how an individual feels animals ought to be treated (Onyango et al., 2007; McKendree et al., 2014). Less than 8% of the sample consumed milk or dairy products only once a week or less, with nearly 40% of the sample consuming dairy multiple times each day. Of the sampled participants, 6.4% subscribed to some form of animal-product restricted diet prior to the time of the survey. Nearly half of the sample reported having been on a farm or spoken with a farmer in the past year. Approximately 37% of the sample self-identified as somewhat or very liberal and approximately 24% as somewhat or very conservative. On average, participants reported that their morals or religious beliefs informed their food decisions to some extent, with the average being a 2.6 on a 5-point scale where 1 indicated “Not at All,” and 5 indicated “A Great Deal.”

Participants were asked two types of knowledge questions, eliciting their level of subjective and objective knowledge regarding production practices in the dairy industry. Responses were used to assess how knowledge affects the demand for products produced using biotechnology when various non-GMO-labeled alternatives are present. Subjective knowledge was measured using a single question where participants were asked to rate their own knowledge of GMOs in agriculture on a 7-point scale ranging from “Not at all knowledgeable” (1) to “Very knowledgeable” (7). The mean subjective knowledge value was 3.7. Answers to four true or false questions were used to measure objective knowledge regarding GMOs in the dairy industry (Appendix D). Objective knowledge scores ranged from 0 to 4, depending on how many statements were correctly identified as true or false. The mean objective knowledge score was 2.2.

One of the difficulties in evaluating consumer demand for animal welfare is the variation in definitions of good animal welfare (Ufer et al., 2019).[8] Hence, measures of knowledge are difficult to objectively define and compare. Instead, we account for participant attitudes toward animal welfare in the dairy industry by asking participants to rate their agreement with five statements on a five-point Likert scale ranging from “Strongly disagree” (1) to “Strongly agree”

[8] While the World Animal Health Organization has provided a global definition of good animal welfare guided by the Five Freedoms (see OIE, 2019), consumers may demand additional or alternative provisions to meet their own definitions of good animal welfare. When evaluating consumer demands for such traits, it is important to bear in mind that the consumer’s perception of the trait in question can be as influential to their purchase decision as the actual definition itself.

(5) (Appendix D). Factor analysis was conducted using the principal-factor method with varimax rotation, with the five items loading onto two factors (Kaiser, 1958). We elected to use a single factor that explains the common variance in the five items. The resulting variable represents animal welfare attitude, where higher values indicate greater concern for animal welfare issues in agriculture.

Methods

Consumer WTP premiums for milk labels are modeled as a function of participant sociodemographic and consumption characteristics, subjective and objective knowledge relevant to GMOs in agriculture, animal welfare attitudes, farm contact history, and political and moral influences on food purchase decisions. A difference estimator was specified using weighted panel OLS:

$$WTP_{ni} = \alpha + \boldsymbol{x}_n\boldsymbol{\beta} + \boldsymbol{d}_i\boldsymbol{\gamma} + r\rho + (r*\boldsymbol{d}_i)\boldsymbol{\lambda} + \varepsilon_{ni} \qquad \varepsilon_{ni}\sim N(0,\sigma^2) \tag{2.1}$$

Where WTP_{ni} is individual n's observed bid for a half-gallon of milk of type i. $\boldsymbol{d}$ is a vector of dummy variables, where $d_i = 1$ for i in the set {organic, non-GMO, animal-friendly, organic/non-GMO, organic/animal-friendly and non-GMO/animal-friendly} if the product bears that label and 0 otherwise. The model is estimated using the direct bids rather than the premiums as the dependent variable, so the conventional product serves as the base case. $\boldsymbol{x}_n$ is a vector of participant characteristics (age, gender, household income, education, household size, dairy consumption frequency, farm contact, political leaning, subjective and objective knowledge, animal welfare attitude and moral influence on food choices) and ε_{ni} is the error term with zero-mean. r is a general indicator variable for post-treatment bids ("with information"), and $r*\boldsymbol{d}_i$ is a vector of interactions representing each bid specifically post-treatment. A population weighting approach was employed, and standard errors were clustered by individual. The vectors $\boldsymbol{\gamma}$, $\boldsymbol{\lambda}$ and $\boldsymbol{\beta}$, and α and ρ are all parameters to be estimated.

Results and Discussion

Descriptive statistics for participant bids and premiums, before and after information, for each of the seven types of milk are presented in Table 2.2. Pre-information, the mean bid for a half-gallon of conventional milk was $1.97, with a maximum bid of $5. Premiums were calculated for bids without and with information for each participant as the difference between their bid for conventional milk and their bid for each labeled milk. For individual labels, consumers had the highest premium for organic ($0.96), then animal-friendly ($0.88) and non-GMO last ($0.64). All the redundant or dual-labeled milks had higher mean premiums than the single labeled milks, with all redundant and dual-labeled milks having a mean premium between $1.24 and $1.28. The dual-labeled non-GMO and animal-friendly milk had the highest mean. In the post-information case, the mean premiums for all labeled milks almost unilaterally increased, the only exceptions being the dual-labeled and individual non-GMO labeled milk.

A common assumption in many consumer preference models is the additivity of traits in consumer utility functions, which is sometimes extended to WTP estimates. However, our data shows that consumers do not view these labels as separable and, consequently, additive in value. This is demonstrated in the mean premiums, where the pairwise sums of the individual premiums for organic, non-GMO, and animal-friendly do not equal the premiums of the corresponding redundant or dual-labeled products. These inequalities indicate a substitute relationship between non-GMO and animal-friendly labels. This could possibly be driven by these two labels simultaneously contributing to the same purchase motive of consumers, such as a perceived increased ethical standard or higher quality of the end product. The increased value of the redundant label over the organic label alone may indicate that the explicit statement of the redundant trait adds value.

Model Results

The results of the weighted panel OLS model are presented in Table 2.3. The results indicate that women, on average, were willing to pay $0.44 more for any type of milk. Individuals who only had a high school diploma and no further education had substantially higher WTP for milk on average ($0.96 more than the average), as did individuals who identified as politically liberal, with bids approximately $0.43 higher than average. Individuals from larger households had lower WTP for milk overall than those from smaller households. The coefficients on all other control variables are statistically insignificant at the conventional levels.

The coefficients for each of the individual and redundant/dual labels without information is statistically significant at the 1% level. Additionally, all individual and redundant/dual labels have significant, positive coefficients, meaning consumers are willing to pay premiums for all those types of milk over conventional. This indicates that, on average, consumers positively value all of the traits included in the analysis and are willing to pay a premium for these traits, whether labeled alone or in combination. These findings are consistent with those of previous studies on these traits (Bernard et al., 2006; Hemmerling et al., 2015; Ortega & Wolf, 2018). For the individual organic label, animal-friendly label, and redundant animal-friendly organic label, the provision of information had a statistically significant positive effect on the value of the label of $0.14, $0.08, and $0.19, respectively. As the information treatment was focused on the organic label, this may have increased the subject’s knowledge of what the label entails, such that their value of the individual label increased, without necessarily having the subsequent effect of decreasing the relative value of redundant labels. The information treatment also highlighted animal-friendly production practices, which may have had a general impact on consumer value for an animal-friendly label.

The coefficient for the non-GMO individual label following the information treatment is not significantly different from zero. Furthermore, the premium for the dual-labeled animal-friendly and non-GMO milk did not change from pre- to post-treatment. The absence of information effects on these labels indicates that the treatment did not cause subjects to unilaterally inflate bids before and after information but only adjusted their bids for those labels, which might be relevant to the provided information. This is further reinforced by the statistical insignificance and near-zero magnitude of the coefficient on the post-treatment dummy variable r. However, the premium for the redundantly labeled non-GMO organic milk, also experienced no significant change following the information treatment. While information does increase the weighted mean premium for the organic label alone to approximately $1.08 it is still less than that of the premium for the redundant label. This could indicate that the information is somewhat effective. The redundant label loses much of its relative value but is still valued on average more highly than the individual organic label.

Market Impacts of Introducing Redundant and Dual Labels

The results of the weighted panel OLS model offer substantial insight into the values consumers place on the individual, dual and redundant labels before and after the provision of information. The results do not, however, offer any further insight on the market implications of the offering of these labels beyond the premiums consumers may be willing to pay and the potential impacts of education on those premiums. In this case, a market share simulation can be very useful in understanding market dynamics under the introduction of novel labels. We employ market simulations to evaluate multiple scenarios and understand how dual or redundant labels might impact markets. Additionally, one market share simulation which investigates the impacts of the proliferation of non-GMO labels in the fluid milk market on organic dairy farmers is also presented. In total, four market scenarios are simulated each for both the pre- and post-information treatment cases. Two evaluate the impacts on the market shares of single label products once the corresponding redundant-labeled product enters the market. One evaluates the impact of the dual animal-friendly, non-GMO label on organic dairy farmers' market shares, as well as the single label counterparts of the dual label. Another one evaluates the impact of the non-GMO label on organic dairy farmers' shares.

The derivation of market shares from BDM bids was conducted following the framework proposed by Lusk and Shogren (2007) and Lusk (2010). To increase the robustness of the conclusions drawn from the simulations, confidence intervals were constructed using standard errors derived from bootstrapping techniques. Similar to Bernard and Bernard (2010), we employ the sample mean bid as the market price for the individually-labeled products and the redundant and dual-labeled product, and the Midwest average price for conventional milk as reported by the Agricultural Marketing Service for June, 2019.

Market Share Simulation Results

Results of the simplest simulation of introducing a non-GMO labeled alternative into a market initially offering only conventional and organic milk are presented in Table 2.4. This scenario evaluates the extent to which consumers value the absence of biotechnology in the organic label alone. Approximately 12% of individuals chose the novel non-GMO labeled milk following its introduction. This group is primarily comprised of individuals who were previously purchasing organic milk. When consumers are informed that organic includes non-GMO, approximately 23% of organic consumers still shift to purchasing the single label. This would indicate that 23% of organic purchasers choose organic primarily for the non-GMO trait.

Results from the simulation of the introduction of the redundant non-GMO/organic or animal-friendly/organic labeled milk into markets that initially offer conventional, organic, and the corresponding single label (either non-GMO or animal-friendly) labeled milk are presented in Tables 2.5 and 2.6. Upon introducing the redundant label, small changes in the share of consumers making no purchase indicate that the redundant labels' market shares come from redistribution of individuals already purchasing milk, rather than by drawing new customers into the market. The redundant labels achieve market shares of approximately 15% to 16%. Of the individuals choosing the redundant labels, 70% are redistributed from previous organic and non-GMO consumers. Between one-half and one-third of the previous organic market shares have been 'lost' to the redundant labels. The recapturing of market share through the redundant label (and thus by organic producers) from the single non-GMO or animal-friendly labels would indicate that approximately 3% to 6%, respectively, of all consumers are unaware of the provision of these traits but would purchase organic if it were also explicitly labeled as either non-GMO or animal-friendly.

The introduction of the redundant label to informed consumers, following the information treatment, has a substantially lower impact on the single label organic purchasers. The single label organic market share decreases by less than in the pre-information case. For example, when the non-GMO/organic redundant label is introduced following the information treatment, the single label organic market share decreases by only 20% instead of 44%. The non-GMO/organic and animal-friendly/organic redundant labels are also able to garner 15% to 17% of their respective markets, derived mainly from customers who previously purchased the individual labels or conventional milk. Thus, while educating consumers appears to reduce the efficacy of redundant labels for organic consumers, it remains an effective strategy in capturing greater market share for individuals demanding explicit labeling of non-GMO or animal-friendly traits.

Results from the simulation of the introduction of the dual non-GMO, animal-friendly labeled milk into a market that initially offers conventional, organic, non-GMO, and animal-friendly labeled milk are presented in Table 2.7. The dual label captures approximately 14% of the milk market, with between 3 and 4 percentage points of that share drawn from each of the individual label milks. Over a third of the market shares for animal-friendly and non-GMO labeled milks is captured by the dual label. This could indicate that over 8% of the market desires these two traits together but, not knowing they are simultaneously available in the organic label, may prioritize the most important trait in their purchase decision by electing a product explicitly labeled with only one of the two. The loss of nearly a quarter of the organic market share to the dual label in the pre-information case would indicate a substantial portion of organic consumers are unaware of the full provisions of the organic label. This may be explained by the organic and dual labels playing different roles in consumers' minds. Caputo et al. (2017) recently found that the value that consumers put on 'cue' attributes, such as organic, may diminish when 'independent' attributes (non-GMO and animal-friendly) are available. This is remedied in the post-information case where little more than 1% of the market is redistributed from organic to the dual label.

Discussion and Policy Implications

The overall results of our study clearly point to the value consumers have for these alternative labeling strategies. The positive coefficients on all label variables but non-GMO milk in the post-information case are the first indication of the persistence of the labels' value for consumers, even in the face of information that exposes the redundancy. This implies that not only are redundant labels a potentially effective strategy in capturing consumer attention, but they may even increase the profitability of organic products with no substantial additional cost. This is, of course, in the case that the redundant labels are simply pointing out those traits which are present in the comprehensive certification, rather than achieved through producers obtaining additional, costly certifications. These results are in line with Bernard et al.'s (2019) and Wilson and Lusk's (2020) findings of consumer value for labels that provide no further information.

While the market share simulations each present different market scenarios, many of the results are consistent. In the pre-information cases, shifts in market share away from the individual organic label into the redundant label indicate two possibilities. Consumers are either unaware of the provision of the explicitly labeled trait in the organic label or value the explicit reassurance of that trait's presence in the organic label. Poor consumer awareness of the provisions of the organic label is further demonstrated by the redundant labels' ability to capture market share from the individual non-GMO or animal-friendly labeled milks. This suggests that these captured consumers value the organic label as well as the explicitly labeled trait but are unaware of the trait's provision in organic. The post-information case provides insight into the magnitudes of these two drivers. Organic consumer responsiveness to redundant labels decreases in the post-information case, indicating that the value of the redundant label is nullified upon learning of the trait's presence in the organic label for those consumers who were previously unaware. However, the persistence of some organic consumers shifting to the redundant label, even when informed, indicates that a proportion of organic consumers do value the explicit reassurance that the trait of interest is indeed present in the organic product. This is consistent with the findings of Heng et al. (2016) and Wilson and Lusk (2020) of the persistence of value for redundant labels, even in the face of information. It should be noted that, given the inherent vagueness of animal-welfare labels, the continued value of organic consumers for the redundant organic, animal-friendly label may indicate a belief that the animal-friendly label includes additional provisions over the organic label alone. Indeed, Lusk et al. (2014) have shown the potential for beliefs to drive purchase decisions, regardless of preferences over explicit labels.

While the simulation results also point to the value of redundant labels as an effective marketing strategy that can both recapture lost market share in markets with uninformed consumers as well provide additional value to informed consumers, this does not mean organic producers and market strategists should abandon educational efforts. This is demonstrated by the final simulation, which introduces the dual non-GMO, animal-friendly labeled milk. The results of this simulation clearly show that educational efforts can be effective at dramatically reducing the losses of organic market share to products labeled with some of the individual traits of organic but not the full suite. In addition, in combining these results with those of the model, continuing educational efforts may increase the premiums that could be received for redundantly-labeled organic milk, as premiums increase for such milk when the market share is limited to those consumers who value the explicit reassurance.

Our results also lead to important policy implications. The clear value consumers hold for redundantly labeled products indicates that the comprehensive USDA organic label alone may not be sufficient, and its presentation may merit reevaluation. The USDA organic program may also consider providing approved redundant labels that highlight the particular traits of importance to maintain consistency in the marketplace but also provide for consumer demands of more explicit labels. The evidence of consumer misinformation from our results also indicates that the USDA organic program's promotional strategy may need to undergo reorganization. Such a reorganization should aim to reduce consumer susceptibility to misinterpreting the label, minimizing producer risk should consumers discover the traits they assumed the organic label implied are, in fact, not included.

Our study has limitations that are important to consider when analyzing our results. First is the issue of label dynamics, where the reported premiums for a product may be subject to a novelty effect that does not persist in the long term. This topic is beyond the scope of this study, and future research could help inform the implications of label dynamics for redundant labels. Though we have taken special care through our weighting approach to make our results as generalizable as possible, it should be noted that the representativeness of our sample also constitutes a potential limitation. Additional research is needed to address any geographical or regional differences in consumer behavior that may exist. While our study does not address the phenomenon directly, the addition of more labels to a product is subject to diminishing marginal returns, as was observed by Heng et al. (2016) and Bernard et al. (2019). Thus, producers and marketers should be conscientious of which labels will provide the optimal combination of communicating value to consumers and counteracting market share losses to competing individual-labeled products.

Beyond these considerations of labeling strategies, however, our results provide strong evidence for the potential efficacy of a redundant labeling strategy combined with continuing educational efforts. These labels represent both an opportunity to better meet some consumer demands and a risk of further complicating consumer purchase decisions. Thus, policymakers and industry strategists should carefully consider how best to combine education and the direct labeling of foods to meet this opportunity and minimize the risks.

Conclusion

The results of this study demonstrate consumer value for redundant labels, regardless of consumer information level. While, as expected, all of the labeled milk products obtained premiums over conventional milk, the redundant labels received greater premiums in every case over their individual counterparts. These greater premiums persisted even after consumers were informed of the redundancy of the label. And while informed consumers are less influenced by a redundant label than uninformed consumers, as demonstrated in the market share simulations, redundant labels still offer an effective means of recapturing market share lost to products produced using only a subset of the traits provided in a comprehensive label.

Our findings have significant implications for stakeholders who market products under a comprehensive label such as USDA organic. We find evidence that redundant labels are an effective marketing strategy. Redundant labels demonstrate the potential to recapture market share lost to products offering only a subset of the comprehensive label’s traits. They may also offer a means for these producers to garner even greater premiums than the comprehensive label alone. Whether consumers derive greater value from the redundant labels through explicit reassurance or by the advertisement of the provision of traits they were previously unaware of, WTP is markedly higher for redundantly labeled products. For organic producers and food firms, marketing strategists should identify which traits of organic are most valuable or most highly prioritized and consider including explicit labels. This should not be limited to just organic consumers, given that redundant labels may serve as a means of capturing consumers from the conventional market who are unaware that organic provides traits of interest to them.

While redundant labels clearly are of value to the consumer, their adoption as a marketing strategy should not necessarily occur at the expense of informational marketing efforts. The value of such efforts is best demonstrated by the market share simulation of products labeled with a subset of multiple traits present in the organic label, in which such products pose less threat of market share loss of the informed consumer than the uninformed consumer. Additionally, educational efforts focused on the full suite of traits offered by a comprehensive label may help reduce the strain of shifting consumer priorities on marketing strategies

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APPENDICES

Appendix A: Tables and Figures

Table 2.1: Sample Summary Statistics

Variable	**Sample**	**United States**
Female	59.60%	50.80%[a]
Age	54.42 (14.62)	37.8 [a]
College Degree	35.47%	27.41% [b]
Postgraduate or Professional Degree	45.32%	11.80% [b]
Low Income (<$40,000)	8.38%	32.10% [c]
High Income (>$80,000)	59.11%	39.83% [c]
Household Size	2.69 (1.45)	2.63 [a]
Restricted Diet[f]	6.40%	5%[d]
Farm Contact	49.76%	
Liberal	36.95%	26% [e]
Conservative	23.65%	35% [e]
GMO Objective Knowledge (0 to 4)[g]	2.22 (1.11)	
GMO Subjective Knowledge (1 to 7)[g]	3.71 (1.74)	
N	203	

Standard deviations are in parentheses.

[a] U.S. Census Bureau (2019). Quick Facts United States.

[b] U.S. Census Bureau (2019). American Fact Finder: Educational Attainment.

[c] U.S. Census Bureau (2019). Income Distribution to $250,000 or More for Households.

[d] Hrynowski (2019).

[e] Saad (2019).

[f] Restricted diet refers to diets which restrict animal product consumption, either vegetarian or vegan.

[g] Objective knowledge of 0 indicates low knowledge, while 4 indicates high knowledge. Subjective knowledge of 1 indicates ‘not at all knowledgeable’, 7 indicates ‘extremely knowledgeable’.

Table 2.2: Summary Statistics of Bids (unweighted)

	Pre-Information				Post-Information				Sig. Diff.[a]
Direct Bids (n=203)	Mean	St. Dev.	Min	Max	Mean	St. Dev.	Min	Max	
Conventional	1.975	0.881	0	5	1.982	0.965	0	5	
Organic	2.930	1.247	0	7	3.138	1.297	0	7	***
Non-GMO	2.618	1.213	0	8	2.598	1.204	0	8	
Animal-Friendly	2.851	1.197	0	7	2.922	1.224	0	7	
Animal-Friendly Organic	3.249	1.438	0	9	3.443	1.470	0	9	***
Animal-Friendly Non-GMO	3.259	1.450	0	9	3.228	1.405	0	9	
Non-GMO Organic	3.223	1.430	0	8	3.388	1.407	0	8	***
Premiums									
Organic	0.955	1.189	-2.5	7	1.156	1.276	-2.5	7	***
Non-GMO	0.643	1.157	-2.5	8	0.616	1.066	-2.5	8	
Animal-Friendly	0.876	1.058	-2	7	0.940	1.090	-2	7	
Animal-Friendly Organic	1.274	1.441	-2.5	9	1.460	1.489	-2.5	9	***
Animal-Friendly Non-GMO	1.284	1.433	-2.5	9	1.245	1.359	-2.5	9	
Non-GMO Organic	1.248	1.478	-2.5	8	1.406	1.464	-2.5	8	***

[a] Sig. Diff. indicates whether there is a statistically significant difference in the mean bids or premiums for a label from the pre-information to post-information round. Significance is consistent between both parametric (t-test) and non-parametric (Wilcoxon sign rank) tests. Statistical significance is denoted for the 1% ($p < 0.01$, ***) significance level.

Table 2.3: Weighted Panel OLS Model - Dependent Variable: Bids ($/0.5 gal)

	Coefficient	**S.E.**
Organic	0.938***	0.100
Organic w/ Info	0.142**	0.062
Non-GMO	0.569***	0.088
Non-GMO w/ Info	-0.039	0.057
Animal-Friendly	0.861***	0.101
Animal-Friendly w/ Info	0.078*	0.046
Animal-Friendly Organic	1.281***	0.121
Animal-Friendly Organic w/ Info	0.186***	0.043
Non-GMO Organic	1.298***	0.159
Non-GMO Organic w/ Info	0.090	0.104
Animal-Friendly Non-GMO	1.381***	0.163
Animal-Friendly Non-GMO w/ Info	-0.058	0.120
Information Treatment	0.087	0.091
Female	0.435**	0.179
Age	-0.003	0.007
High School Only	0.962**	0.449
Postgraduate	-0.084	0.163
High Income	0.027	0.187
Consumption	-0.062	0.080
Household Size	-0.190**	0.075
Farm Contact	0.125	0.216
Liberal	0.433*	0.214
GMO Subjective Knowledge	-0.033	0.056
GMO Objective Knowledge	-0.024	0.105
Food Morals	-0.046	0.082
Animal Welfare Attitude	-0.082	0.121
Constant	2.776***	0.621
Root MSE	1.168	
R^2	0.256	
***F*-stat**	16.15***	
N	2,842	
No. clusters	203	

Statistical significance is denoted for the 1% (p < 0.01, ***), 5% (p < 0.05, **) and 10% (p < 0.1, *) levels.

Table 2.4: Market Scenario: Introducing the non-GMO label when organic is initially present

Label Type	Base Pre-Info	95% CI	Introduce Non-GMO	95% CI	Base Post-Info	95% CI	Introduce Non-GMO	95% CI
Percent of individuals choosing								
Conventional	62.92	[56.16, 69.46]	60.03	[53.69, 66.50]	61.41	[54.19, 67.98]	58.04	[50.74, 65.02]
Organic	24.16	[18.72, 30.05]	15.82	[10.84, 20.69]	24.21	[18.72, 30.05]	18.27	[13.30, 23.65]
Non-GMO			11.76	[7.39, 15.76]			10.32	[6.40, 14.29]
None	12.91	[7.88, 17.24]	12.39	[7.88, 17.24]	14.28	[8.87, 19.70]	13.37	[8.37, 18.23]
Market Share (%)								
Conventional	72.25	[65.88, 78.36]	68.52	[62.22, 74.73]	71.73	[64.74, 77.78]	67.00	[59.89, 73.21]
Organic	27.75	[21.64, 34.12]	18.06	[12.57, 23.56]	28.27	[22.22, 35.26]	21.09	[15.43, 27.43]
Non-GMO			13.42	[8.52, 18.18]			11.91	[7.19, 16.76]
Absolute change in market share from baseline (%)								
Conventional			-3.74	[-6.61, -1.14]			-4.73	[-7.94, -1.91]
Organic			-9.69	[-14.13, -5.77]			-7.02	[-11.28, -3.06]
Non-GMO			13.42	[8.52, 18.18]			11.91	[7.19, 16.76]
Percentage change in market share from baseline								
Conventional			-5.17	[-9.23, -1.56]			-6.59	[-11.02, -2.74]
Organic			-34.93	[-49.52, -21.95]			-25.37	[-39.22, -13.21]

Table 2.5: Market Scenario: Introducing the redundant non-GMO/organic label when individual counterparts are initially present

Label Type	**Base Pre-Info**	**95% CI**	**Introduce Redundant**	**95% CI**	**Base Post-Info**	**95% CI**	**Introduce Redundant**	**95% CI**
Percent of individuals choosing								
Conventional	60.03	[53.69, 66.50]	56.64	[50.25, 63.55]	58.04	[50.74, 65.02]	52.73	[46.31, 59.11]
Organic	15.82	[10.84, 20.69]	8.93	[5.42, 12.81]	18.27	[13.30, 23.65]	14.79	[10.34, 20.20]
Non-GMO	11.76	[7.39, 15.76]	8.81	[4.93, 12.32]	10.32	[6.40, 14.29]	6.83	[3.45, 10.34]
Organic Non-GMO			14.14	[9.36, 18.72]			13.65	[9.36, 18.23]
None	12.39	[7.88, 17.24]	11.49	[6.90, 16.26]	13.37	[8.37, 18.23]	12.00	[7.39, 16.75]
Market Share (%)								
Conventional	68.52	[62.22, 74.73]	63.99	[57.38, 70.56]	67.00	[59.89, 73.21]	59.92	[53.07, 66.30]
Organic	18.06	[12.57, 23.56]	10.09	[5.98, 14.61]	21.09	[15.43, 27.43]	16.80	[11.73, 22.73]
Non-GMO	13.42	[8.52, 18.18]	9.95	[5.59, 13.94]	11.91	[7.19, 16.76]	7.76	[4.00, 11.67]
Organic Non-GMO			15.97	[10.99, 21.11]			15.51	[10.93, 20.34]
Absolute change in market share from baseline (%)								
Conventional			-4.63	[-7.97, -1.94]			-7.07	[-10.88, 3.68]
Organic			-7.97	[-11.80, -4.10]			-4.29	[-7.09, -1.84]
Non-GMO			-3.47	[-6.33, -1.18]			-4.15	[-7.34, -1.72]
Organic Non-GMO			15.97	[10.98, 21.11]			15.51	[10.93, 20.34]
Percentage change in market share from baseline								
Conventional			-6.60	[-11.40, -2.79]			-10.54	[-15.93, -5.77]
Organic			-44.12	[-60.69, -26.24]			-20.35	[-32.65, -9.67]
Non-GMO			-25.91	[-43.19, -9.27]			-34.93	[-55.26, -15.00]

Table 2.6: Market Scenario: Introducing the redundant animal-friendly/organic label when individual counterparts are initially present

Label Type	**Base Pre-Info**	**95% CI**	**Introduce Redundant**	**95% CI**	**Base Post-Info**	**95% CI**	**Introduce Redundant**	**95% CI**
Percent of individuals choosing								
Conventional	58.99	[52.22, 65.52]	55.57	[48.77, 62.07]	55.06	[48.28, 61.08]	51.64	[44.83, 58.13]
Organic	13.82	[9.36, 18.72]	9.84	[5.91, 14.29]	15.79	[11.33, 20.69]	11.78	[7.39, 16.26]
Animal-Friendly	14.80	[9.85, 19.70]	9.43	[5.42, 13.79]	15.77	[11.33, 20.69]	9.42	[5.91, 13.30]
Organic Animal-Friendly			13.24	[8.37, 18.23]			14.71	[9.85, 19.70]
None	12.39	[7.88, 17.24]	11.93	[7.39, 16.75]	13.37	[8.37, 18.23]	12.44	[7.88, 17.24]
Market Share (%)								
Conventional	67.33	[60.23, 73.84]	63.10	[56.04, 69.61]	63.56	[57.06, 69.59]	58.98	[51.98, 65.59]
Organic	15.78	[10.53, 21.31]	11.17	[6.99, 16.29]	18.23	[12.99, 23.98]	13.46	[8.82, 18.29]
Animal-Friendly	16.89	[11.43, 22.35]	10.70	[6.32, 15.56]	18.21	[12.72, 24.07]	10.76	[6.82, 15.17]
Organic Animal-Friendly			15.03	[9.83, 20.22]			16.80	[11.30, 22.29]
Absolute change in market share from baseline (%)								
Conventional			-4.24	[-7.47, -1.65]			-4.58	[-7.46, -1.99]
Organic			-4.61	[-7.98, -1.81]			-4.77	[-8.12, -1.88]
Animal-Friendly			-6.19	[-9.60, -2.79]			-7.45	[-11.23, -4.05]
Organic Animal-Friendly			15.03	[9.83, 20.22]			16.80	[11.30, 22.29]
Percentage change in market share from baseline								
Conventional			-6.29	[-10.77, -2.51]			-7.21	[-11.59, -3.15]
Organic			-29.20	[-46.43, -13.01]			-26.18	[-40.69, -11.11]
Animal-Friendly			-36.63	[-54.37, -20.33]			-40.90	[-56.90, -23.78]

Table 2.7: Market Scenario: Introducing the dual non-GMO/animal-friendly label when organic and individual counterparts are initially present

Label Type	**Base Pre-Info**	**95% CI**	**Introduce Redundant**	**95% CI**	**Base Post-Info**	**95% CI**	**Introduce Redundant**	**95% CI**
Percent of individuals choosing								
Conventional	57.55	[50.74, 63.55]	55.60	[48.77, 62.07]	53.61	[46.80, 60.09]	51.18	[44.83, 57.14]
Organic	11.88	[7.39, 16.26]	8.92	[5.42, 12.81]	14.37	[10.34, 18.72]	13.34	[8.87, 17.73]
Non-GMO	9.33	[5.42, 13.30]	5.89	[2.46, 9.36]	7.85	[3.94, 11.82]	5.41	[2.46, 8.87]
Animal-Friendly	8.85	[5.42, 12.81]	4.97	[1.97, 8.37]	10.80	[6.90, 15.76]	5.91	[2.96, 9.85]
Non-GMO Animal-Friendly			12.23	[8.37, 16.75]			10.79	[6.90, 15.27]
None	12.39	[7.88, 17.24]	12.39	[7.88, 17.24]	13.37	[8.37, 18.23]	13.37	[8.37, 18.23]
Market Share (%)								
Conventional	65.68	[59.09, 72.32]	63.47	[56.40, 70.06]	61.88	[54.44, 68.02]	59.08	[52.02, 65.54]
Organic	13.56	[8.62, 18.64]	10.18	[6.04, 14.71]	16.58	[11.66, 21.91]	15.40	[10.50, 20.59]
Non-GMO	10.65	[6.40, 15.00]	6.72	[2.89, 10.67]	9.07	[4.60, 13.33]	6.25	[2.67, 10.30]
Animal-Friendly	10.11	[6.08, 14.71]	5.68	[2.31, 9.47]	12.47	[8.02, 17.65]	6.82	[3.39, 10.98]
Non-GMO Animal-Friendly			13.96	[9.09, 18.89]			12.45	[7.91, 17.26]
Absolute change in market share from baseline (%)								
Conventional			-2.22	[-4.55, -0.56]			-2.80	[-5.32, -0.58]
Organic			-3.38	[-6.29, -1.13]			-1.18	[-2.84, 0.00]
Non-GMO			-3.93	[-7.19, -1.16]			-2.82	[-5.49, -0.60]
Animal-Friendly			-4.43	[-7.47, -1.68]			-5.65	[-9.14, -2.29]
Non-GMO Animal-Friendly			13.96	[9.09, 18.89]			12.45	[7.91, 17.26]
Percentage change in market share from baseline								
Conventional			-3.38	[-6.90, -0.83]			-4.52	[-8.85, -0.94]
Organic			-24.93	[-41.67, -9.09]			-7.14	[-17.24, 0.00]
Non-GMO			-36.93	[-61.90, -15.38]			-31.26	[-58.33, -10.53]
Animal-Friendly			-43.83	[-68.75, -20.83]			-45.35	[-66.67, -25.00]

Figure 2.1: An example of an Organic is Always non-GMO redundant label seen on dairy products

Appendix B: Information Treatment

"The USDA Organic label imposes strict requirements on dairy farmers which include the exclusive use of non-GMO feeds and inputs, forbid the use of synthetic additives, administration of hormones and antibiotics; and requires some explicit animal welfare standards such as pasture access, access to outdoors, shade, shelter, exercise areas, fresh air and direct sunlight."

Appendix C: Experimental Procedures

Participants who qualified by our selection criteria were first informed of the benefits and risks of participation in conjunction with the nature of the study and, if they were willing to participate, consent was obtained. In the second step, consented participants were given a survey eliciting sociodemographic and dairy consumption information, opinions on GMOs and animal welfare in agriculture, knowledge relative to these subjects and political and moral beliefs relative to food purchase behavior. Survey questions were structured and worded following a pilot phase so as to reduce the likelihood of influencing bid formulation. Participants were introduced to the BDM mechanism in the third step. Participants were informed that they would be bidding for seven different types of milk, one of which would be selected at random to be binding. A full explanation of the BDM mechanism was provided, after which participants were given the opportunity to ask any questions to clarify the BDM process, which were subsequently answered. Upon understanding the workings of the BDM mechanism, in the fourth step, participants submitted their bids for the seven types of milk without any additional information provided. Participants were free to bid any non-negative dollar value. We opted for assessing each individual's understanding of the BDM mechanism as opposed to conducting a practice round given feedback received during a pilot study. The labeled types of milk were randomized to ensure no ordering effects were present, though all participants evaluated conventional milk first. This was done so that consumers could establish their baseline value for a conventional product first, such that their premiums for labeled products are more accurately represented in their bids. In step 5, participants were provided with the information regarding the relationship between USDA organic, non-GMO, and animal-friendly. Next, participants were asked to submit new bids for the seven types of milk under the context of being more informed. In the seventh step, using a multi-sided die, participants determined the binding type of milk by drawing a random number between one and seven. A computer tablet was then used to randomly draw a market price, uniformly distributed between $0 and $5, for the binding milk. Similar to previous studies, the distribution of prices was not revealed to participants (Lusk et al., 2001; Noussair et al., 2004; Ortega & Wolf, 2018). In the final step, the participant's bid for the selected type of milk was compared to the randomly drawn market price. The bids from the second round of bidding were used as the binding bids as they reflected the participant's value for each product under full information. If the participant's bid exceeded the market price, they paid for the selected milk at the randomly drawn price and received the product and their compensation for participating in the study. Participants received unflavored milk of their preferred fat content. If the randomly drawn price exceeded the participant's post-treatment bid, no transaction occurred, and the participant only received the participation fee ($10). To conclude each individual session, participants were thanked and debriefed by answering any questions about the study they had. Each survey and BDM experiment was conducted in close proximity to the dairy case of the grocery store setting to best ensure the real context of a milk purchase. However, in order to prevent any anchoring effects, participants were not able to observe the retailer's listed price for each of the products. This was achieved by approaching each participant prior to them approaching the milk products for purchase.

Appendix D: Knowledge and Attitude Assessments

True/False Questions to assess consumer knowledge of GMO use in agriculture

1. Animals which consume GMO feed produce milk and/or meat with genetically modified DNA
2. The only requirement to qualify for non-GMO status is to use dairy cows which were not genetically modified
3. Most dairy cows in the US consume GMO feeds
4. Most dairy cows in the US have had their DNA genetically modified in order to produce more milk

Statements regarding animal welfare attitudes – rated on a 5-point Likert scale

1. It is important to me how the animals involved in my food's production were treated
2. Current, conventional dairy production practices are acceptable
3. Current, conventional dairy production practices are necessary to meet society's needs
4. Good animal welfare should be the farmer's top priority
5. Consumers have a responsibility to demand high animal welfare standards

REFERENCES

REFERENCES

Becker, G. M., DeGroot, M. H. and Marschak, J. (1964). Measuring utility by a single-response sequential method. *Behavioral Science, 9*(3): 226-232.

Bergmann, M. (2011). ipfweight: Stata module to create adjustment weights for surveys. Statistical Software Components S457353, Department of Economics, Boston College.

Bernard, J.C., & Bernard, D.J. (2010). Comparing parts with the whole: Willingness to pay for pesticide-free, non-GM, and organic potatoes and sweet corn. *Journal of Agricultural and Resource Economics, 35*(3): 457-475.

Bernard, J.C., Duke, J.M., & Albrecht, S.E. (2019). Do labels that convey minimal, redundant, or no information affect consumer perceptions and willingness to pay?. *Food Quality and Preference, 71*: 149-157.

Bernard, J.C., Zhang, C., & Gifford, K. (2006). An experimental investigation of consumer willingness to pay for non-GM foods when an organic option is present. *Agricultural and Resource Economics Review, 35*(2): 374-385.

Canavari, M., Drichoutis, A.C., Lusk, J.L., & Nayga Jr., R.M. (2019). How to run an experimental auction: A review of recent advances. *European Review of Agricultural Economics, 46*(5): 862-922.

Caputo, V., Scarpa, R., & Nayga Jr., R.M. (2017). Cue versus independent food attributes: the effect of adding attributes in choice experiments. *European Review of Agricultural Economics, 44*(2): 211-230.

Cason, T.N., & Plott, C.R. (2014). Misconceptions and game form recognition: Challenges to theories of revealed preference and framing. *Journal of Political Economy, 122*(6): 1235-1270.

Caswell J, & Mojduszka E. (1996). Using informational labeling to influence the market for quality in food products. *American Journal of Agricultural Economics, 78*(5):1248–53.

Chen, S., & Chaiken, S. (1999). The heuristic-systematic model in its broader context. In: Chaiken, S., Trope, Y. (Eds.), *Dual-process Theories in Social Psychology*. Guillford Press, New York, NY, US, pp. 73e96.

Conner, D.S., & Christy, R.D. (2004). The organic label: How to reconcile its meaning with consumer preferences. *Journal of Food Distribution Research, 35*(1): 40-43.

Drugova, T. (2019). *The Organic Wheat Market: Three Essays on Pricing, Consumer Segments, and the Importance of Labels*. (Doctoral Dissertation) Utah State University.

Economic Research Service (ERS) (2018). *Price Spreads from Farm to Consumer: Whole Milk, one gallon*. U.S. Department of Agriculture (USDA). Retrieved November 29, 2019 from: https://www.ers.usda.gov/data-products/price-spreads-from-farm-to-consumer/.

Economic Research Service (ERS). (2020). *Food Dollar Series*. U.S. Department of Agriculture (USDA). Retrieved March 12, 2021 from: https://www.ers.usda.gov/data-products/food-dollar-series/.

Ellison, B., Brooks, K., & Mieno, T. (2017). Which livestock production claims matter most to consumers?. *Agriculture and Human Values, 34*(4): 819-831.

Grunert, K.G., Hieke, S., & Wills, J. (2014). Sustainability labels on food products: Consumer motivation, understanding and use. *Food Policy, 44*: 177-189.

Hemmerling, S., Hamm, U., & Spiller, A. (2015). Consumption behaviour regarding organic food from a marketing perspective—a literature review. *Organic Agriculture, 5*(4): 277-313.

Heng, Y., Peterson, H.H., & Li, X. (2016). Consumer responses to multiple and superfluous labels in the case of eggs. *Journal of Food Distribution Research, 47*(2): 62-82.

Horowitz, J.K. (2006). The Becker-DeGroot-Marschak mechanism is not necessarily incentive compatible, even for non-random goods. *Economics Letters, 93*(1): 6-11.

Howden, L.M., & Meyer, J.A. (2011). *Age and sex composition, 2010*. U.S. Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau.

Hrynowski, Z. (2019). What Percentage of Americans are Vegetarian? *Gallup: The Short Answer*. September 27, 2019. Retrieved November 29, 2019 from: https://news.gallup.com/poll/267074/percentage-americans-vegetarian.aspx.

Janßen, D., & Langen, N. (2017). The bunch of sustainability labels–Do consumers differentiate? *Journal of Cleaner Production, 10*(143): 1233-1245.

Kaiser, H.F. (1958). The varimax criterion for analytic rotation in factor analysis. *Psychometrika, 23*(3): 187-200.

Lusk, J.L. (2010). Experimental auction markets for studying consumer preferences. In *Consumer-Driven Innovation in Food and Personal Care Products* 332-357. Woodhead Publishing.

Lusk, J. L., Fox, J.A., Schroeder, T.C., Mintert, J., and Koohmaraie, M. (2001). In-store valuation of steak tenderness. *American Journal of Agricultural Economics, 83*(3): 539-550.

Lusk, J.L., Schroeder, T.C., & Tonsor, G.T. (2014). Distinguishing beliefs from preferences in food choice. *European Review of Agricultural Economics, 41*(4): 627-655.

Lusk, J.L., & Shogren, J.F. (2007). *Experimental Auctions: Methods and Applications in Economic and Marketing Research,* 109-112. Cambridge University Press.

McCluskey, J.J. (2000). A game theoretic approach to organic foods: An analysis of asymmetric information and policy. *Agricultural and Resource Economics Review, 29*(1): 1-9.

McFadden, B.R., & Lusk, J. L. (2017). Effects of the National Bioengineered Food Disclosure Standard: Willingness to pay for labels that communicate the presence or absence of genetic modification. *Applied Economic Perspectives and Policy, 40*(2): 259-275.

McFadden, J.R., & Huffman, W.E. (2017). Willingness-to-pay for natural, organic, and conventional foods: The effects of information and meaningful labels. *Food Policy, 68*: 214-232.

McKendree, M.G.S., Croney, C.C., & Widmar, N.O. (2014). Effects of demographic factors and information sources on United States consumer perceptions of animal welfare. *Journal of Animal Science, 92*(7): 3161-3173.

Noussair, C., Robin, S., & Ruffieux, B. (2004). Revealing consumers' willingness-to-pay: A comparison of the BDM mechanism and the Vickrey auction. *Journal of Economic Psychology, 25*(6): 725-741.

OIE (World Animal Health Organization). (2019). *Introduction to the Recommendations for Animal Welfare*. Retrieved January 17, 2020 from: https://www.oie.int/en/standard-setting/terrestrial-code/access-online/?htmfile=chapitre_aw_introduction.htm.

Onyango, B.M., Hallman, W.K., & Bellows, A.C. (2007). Purchasing organic food in US food systems: A study of attitudes and practice. *British Food Journal, 109*(5): 399-411.

Ortega, D.L., & Wolf, C.A. (2018). Demand for farm animal welfare and producer implications: Results from a field experiment in Michigan. *Food Policy, 74*: 74-81.

Saad, L. (2019). U.S. Still Leans Conservative, but Liberals Keep Recent Gains. *Gallup Politics*. January 8, 2019. Retrieved November 29, 2019 from: https://news.gallup.com/poll/245813/leans-conservative-liberals-keep-recent-gains.aspx.

Ufer, D., Ortega, D.L., & Wolf, C.A. (2019). Economic foundations for the use of biotechnology to improve farm animal welfare. *Trends in Food Science & Technology, 91:* 129-138.

USDA AMS (USDA Agricultural Marketing Service). (2019). National Retail Report-Dairy. *Dairy Market News Branch, 86*(27).

U.S. Census Bureau. (2019). United States Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau. Data. Retrieved November 29, 2019 from: https://www.census.gov/data.html.

Wilson, L. & Lusk, J. L. (2020). Consumer willingness to pay for redundant food labels. *Food Policy*, *97*: 101938.

CHAPTER 3

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

Introduction

Animal agriculture industries are responding to consumers' increasing interest in improving farm animal welfare conditions with innovative technologies and new methods of measuring and assessing animal wellbeing. 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 et al., 2009; Smithson et al., 2014; Ortega & Wolf, 2018). In addition to better living conditions, improvements in animal welfare include eliminating potentially painful routine procedures performed during the lifetime of the animal. 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, is essential to avoid "boar taint," which affects pork product quality and gives rise to a strong, undesirable smell and flavor when the meat is cooked (Font-i-Furnols, 2012) and reduces male aggression (Guay et al., 2013). Castration prevents male sexual maturation, eliminating the natural deposition and buildup of androstenone and skatole compounds in the meat, which produce the unpleasant smell and off-flavor of boar taint (Font-i-Furnols, 2012).

Two novel biotechnologies to address painful castration in the pork industry are immunocastration and gene editing. Immunocastration uses a series of two injections of a vaccine 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). The vaccine prevents puberty in the boars (Dunshea et al., 2001). Gene editing has various applications, including the elimination of the need for castration by turning off the genes that control reproductive development. CRISPR-Cas9 and TALENs are the most common gene-editing technologies currently used, both of which allow for high precision genome alterations (Bhat et al., 2017). Gene editing has already proven potential in preventing boar taint in the meat of gene-edited male pigs, which remain in a pre-pubertal state, thus eliminating the need for castration (Menchaca et al., 2020). With both technologies, male pigs' sexual maturation is prevented without the need for painful castration procedures.

Biotechnologies, especially genetic biotechnologies in livestock, can carry a tremendous regulatory burden in terms of time and financial costs, to receive approval. A prime example of this is the nearly 20-year approval journey the AquAdvantage genetically engineered salmon underwent in the U.S. prior to its approval in 2015, though further hurdles to commercial sale of the fish persisted even after approval (Van Eenennaam, 2019). With such 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 decimate financial investments. Prime examples of such marketing failures include recombinant bovine somatotropin (rbST) in the U.S. dairy industry, which received substantial consumer and retailer rejection, and the Flavr-Savr genetically-modified tomato, which experienced a short-lived market presence (Bruening & Lyon, 2000; An, 2013). 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 potentially benefit both consumers and producers in the U.S. pork industry. For consumers, these technologies meet the demand for production methods, which 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 offer enormous potential benefits to consumers, producers, and animals, their market evaluation using traditional research methods is complicated by their novelty and limited availability. While immunocastration is currently approved for use by veterinary prescription and available in the market, its adoption is currently very low, with only 1.3 million pigs, approximately 0.13% of the live hog population, immunocastrated worldwide in 2015 (Zamaratskaia & Rasmussen, 2015; FAO, 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 individually (for example, see Novoselova et al., 2005; Lagerkvist et al., 2006; Meuwissen et al., 2007; Norwood & Lusk, 2011; Ortega & Wolf, 2018); however, the simultaneous evaluation of biotechnology and animal welfare has received less extensive treatment, particularly in U.S. pork. Negative consumer attitudes towards biotechnology can be ameliorated by direct consumer benefit from the technology (Lusk et al., 2004; Novoselova et al., 2005; Costa-Font et al., 2008; Ribeiro et al., 2016). Simply combining market premiums for increased animal welfare with discounts for biotechnology to determine a net effect is insufficient to truly evaluate the market viability of products with both traits. Instead, the two must be evaluated simultaneously to determine if consumers actively tradeoff between the premium and discount mentality to a net increase or net decrease in WTP. While consumer acceptance of immunocastration in the pork industry has been studied previously, it has primarily been studied in European markets with an emphasis on qualitative acceptance or sensory preferences rather than consumer demand (Lagerkvist et al., 2006; Font-i-Furnols et al., 2008; Huber-Eicher & Spring, 2008; Latacz-Lohman & Schreiner, 2019). Consumer demand for immunocastration, a non-genetic 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 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 the 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 if 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. Furthermore, 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 Becker-DeGroot-Marschak (BDM) mechanism (Becker et al., 1964).

Methods

A field experiment was designed and conducted in October and November of 2019 in a local, non-specialty 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 socio-demographic information, subjective and objective knowledge of biotechnology in agriculture, attitudes towards 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,"[9] 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 the 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 were chosen to more closely simulate the pork purchasing environment due to their availability and prevalence in several grocery stores in the area in which the study was conducted. 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 & Wohlgenant, 1989; Aldrich & 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 the 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 been demonstrated to often be unaware of this and treat conventional products as having been produced with added hormones (Yang et al., 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

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[9] We specifically denote "no added hormones" throughout using quotations marks as the claim is technically true of all U.S.-produced pork, however the claim is only made on some products.

format without requiring the presence of multiple participants at a time (Becker et al., 1964). It 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 & Shogren, 2007; Canavari et al., 2019). Despite the manifold benefits of the BDM mechanism for our study, the method's limitations must also be considered. One limitation is that participants can become confused with the second-price auction incentives of the mechanism, instead operating as though the BDM employs a first-price auction format and incentives (Cason & 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 producing 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.[10] In accordance with the findings of Chavez et al. (2020)[11], 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 the commonly associated pitfalls for economic experiments (Rousu et al., 2015). While Chavez et al.

[10] 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, and gene-edited pork is not yet approved for commercial sale.
[11] Chavez et al. (2020) found that, when presenting both available and unavailable products in a choice experiment, while informing participants of the partial availability of products but not which products were specifically unavailable, bidding behavior was identical to when all products in the experiment were available.

(2020) 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 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 one-pound packages of pork chops. Participants were not assumed to have pre-existing knowledge of the biotechnologies employed in immunocastration and gene editing, so a neutral informational card was provided.[12] 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.[13] Any non-negative value constituted a valid bid. In the fifth step, the participant rolled a multi-sided die to determine the binding type of pork chop from amongst 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

[12] 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.

[13] 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.

distributed between $0 and $5 per pound. As with previous studies, participants were not aware of the distribution of random market prices (Lusk et al., 2001; Noussair et al., 2004; Ortega & 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 one-pound 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

Our data consists of 1,218 product bids from 203 individuals. Descriptive statistics for our sample are presented in Table 3.1. The mean age of individuals in the sample was 55 years, and approximately 52% of the sample was female. 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 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 of 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 responses out of 5. Approximately 37% of the sample had some form of agricultural or farm contact in the previous year. On a scale of 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 3.1). In addition to knowledge and support for legislation, participant average pork consumption levels were elicited on a 6-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, on average, consumers will require a discount to accept gene-editing technology, despite the consumer benefit of increased animal welfare. While previous research has shown that biotechnology can become acceptable to a generally antagonistic consumer market if direct consumer benefits exist, 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 slight premium due to the animal welfare benefits. Finally, for both gene-edited and immunocastrated pork, we expect that consumer attitudes towards biotechnology and animal welfare will significantly influence WTP. Given previous research, negative attitudes towards 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 socio-demographic and consumption traits, subjective and objective knowledge of biotechnology and science relevant to agriculture, farm contact history, and attitudes towards possible legislation in agriculture. Individual regressions were specified for each type of pork but were estimated simultaneously using the seemingly unrelated estimation procedure. The seemingly unrelated estimation approach allows for 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 et al., 2011; Shi et al., 2014). The specification for the model is as follows:

$$\boldsymbol{PREM = X\beta + \varepsilon} \tag{3.1}$$

Where

$$\boldsymbol{PREM} = \begin{pmatrix} \boldsymbol{PREM_1} \\ \boldsymbol{PREM_2} \\ \boldsymbol{PREM_3} \\ \boldsymbol{PREM_4} \\ \boldsymbol{PREM_5} \end{pmatrix} = \begin{pmatrix} \boldsymbol{X_1} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{X_2} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{X_3} & \boldsymbol{0} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{X_4} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{0} & \boldsymbol{X_5} \end{pmatrix} \cdot \begin{pmatrix} \boldsymbol{\beta_1} \\ \boldsymbol{\beta_2} \\ \boldsymbol{\beta_3} \\ \boldsymbol{\beta_4} \\ \boldsymbol{\beta_5} \end{pmatrix} + \begin{pmatrix} \boldsymbol{\varepsilon_1} \\ \boldsymbol{\varepsilon_2} \\ \boldsymbol{\varepsilon_3} \\ \boldsymbol{\varepsilon_4} \\ \boldsymbol{\varepsilon_5} \end{pmatrix} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon} \qquad (3.2)$$

$\boldsymbol{PREM_j}$ 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:

$$PREM_{n,j} = WTP_{n,j} - WTP_{n,Conventional} \qquad (3.3)$$

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 normally distributed error terms are contained in the vectors $\boldsymbol{\varepsilon_1}$ to $\boldsymbol{\varepsilon_5}$ and are assumed to be correlated within products but not across participants.

Results

Descriptive statistics for bids and premiums for all six types of pork are presented in Table 3.2. The mean bid for conventional pork was $3.07 per pound, with a standard deviation of $1.54 per pound and a maximum of $9.00 per pound. The mean premium for gene-edited pork was $0.06 per pound, with a standard deviation of $1.65 per pound. This result supports the finding of Yunes et al. (2019) of a majority of consumers accepting pork from gene-edited pigs, though their results represented the Brazilian market. The average premium for immunocastrated pork was $0.16 per pound, with a standard deviation of $1.52 per pound. In comparison, the mean premiums for Certified Humane®, local, and “no added hormones” pork were $0.94, $0.78 and $0.62 per pound, respectively. The relatively large standard deviations of the premiums indicate that there are individuals in the sample who would demand a discount relative to conventional for all five types of pork or, rather, that conventional pork is the preferred type of pork for some consumers. Between 3.4% (Certified Humane®) and 19.2% (gene-edited) of consumers required discounts to purchase non-conventional 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 non-conventional 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 non-conventional pork produced without biotechnology.

Boxplots of consumer WTP distributions indicate that most consumer premiums are small compared to relatively few discounts of considerably greater magnitude (Figure 3.2). 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, non-parametric Wilcoxon sign rank tests of bids indicate statistically significant premiums for every labeled variety of pork over conventional pork. Therefore, we find evidence consumers are either indifferent to or willing to pay a premium for gene-edited and immunocastrated pork on average. 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

Results of the seemingly unrelated estimation model are presented in Table 3.3. The 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. Despite being significant, the magnitude of this effect is small and negative in all cases, indicating 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 socio-demographic variables, the exceptions being 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 were most strongly influenced by attitudes towards 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 towards biotechnology. Both of these variables were significant in the gene-edited and immunocastrated case. Support for a gene editing ban had a negative effect corresponding to approximately a $0.16 reduction in WTP for a pound of pork for a one-point increase over the mean on a ten-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 on both types of pork of approximately $0.07 per pound. This indicates 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 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 as the positive impact for the animal welfare benefits. This is true for both technologies. Hence, our results indicate 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 of -0.32. This suggests that increasing knowledge of genetics and biotechnology decreased opposition to its 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, including Baker and Burnham (2001), Wolfe et al. (2017) and Shew et al. (2018). On the other hand, this result contrasts those of Yunes et al. (2019) which found no significant relationship between gene editing acceptance and objective knowledge. This discrepancy, however, could be attributed to differences in American and Brazilian consumers. Other studies have similarly found no link between objective knowledge and acceptance of genetic biotechnology (House et al., 2004). However, our findings may differ due to the 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 the general public have 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 for a pound of Certified Humane® pork chops than men. This finding is in line with those of McKendree et al. (2014) and Miranda-de la Lama et al. (2017), who observed 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 statistically 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 per pound, 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 was reflected in the average premium for Certified Humane® pork of $0.94 per pound compared to the average premiums for gene-edited pork of $0.06 per pound and immunocastrated pork of $0.16 per pound (Table 3.2). 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 in the pork industry, we investigated other products and marketing strategies in the pork industry. The labels of "no added hormones" and "local" could speak to consumers' demands for production methods, which eschew conventional practices. Individuals who spoke with a farmer about agriculture in the last year or visited a farm were willing to pay significantly (10% level) higher premiums for local pork. This is to be expected as 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.

As 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 which 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, it was only those technologies that are specifically engineered where this attitude has a significant effect.[14]

Policy Implications and Market Considerations

Our results have implications for both policy considerations and 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. Furthermore, policymakers should be mindful of the degree of regulatory oversight for these technologies, gene editing in particular, to ensure that achieving

[14] 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.

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 it is to gain adequate consumer acceptance. In this respect, our findings corroborate those of others (Lusk et al., 2004; Novoselova et al., 2005; Costa-Font et al., 2008; Ribeiro et al., 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 as these could potentially lead to negative consumer attitudes towards the industry on the 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 biotechnology'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 per pound. These premiums are substantial enough to merit consideration by producers in the potential tradeoffs of increased revenues from premiums and increased costs to meet third-party certifiers' stringent welfare standards like 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 & Wolf, 2018). Even so, in the case of boneless top loin chops, a premium of $0.94 per pound 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 animal welfare standards industry-wide 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 of 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 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 Agricultural Marketing Service currently offers a version of this though it currently lacks widespread consumer awareness in addition to 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. This strategy has already been employed with some success by the Canadian National Farm Animal Care Council and their Codes of Practice.

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, 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 which 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 et al., 2003; Bowman et al., 2016). This appears to be the case given the premiums we observe in this study for “no added hormones”-labeled pork relative to conventional pork, which are effectively identical. Our results are consistent with those of Yang et al. (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 explores consumer acceptance and preference for biotechnologies in the pork industry which improves animal welfare. In addition, it investigates demand for other types of pork in the context of consumer attitudes over 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. Furthermore, we found that negative attitudes towards biotechnology had a stronger influence on WTP for pork produced using biotechnology with animal welfare-improving applications than positive attitudes towards animal welfare. The animal welfare-improving benefits did not appear to substantially outweigh a 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.

While this study provides essential insight into the interactions of consumer attitudes regarding animal welfare and biotechnology, it is limited in some respects. Because our field experiment required a very concise format, we use attitudes towards potential legislation as a proxy for attitudes towards 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 which focus on other regions of the U.S. 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 the ability to evaluate both a genetic and a non-genetic biotechnology with similar welfare outcomes. Future research should identify animal welfare outcomes that are more salient to prominent consumer concerns to determine if consumer awareness of current practices influences their acceptance of biotechnologies, which 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 amongst 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, policymakers and researchers must be mindful of the 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.

While future endeavors to improve animal agriculture practices through biotechnological advances hold great potential for progress in these industries, 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 towards 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.

APPENDIX

Table 3.1: Sample Summary Statistics

Variable	**Sample**	**United States**
Female	51.7%	50.8%[a]
Age	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)	9.9%	32.1%[c]
High Income (>$100,000/year)	46.3%	30.4%[c]
Household Size	2.6 (1.3)	2.6[a]
Subjective Knowledge (1 to 10)	4.3 (2.4)[d]	
Objective Knowledge (0 to 5)	3.3 (1.5)[d]	
Farm Contact	37.0%	
Stricter AW Legislation (1 to 10)	7.2 (2.3)	
Gene Editing Ban Legislation (1 to 10)	4.8 (2.6)	
Consumption	2.50 (1.0)[f]	

Standard deviations are in parentheses.

[a] U.S. Census Bureau (2019). Quick Facts United States.

[b] U.S. Census Bureau (2019). American Fact Finder: Educational Attainment.

[c] U.S. Census Bureau (2019). Income Distribution to $250,000 or More for Households.

[d] On a scale of 1 (“Not at all knowledgeable”) to 10 (“Very knowledgeable”).

[e] A score of 0 to 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”.

Table 3.2: Summary Statistics of Bids and Premiums in $/lb

	Mean	St. Dev.	Min	Max	Parametric p-value[a]	Non-Parametric p-value[a]
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		

[a] Parametric and non-parametric tests compare the bids for each type of pork against conventional pork.

Table 3.3: Seemingly Unrelated Equation Model Results

	Gene-Edited		**Immunocastrated**		**Certified Humane®**		**Local**		**"No Added Hormones"**	
Variable	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**	**Coeff.**	**S.E.**
Female	0.19	0.21	0.08	0.19	0.48***	0.17	0.26	0.18	0.23	0.17
Age	-0.02***	0.01	-0.02**	0.01	-0.04***	0.01	-0.03***	0.01	-0.02***	0.01
High School	-0.22	0.76	-0.39	0.73	-0.47	0.34	-0.68	0.87	-0.62	0.77
Postgraduate	-0.30	0.22	-0.25	0.20	0.15	0.19	0.31	0.19	-0.05	0.18
High Income	-0.05	0.22	0.33*	0.19	-0.11	0.16	-0.07	0.19	0.05	0.17
Consumption	-0.03	0.10	0.08	0.11	-0.16*	0.09	0.07	0.09	-0.05	0.08
Household Size	-0.01	0.10	-0.06	0.10	0.04	0.07	-0.05	0.07	0.02	0.07
Obj Knowledge	0.15*	0.08	0.05	0.08	0.06	0.06	-0.03	0.06	0.00	0.07
Subj Knowledge	-0.09	0.06	-0.05	0.05	-0.03	0.03	0.00	0.05	0.03	0.04
Farm Contact	-0.20	0.25	-0.28	0.21	0.06	0.16	0.33*	0.19	-0.08	0.17
Stricter Animal Welfare Support	0.07*	0.04	0.08**	0.04	0.08**	0.04				
Gene Editing Ban Support	-0.15***	0.06	-0.16***	0.05					0.02	0.05
Constant	1.69**	0.69	1.33*	0.73	2.46***	0.67	2.18***	0.53	1.72***	0.66
R^2	0.15		0.14		0.26		0.14		0.09	
Observations	203		203		203		203		203	

Statistical significance is denoted for the 1% (p < 0.01, ***), 5% (p < 0.05, **) and 10% (p < 0.1, *) levels, using robust standard errors as reported.

Figure 3.1: Distribution of Consumer Attitudes towards Stricter Animal Welfare and Gene Editing Ban Legislation

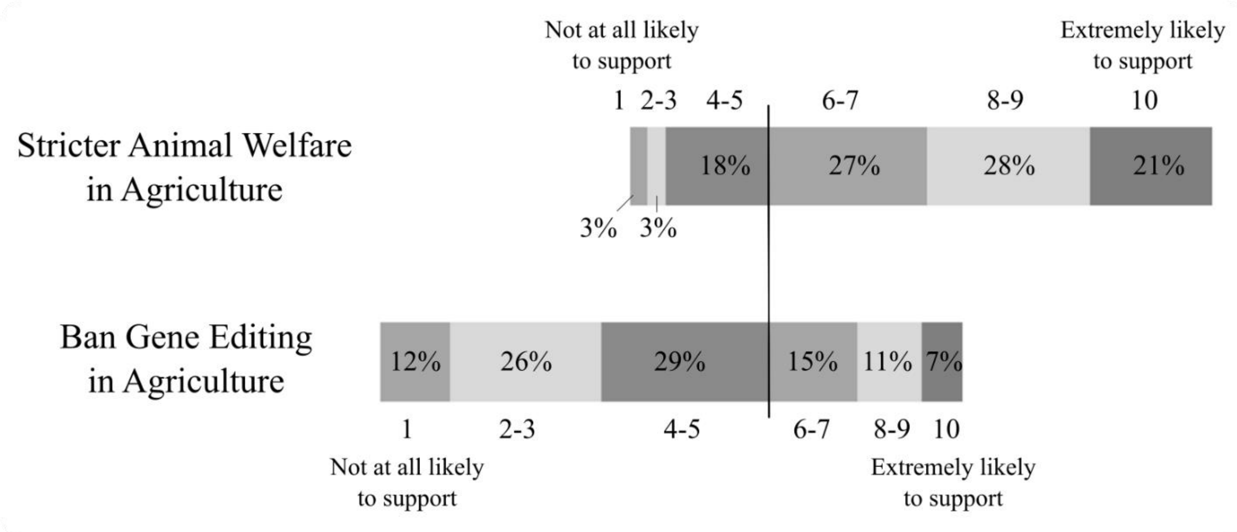
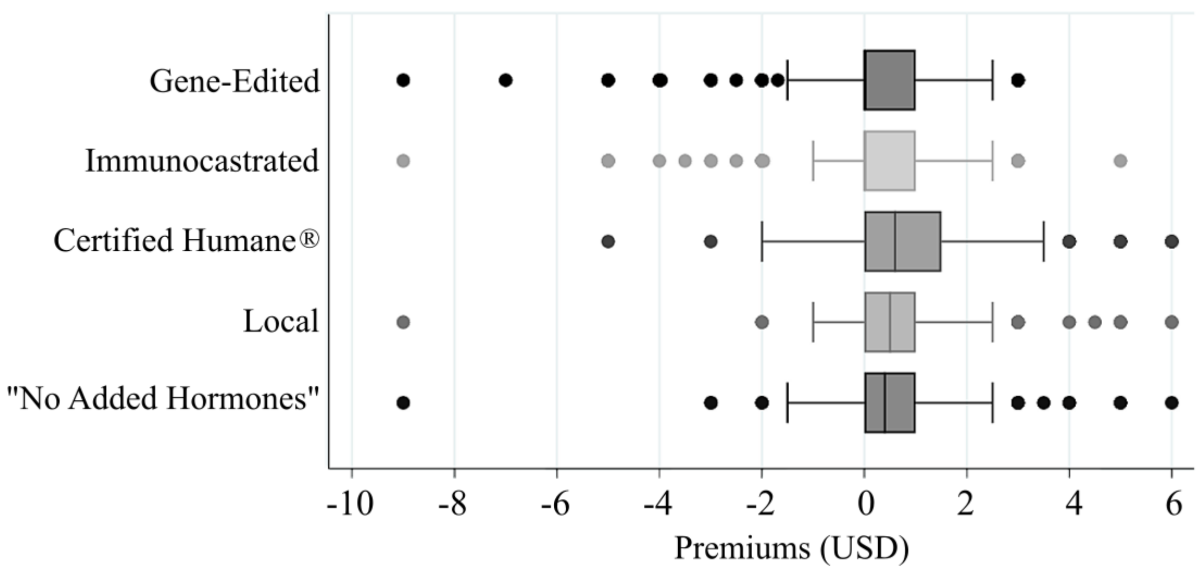


Figure 3.2: Boxplots of Premiums in $/lb



REFERENCES

REFERENCES

Aldrich, L. M. & Blissard, N. (1998). *Consumer Acceptance of Biotechnology: Lessons from the rbST Experience* (No. 33663). United States Department of Agriculture, Economic Research Service.

An, H. (2013). The disadoption of rbST and its economic impact: A switching regression approach. *Applied Economic Perspectives and Policy*, *35*(3): 528-549.

Baker, G. A. & Burnham, T. A. (2001). Consumer Response to Genetically Modified Foods: Market Segment Analysis and Implications for Producers and Policy Makers. *Journal of Agricultural and Resource Economics, 26*(2): 387-403.

Bartels, R. (2006). Seemingly unrelated regressions. In *Encyclopedia of Environmetrics, 5*.

Bhat, S. A., Malik, A. A., Ahmad, S. M., Shah, R. A., Ganai, N. A., Shafi, S. S., & Shabir, N. (2017). Advances in genome editing for improved animal breeding: A review. *Veterinary World*, *10*(11): 1361.

Becker, G. M., DeGroot, M. H., & Marschak, J. (1964). Measuring utility by a single-response sequential method. *Behavioral Science*, *9*(3): 226-232.

Bowman, M., Marshall, K. K., Kuchler, F., & Lynch, L. (2016). Raised without antibiotics: lessons from voluntary labeling of antibiotic use practices in the broiler industry. *American Journal of Agricultural Economics, 98*(2): 622-642.

Breuning, G. & Lyons, J. (2000). The case of the FLAVR SAVR tomato. *California Agriculture, 54*(4): 6-7.

Canavari, M., Drichoutis, A. C., Lusk, J. L., & Nayga Jr., R. M. (2019). How to run an experimental auction: A review of recent advances. *European Review of Agricultural Economics, 46*(5): 862-922.

Cason, T. N. & Plott, C. R. (2014). Misconceptions and game form recognition: Challenges to theories of revealed preference and framing. *Journal of Political Economy, 122*(6): 1235-1270.

Chavez, D. E., Palma, M. A., Nayga Jr., R. M., & Mjelde, J. W. (2020). Product availability in discrete choice experiments with private goods. *Journal of Choice Modelling, 36:* 100225.

Colson, G. J., Huffman, W. E., & Rousu, M. C. (2011). Improving the nutrient content of food through genetic modification: Evidence from experimental auctions on consumer acceptance. *Journal of Agricultural and Resource Economics*, *36*(2): 343-364.

Costa-Font, M., Gil, J. M., & Traill, W. B. (2008). Consumer acceptance, valuation of and attitudes towards genetically modified food: Review and implications for food policy. *Food Policy, 33*(2): 99-111.

Dunshea, F.R., Colantoni, C., Howard, K., McCauley, I., Jackson, P., Long, K. A., Lopaticki, S., Nugent, E. A., Simons, J. A., Walker, J., & Hennessy, D. P. (2001). Vaccination of boars with a GnRH vaccine (Improvac) eliminates boar taint and increases growth performance. *Journal of Animal Science, 79*(10): 2524-2535.

Food and Agricultural Organization of the United Nations (FAO). (2021). *FAOStat: Live Animals Production of Pigs in World (Total)*. Rome, Italy: FAO. Retrieved March 22, 2021 from: http://www.fao.org/faostat/en/#data/QA.

Font-i-Furnols, M. (2012). Consumer studies on sensory acceptability of boar taint: A review. *Meat Science, 92*(4): 319-329.

Font-i-Furnols, M., Gispert, M., Guerrero, L., Velarde, A., Tibau, J., Soler, J., Hortós, M., García-Regueiro, J. A., Pérez, J., Suárez, P., & Oliver, M. A. (2008). Consumers' sensory acceptability of pork from immunocastrated male pigs. *Meat Science, 80*(4): 1013-1018.

Guay, K., Salgado, G., Thompson, G., Backus, B., Sapkota, A., Chaya, W., & McGlone, J. J. (2013). Behavior and handling of physically and immunologically castrated market pigs on farm and going to market. *Journal of Animal Science, 91*(11): 5410-5417.

Harvey, D. & Hubbard, C. (2013). Reconsidering the political economy of farm animal welfare: An anatomy of market failure. *Food Policy, 38*: 105-114.

Horowitz, J. K. (2006). The Becker-DeGroot-Marschak mechanism is not necessarily incentive compatible, even for non-random goods. *Economics Letters, 93*(1): 6-11.

House, L., Lusk, J., Jaeger, S., Traill, W. B., Moore, M., Valli, C., Morrow, B., & Yee, W. M. S. (2004). Objective and subjective knowledge: impacts on consumer demand for genetically modified foods in the United States and the European Union. *AgBioForum, 7*(3): 113-123.

Huber-Eicher, B. & Spring, P. (2008). Attitudes of Swiss consumers towards meat from entire or immunocastrated boars: A representative survey. *Research in Veterinary Science, 85*(3): 625-627.

Lagerkvist, C. J., Carlsson, F., & Viske, D. (2006). Swedish Consumer Preferences for Animal Welfare and Biotech: A Choice Experiment." *AgBioForum, 9*(1): 51-58.

Latacz-Lohmann, U. & Schreiner, J. A. (2019). Assessing consumer and producer preferences for animal welfare using a common elicitation format. *Journal of Agricultural Economics, 70*(2): 293-315.

Lemieux, C. M. & Wohlgenant, M. K. (1989). Ex ante evaluation of the economic impact of agricultural biotechnology: The case of porcine somatotropin. *American Journal of Agricultural Economics*, *71*(4): 903-914.

Lusk, J. L., Fox, J. A., Schroeder, T. C., Mintert, J., & Koohmaraie, M. (2001). In-store valuation of steak tenderness. *American Journal of Agricultural Economics, 83*(3): 539-550.

Lusk, J. L., House, L. O., Valli, C., Jaeger, S. R., Moore, M., Morrow, J. L., & Traill, W. B. (2004). Effect of information about benefits of biotechnology on consumer acceptance of genetically modified food: evidence from experimental auctions in the United States, England, and France. *European Review of Agricultural Economics, 31*(2): 179-204.

Lusk, J. L., Roosen, J., & Fox, J. A. (2003). Demand for beef from cattle administered growth hormones or fed genetically modified corn: A comparison of consumers in France, Germany, the United Kingdom, and the United States. *American Journal of Agricultural Economics, 85*(1): 16-29.

Lusk, J. L. & Shogren, J. F. (2007). *Experimental Auctions: Methods and Applications in Economic and Marketing Research*. Cambridge University Press.

McKendree, M. G., Croney, C. C., & Widmar, N. O. (2014). Effects of demographic factors and information sources on United States consumer perceptions of animal welfare. *Journal of Animal Science, 92*(7): 3161-3173.

Menchaca, A., dos Santos-Neto, P. C., Mulet, A. P., & Crispo, M. (2020). CRISPR in livestock: From editing to printing." *Theriogenology, 150*: 247-254.

Meuwissen, M. P., Van Der Lans, I. A., & Huirne, R. B. (2007). Consumer preferences for pork supply chain attributes. *NJAS-Wageningen Journal of Life Sciences, 54*(3): 293-312.

Miranda-de la Lama, G. C., Estévez-Moreno, L. X., Sepulveda, W. S., Estrada-Chavero, M. C., Rayas-Amor, A. A., Villarroel, M., & María, G. A. (2017). Mexican consumers' perceptions and attitudes towards farm animal welfare and willingness to pay for welfare friendly meat products. *Meat Science, 125*: 106-113.

Norwood, F. B. & Lusk, J. L. (2011). A calibrated auction-conjoint valuation method: Valuing pork and eggs produced under differing animal welfare conditions. *Journal of Environmental Economics and Management, 62*(1): 80-94.

Noussair, C., Robin, S., & Ruffieux, B. (2004). Revealing consumers' willingness-to-pay: A comparison of the BDM mechanism and the Vickrey auction. *Journal of Economic Psychology, 25*(6): 725-741.

Novoselova, T. A., van der Lans, I. A., Meuwissen, M. P., & Huirne, R. (2005). *Consumer Acceptance of GM Applications in the Pork Production Chain: A Choice Modelling Approach*, (2005 European Association of Agricultural Economists International Congress, August 23-27, 2005, Copenhagen, Denmark: No. 24527).

Ortega, D. L. & Wolf, C. A. (2018). Demand for farm animal welfare and producer implications: Results from a field experiment in Michigan. *Food Policy, 74*: 74-81.

Ribeiro, T. G., Barone, B., & Behrens, J. H. (2016). Genetically modified foods and their social representation. *Food Research International, 84*: 120-127.

Rousu, M. C., Colson, G., Corrigan, J. R., Grebitus, C., & Loureiro, M. L. (2015). Deception in experiments: towards guidelines on use in applied economics research. *Applied Economic Perspectives and Policy*, *37*(3): 524-536.

Scheufele, D. A., Xenos, M. A., Howell, E. L., Rose, K. M., Brossard, D., & Hardy, B. W. (2017). US attitudes on human genome editing. *Science, 357*(6351): 553-554.

Shanker, D. (2018). Why It's Difficult to Find Organic Pork. *Bloomberg*. November 1, 2018. Retrieved August 18, 2020 from: https://www.bloomberg.com/news/articles/2018-11-01/why-it-s-difficult-to-find-organic-pork.

Shew, A. M., Nalley, L. L., Snell, H. A., Nayga Jr., R. M., & Dixon, B. L. (2018). CRISPR versus GMOs: Public acceptance and valuation. *Global Food Security, 19*: 71-80.

Shi, L., Gao, Z., & Chen, X. (2014). The cross-price effect on willingness-to-pay estimates in open-ended contingent valuation. *Food Policy, 46*: 13-21.

Smithson, K., Corbin, M., Lusk, J. L., & Norwood, F. B. (2014). Predicting state-wide votes on ballot initiatives to ban battery cages and gestation crates. *Journal of Agricultural and Applied Economics*, *46*(1): 107-124.

Tonsor, G. T., Wolf, C., & Olynk, N. (2009). Consumer voting and demand behavior regarding swine gestation crates. *Food Policy, 34*(6): 492-498.

U.S. Census Bureau. (2019). United States Department of Commerce, Economics and Statistics Administration, U.S. Census Bureau. Data. Retrieved November 29, 2019 from: https://www.census.gov/data.html.

Van Eenennaam, A. (2019). The science and politics of genetically engineered salmon: 5 questions answered. *The Conversation*. March 27, 2019. Retrieved March 3, 2021 from: https://theconversation.com/the-science-and-politics-of-genetically-engineered-salmon-5-questions-answered-114068.

Videras, J. (2006). Religion and animal welfare: Evidence from voting data. *The Journal of Socio-Economics, 35*(4): 652-659.

Wolfe, E., Popp, M., Bazzani, C., Nayga Jr., R. M., Danforth, D., Popp, J., Chen, P., & Seo, H. S. (2018). Consumers' willingness to pay for edamame with a genetically modified label. *Agribusiness*, *34*(2): 283-299.

Yang, R., Raper, K. C., & Lusk, J. L. (2020). Impact of Hormone Use Perceptions on Consumer Meat Preferences. *Journal of Agricultural and Resource Economics, 45*(1): 107-123.

Yunes, M. C., Teixeira, D. L., von Keyserlingk, M. A., & Hötzel, M. J. (2019). Is gene editing an acceptable alternative to castration in pigs? *PLOS One, 14*(6): e0218176.

Zamaratskaia, G. & Rasmussen, M. K. (2015). Immunocastration of male pigs – situation today. *Procedia Food Science*, *5*: 324-327.

CHAPTER 4

Situational Factors and Dairy Farmer Intent to Adopt Animal Welfare-Improving Biotechnology

Introduction

Gene editing technologies and applications are increasing across industries from medicine and pharmaceuticals to crops and livestock. These technologies, which include CRISPR-Cas9 and TALENs, can change an organism's DNA to produce desirable traits or remove undesirable traits without adding foreign genetic material.[15] The advent of commercially approved genetically modified animals for food production could signal a significant shift in the market for animal products. These technologies bring with them controversy. On one hand, they offer a range of potential benefits to livestock producers and consumers alike. Gene-editing can be used to improve animal welfare, catering to the demands of consumers who reject conventional livestock management methods and offering an opportunity for premiums (Napolitano et al., 2008; Clark et al., 2017; Wolf & Tonsor, 2017). An example of such an application is producing polled dairy cattle which do not require traditional dehorning procedures (Carlson et al., 2016). Additionally, gene-editing technology has the potential to substantially reduce costs, depending on the application. On the other hand, gene-editing is liable to inherit the contentions which surround genetically modified organisms (GMOs), despite their differences (Lin et al., 2019; Ufer et al., 2019). Gene-editing use in animals may even increase trepidation, as a greater sense of unease surrounds genetic biotechnology in animals than plants (Frewer et al., 2013; Ribeiro et al., 2016). The complexities of the decision to adopt gene-editing technology at the farm gate are likely to be much greater than a simple matter of profitability, just as market acceptance is subject to more than price.

[15] Clustered regularly interspaced short palindromic repeats (CRISPR-Cas9) and transcription activator-like effector nucleases (TALENs) are enzyme-based gene-editing technologies at the forefront of the field. Unlike traditional genetic modification technologies, CRISPR-Cas9 and TALENs are precision biotechnological instruments which target DNA at specific locations for the introduction or alteration of genes.

The farmer's decision may be influenced by many of the same motivations among consumers to reject GMOs, including ethical objection to the technology, or accept them, such as the benefits they can bring to livestock welfare or the progress they represent for the industry. The question arises as to how these non-pecuniary motivations measure up to the profit-maximizing motives of the neo-classical economic producer. Can they be a significant factor in a farmer's decision-making process over whether or not to adopt gene-edited genetics into their herd? Farmers have historically been found to make decisions for any number of reasons outside of profits or costs (for example, see Guehlstorf, 2008; Prokopy et al., 2008; Maertens & Barrett 2013; Garforth, 2015; Sinclair et al., 2017). Farmer motives beyond profits have been investigated and identified for biotechnology adoption in crops production (Marra et al., 2004; Marra & Piggott, 2006; Useche et al., 2009). This phenomenon has not, however, been explored in the context of gene-editing applications in livestock. If non-pecuniary motivations are significant and substantial enough, they may override the farmer's profit motives (Howley et al., 2015). This might explain why potentially profitable technologies sometimes do not receive widespread adoption. Understanding the potential for such an adoption environment may be important for gene-edited genetics developers in anticipation of presenting the technology to farmers.

Non-pecuniary motivations might include farmer prioritization of farm animal welfare, the appeal of novel technology use, potential reduction in labor and time-intensive herd management practices, ethical opposition to or distrust in the efficacy of gene-editing technology, negative or positive experiences with rbST or other biotechnology in the past, aversion to change or risk, and social or professional pressures. These motivations can be purely non-pecuniary or may represent a combination of pecuniary and non-pecuniary values (Marra &

Piggott, 2006). To explore the manner in which some of these motivations influence a farmer's decision, we separate non-pecuniary motivations into two groups, differentiated by the means by which they may influence the farmer's decision. We identify these as 'persistent' non-pecuniary motivations, those which are intrinsically linked to the farmer and do not generally vary across decision contexts, and 'situational' non-pecuniary motivations, those which are circumstantially present in the specific choice context when a decision is made. However, it is unclear if such situational motivations have a significant bearing on a farmer's decision or not. The standard assumption in producer decision making studies is that the context of the choice has little influence on a decision and that the primary characteristics of importance are the specific traits of the alternatives. This article incorporates both the traditional attribute variables as well as situational variables to explore the role of the circumstances in which a choice is made on the decision outcome.

Farmers are inherently heterogeneous in their preferences for biotechnology (Useche et al., 2009). This heterogeneity may extend to the role of non-pecuniary motivations as well, though studies on the subject of farmer heterogeneity in non-pecuniary motivations are scant. Because the situation in which a choice arises varies markedly for farmers, this article also investigates the degree of heterogeneity in these non-pecuniary motivations amongst farmers. In doing so, we identify common traits amongst farmers most or least impacted by non-pecuniary motivations in their decision-making process.

Given that gene-editing applications in livestock have yet to be approved in the U.S. for commercial production, farmers only have the ability to intend to adopt upon approval or not, rather than the choice to adopt, not adopt or disadopt. As such, we investigate *ex ante* technology adoption intent. Specifically, we investigate the question of how both uncertainty of outcomes and non-pecuniary motivations influence a dairy farmer's intention to adopt gene-editing technology with animal welfare-improving benefits. The U.S. dairy industry is a key target of gene-editing technologies, with potential applications for gene-edited polling and disease resistance already in development (Wu et al., 2015; Carlson et al., 2016). Thus, it is essential to investigate farmer acceptability and adoption potential of these novel biotechnologies with animal welfare-improving implications. We concentrate on a disease resistance application which might improve the welfare of cows. Though only a few applications have currently been developed, the technology shows potential for use in resistance to a variety of diseases (Wu et al., 2015; Ikeda et al., 2017). Such applications can improve animal welfare by potentially eradicating high mortality contagious diseases such as Johne's disease.

Johne's disease, or bovine paratuberculosis (*Mycobacterium avium* ssp. *paratuberculosis*), is a ruminant disease which causes severe inflammation in the intestinal tract resulting in wasting and reduced milk production. The total estimated cost of a clinical case is between $200 and $2300 USD (Garcia & Shalloo, 2015). Recent work places the total annual economic losses in the U.S. due to Johne's disease at approximately $198 million USD (Rasmussen et al., 2021). Johne's disease was estimated to be prevalent on over 68% of U.S. dairy farms in 2007, with some analyses placing true prevalence as high as 91% (USDA APHIS, 2008; Lombard et al., 2013). A major contributor to high prevalence is a long incubation period such that subclinical cases often go undetected for extended periods of time (USDA APHIS, 2008).

This article contributes to the literature by extending random utility theory to account for situational influences or the context of a decision on farmer utility and the decision outcome. The resulting framework is applied to evaluate *ex ante* a farmer's intent to adopt by including non-pecuniary motivations and situational variables. We employ the experimental vignette methodology, a novel method for producer studies, as well as a random parameters ordered logit, a model widely applied in the transportation literature but rarely seen in the agricultural economics field. These novel techniques are combined to evaluate heterogeneity in farmer responsiveness to situational non-pecuniary factors as well as attribute variables. Finally, this study contributes to our understanding of the market potential for gene-editing biotechnologies in animal agriculture, which has been studied in some respects in consumer contexts but has yet to receive much attention from the producer perspective.

The remainder of the article will proceed as follows. First, we develop a conceptual model for the inclusion of situational variables relevant to the choice environment within the producer utility framework. We then implement the framework developed in the conceptual model to investigate the empirical value of taking account of non-pecuniary motivations on the intent to adopt disease resistance gene-edited genetics decision. Results from the empirical model are presented and discussed, including an extended analysis of heterogeneity in farmer responses to non-pecuniary factors.

Conceptual Model

Consider a dairy farmer's intent to adopt gene-editing technology with an animal welfare-improving disease resistance application or not. This application has both the benefits of protecting dairy cows from disease as a welfare improvement and reducing farmer risk but also has potential cost reduction implications from a herd management perspective. Thus, this adoption decision context encompasses both pecuniary and non-pecuniary motivations.

In its simplest form, the farmer intends to adopt the gene-editing technology if their expected utility of adopting gene-editing technology, $E(V_{iGE})$, is greater than that under continued conventional production, $E(V_{iC})$, or $E(V_{iGE}) > E(V_{iC})$. Because gene-editing technology is not yet commercially available, uncertainty exists around several factors including market outcomes, and the farmer's considerations are thus made in the *ex ante* case and subject to expected values. The definition of the farmer's utility is subject to a variety of relevant variables, both pecuniary and non. We define the farmer's utility specifically as a function of the technology's profitability, farm and farmer characteristics, and non-pecuniary motivations, which include past experiences and situational variables.

U.S. dairy farmers are assumed to be profit maximizers. Since the market benefits or costs of the gene-editing technology must be accounted for in the farmer's utility function, we assume the farmer's utility is a function of expected profit. Derivation of expected profits are presented in Appendix B. However, where the neo-classical approach assumes this is the only relevant factor in consideration, our model extends beyond profit expectations to encompass the richer set of variables which influence a farmer's decision, including farmer and farm-level characteristics.

Non-pecuniary motivations influencing adoption are accounted for using persistent and situational factors. Persistent non-pecuniary motivations are assumed to be those traits of a farmer defined by either past experiences or present attitudes which might influence the decision. In modeling adoption of gene-editing technology that improves animal welfare, these include degree of prioritization of animal welfare, personal and professional interest in novel technology, past experience with politicized technology, ethical opposition to genetic biotechnology use in animals, and aversion to change. These variables are essential as they allow for the consideration that, without sufficient market benefit to offset a farmer's non-pecuniary objections, adoption may not occur. Conversely, a substantial enough market benefit may be capable of outweighing a farmer's persistent non-pecuniary motivations.

Past technology adoption experiences have been shown to have predictive value for future adoption intent in U.S. dairy farmers (Klotz et al., 1995). An example of a past experience with technology which might influence a dairy farmer's adoption of gene-edited genetics would be the adoption of recombinant bovine somatotropin (rbST). Recombinant bovine somatotropin is a biosynthesized hormone which increases milk production. It was one of the first commercially available agricultural biotechnologies, approved in 1994, and received widespread adoption, followed by widespread disadoption from market rejection (Foltz & Chang, 2002; Olynk et al., 2012). Thus, a biotechnology effect could arise since rbST represents a biotechnology which offered substantial market benefits but was ultimately rejected by consumers for, at least in part, questionable impacts on cow well-being (Dohoo et al., 2003). Then if a farmer has been willing in the past to adopt a biotechnology with uncertain consumer acceptability like rbST, they may similarly be willing to take on such risks with another biotechnology in the future.

Other non-pecuniary motivations arise through situational variables such as response to peer environment, the weight a farmer gives to a veterinarian's opinion, or reactions to a sales representative's presentation. While these responses represent another facet of farmer attitudes and intrinsic characteristics, they are subject to the farmer's consideration only under certain circumstances. For instance, the farmer's decision may be uninfluenced by her veterinarian's opinion if the veterinarian is indifferent towards gene-editing technology or the farmer is uninformed of the veterinarian's opinion. But upon a recommendation from the veterinarian to adopt the technology, the farmer's entire decision could be affected where, for example, expected profits are less prioritized relative to animal welfare considerations.

Let $E(\pi_{GE})$ and $E(\pi_C)$ denote the farmer's expected profits when using gene-editing technology and conventional genetics, respectively. Farm and farmer characteristic variables which include herd size, gender, education and years of farming experience for farmer *i* are denoted by the vector $\mathbf{D}_i$. Let $\mathbf{Z}_i$ denote a vector of persistent non-pecuniary variables relevant to farmer *i* which includes prioritization of animal welfare, past experiences with biotechnology adoption, interest in novel technology and opposition to genetic biotechnology. Finally, situational variables which might influence the farmer's decision are captured in $\mathbf{S}_i$. These situational variables include professional peer environment and expert opinions from the farm veterinarian. Following, the expected indirect utility specification of the adoption decision can be defined as:

$$E[V_{iGE}(E(\pi_{GE}), \boldsymbol{D}_i, \boldsymbol{Z}_i, \boldsymbol{S}_i)] > E[V_{iC}(E(\pi_C), \boldsymbol{D}_i, \boldsymbol{Z}_i, \boldsymbol{S}_i)]$$

Useche et al. (2009) incorporate farmer heterogeneity and technology trait preferences in modeling farmer biotechnology adoption decisions. We extend their model to comprehensively represent the farmer's decision-making considerations by incorporating non-pecuniary variables in both persistent and situational forms. We first assume a basic linear specification of the indirect utility of an alternative as a function of characteristics x_{ij}:

$$V_{ij} = \beta_i x_{ij} \tag{4.1}$$

In this specification, β_i is a vector of preference parameters for farmer *i* over the traits of the alternative *j*. The model of Useche et al. (2009) further incorporates heterogeneity of farmer preferences by defining these preference parameters as a function of observable, z_i, and unobservable, v_i, farm and farmer characteristics. The elements of z_i can be further distinguished as those which affect farmer preferences, z_{1i}, and those which directly affect utility for an alternative, z_{2i}. Then $\boldsymbol{\beta}_i$ is comprised of a constant, b, observable farm and farmer characteristics $z_{1i,}$ with corresponding effect δ, and unobservable characteristics, $v_{i,}$ with corresponding effect φ.

$$\boldsymbol{\beta}_i = b + \delta z_{1i} + \varphi v_i \tag{4.2}$$

This approach assumes these preferences will be consistently expressed under any circumstances in which the choice arises with those specific alternatives. However, there are clear instances in which the same alternatives are offered, and the individual makes a different choice under different circumstances. This is where the situational variables are essential. In the case of the farmer, the choice may be not to adopt the technology under the circumstances that the veterinarian's opinion is unknown, or the veterinarian is indifferent towards the technology. However, under the circumstances that the farmer becomes aware that her veterinarian encourages adoption of the technology, her choice may change completely. The attributes of the technology and the status quo remain constant throughout, as do the farmer's persistent characteristics. Intuitively, the differentiating factor is the situational variable, the veterinarian's opinion, influencing the farmer's consideration. When the context of the choice changes to where the farmer has a different situation, the evaluation of the same choice set can result in a different outcome.

We account for these situational variables in two ways. First, indirectly, through their effect on farmer preferences over the attributes of an alternative. Second, through direct impact on the utility of a specific alternative. Inherent heterogeneity in farmer response to varying situational factors is incorporated through the inclusion of situational variables, s_i, in both the specification of the preference parameters over attribute variables and directly in the utility function. Furthermore, we extend the approach of Useche et al. (2009) by explicitly including observable, w_i, and unobservable, y_i, persistent non-pecuniary motivations and characteristics of a farmer. Thus, the basic specification of the farmer's utility function takes the form of:

$$V_{ij} = \beta_i x_{ij} + \lambda_i s_{ij} \quad (4.3)$$

With the heterogeneous preference parameters over the traits of the alternatives specified as:

$$\boldsymbol{\beta}_i = b + \delta z_{1i} + \rho w_{1i} + \varphi v_i + \psi y_i + \zeta s_{1i} \quad (4.4)$$

where equation 4.4 further extends the heterogeneous preference parameters proposed in Useche et al. (2009). As with z_i, the vector w_i can be further characterized by the subsets w_{1i}, those persistent non-pecuniary variables which affect farmer preferences, and w_{2i}, those which directly affect utility. The situational variable s_i can be similarly defined. Then the direct effect of some situational variables on the utility of each alternative would be similarly heterogeneous across farmers and is specified as:

$$\boldsymbol{\lambda}_i = c + \alpha z_{1i} + \pi w_{1i} + \mu v_i + \omega y_i \quad (4.5)$$

As with Useche et al. (2009), intrinsic preferences for a specific alternative j may also directly affect the farmer's utility for each of the alternatives. We further expand these intrinsic effects by explicitly distinguishing non-pecuniary motivations from amongst these variables.

$$V_{ij} = \beta_i x_{ij} + \lambda_i s_{2ij} + \gamma_j z_{2i} + \eta_j w_{2i} \quad (4.6)$$

With the resultant behavioral expression

$$\Delta V_{ik} = \beta_i \Delta x_{jk} + \lambda_i \Delta s_{2jk} + \gamma_{jk}^{*} z_{2i} + \eta_{jk}^{*} w_{2i} \quad (4.7)$$

With

$$\gamma_{jk}^{*} = \gamma_j - \gamma_k \quad (4.8)$$

$$\eta_{jk}^{*} = \eta_j - \eta_k \quad (4.9)$$

This highlights the importance of both the fixed and situational non-pecuniary influences relative to a model which overlooks their inclusion. First, equation 4.7 demonstrates the additional explicit distinction of the non-pecuniary fixed variables' effect on utility within both the heterogeneous preference parameters as well as directly in the utility function. Second, the effect of the situational context of the decision is clearly accounted for in our specification and allows both for the preferences of the farmer to vary across situations, as well as for direct utility for some alternatives to be influenced by the situation in which the choice is presented.

Empirical Approach

The theoretical framework developed above is used to assess dairy farmer decisions about whether to adopt gene-editing to increase resistance to Johne's disease in their herd under various scenarios. The assessment of this decision includes considerable uncertainty on the part of the farmer regarding the nature of the technology, the state of the operation and the market at the time the decision might be undertaken, and the situational context under which the decision might be made. Uncertainty has been suggested as an important determinant of a dairy farmer's intent to adopt novel biotechnology in the past, with uncertain market outcomes and effects on animal health driving a declining intent to adopt rbST prior to its FDA approval (Klotz et al., 1995). As such, the farmer's intent to adopt the technology under various situations might be viewed as a binary choice of adopt or not, but incorporation of this uncertainty more appropriately allows farmer responses to represent an increasing probability of adoption. This approach provides greater flexibility in farmers' responses and allows for greater reflection of the potential heterogeneity of influence of situational factors on a farmer's decision. That is, allowing for a 'probable intent to adopt' accounts for the various situational factors which might arise which could negate that intent, while 'definite intent to adopt' would indicate fewer situational contexts which might prevent a farmer from adopting. Thus, we model intent to adopt as an ordered choice of increasing probability of adoption over five levels which are relevant to the dairy producer context: (1) definitely keep current breeding program, (2) probably keep current breeding program, (3) unsure, (4) probably adopt gene-edited genetics, and (5) definitely adopt gene-edited genetics. The heterogeneity of farmer preferences over traits and situational variables are modeled using random parameters. The random parameters ordered logit (RPOL) model can accommodate both the flexibility of a probabilistic intent to adopt decision and the heterogeneity of preferences across farmers. A fixed parameters ordered logit model is first estimated, followed by an RPOL model to test for heterogeneity in preferences through the presence of significant standard deviation estimates. In the presence of significant standard deviation coefficients, the RPOL is the superior specification to use.

The latent variable y_{it}^* is used to estimate dairy farmer *i*'s intent to adopt gene-edited genetics which reduce the risk of Johne's disease in her herd in choice context *t*:

$$y_{it}^* = \boldsymbol{x}_{it}'\boldsymbol{\beta}_i + \mathbf{z}_i'\boldsymbol{\gamma}_i + \varepsilon_{it} \qquad \boldsymbol{\beta}_i \sim N(\boldsymbol{\beta}_i, \boldsymbol{\sigma}_i^2) \tag{4.10}$$

where $\boldsymbol{x}_{it}'$ is the vector of situational variables and technology traits, $\mathbf{z}_i'$ is the vector of farm and farmer characteristics including persistent non-pecuniary traits, $\boldsymbol{\beta}_i$ is the vector of random parameters to be estimated, $\boldsymbol{\gamma}_i$ is a vector of non-random parameters to be estimated, and ε_{it} is a random logistically-distributed error term. The farmer's certainty of intent to adopt increases monotonically across values of y_{it}, such that the farmer's observed intent to adopt gene-edited genetics is defined as:

$$y_{it} = \begin{cases} 0 \text{ if } & -\infty < y_{it}^* \leq \mu_0 \text{ (Definitely keep conventional)} \\ 1 \text{ if } & \mu_0 < y_{it}^* \leq \mu_1 \text{ (Probably keep conventional)} \\ 2 \text{ if } & \mu_1 < y_{it}^* \leq \mu_2 \text{ (Unsure)} \\ 3 \text{ if } & \mu_2 < y_{it}^* \leq \mu_3 \text{ (Probably adopt gene-edited)} \\ 4 \text{ if } & \mu_3 < y_{it}^* < \infty \text{ (Definitely adopt gene-edited)} \end{cases}$$

where μ_k are the unknown threshold parameters for the increasing probability levels of intending to adopt gene-edited genetics. These parameters are assumed to be homogeneous across farmers and are estimated as fixed parameters in the RPOL model, where μ_0 is normalized to zero. In the context of the RPOL, the farmer's probability of responding with the varying levels of intent to adopt gene-edited genetics can then be expressed with the conditional probability density function:

$$f\left(\boldsymbol{Y}_i^* \mid \boldsymbol{X}_i,\ \boldsymbol{Z}_i,\ \boldsymbol{\beta}_i,\ \boldsymbol{\gamma}_i\right) = \prod_{k=1}^{K} [F\left(\mu_k - \boldsymbol{X}_i'\boldsymbol{\beta}_i - \boldsymbol{Z}_i'\boldsymbol{\gamma}_i\right) - F\left(\mu_{k-1} - \boldsymbol{X}_i'\boldsymbol{\beta}_i - \boldsymbol{Z}_i'\boldsymbol{\gamma}_i\right)]^{Y_{ik}} \quad (4.11)$$

where $F(.)$ is the cumulative distribution function of the error term ε_{it}, that is, $F(\varepsilon_{it}) = \Lambda(\varepsilon_{it})$; and $\boldsymbol{Y}_i^*$, $\boldsymbol{X}_i$ and $\boldsymbol{Z}_i$ are vectors of y_{it}, $\boldsymbol{x}_{it}$ and $\boldsymbol{z}_{it}$ across t, respectively. Then, where individuals are assumed to be independent across choice contexts, the joint PDF conditional on $\boldsymbol{\beta}_i$ and $\boldsymbol{\gamma}_i$ is:

$$P\left(\boldsymbol{Y}_i / \boldsymbol{X}_i, \boldsymbol{Z}_i, \boldsymbol{\beta}_i, \boldsymbol{\gamma}_i\right) = \prod_{t=1}^{T} f\left(y_{it}^* \mid \boldsymbol{x}_{it}, \boldsymbol{z}_{it}, \boldsymbol{\beta}_i, \boldsymbol{\gamma}_i\right) \quad (4.12)$$

Because the random parameter cannot be integrated out of the resultant conditional probability, as it has no closed form solution, maximum likelihood estimation cannot be performed. Hence, estimation is conducted using a simulated maximum likelihood method for random parameters ordered choice. A coefficient for the mean of the random parameters is estimated, as well as for a derived standard deviation, where the distribution of the random parameter is assumed to be normal.

$$\beta_{k,ir} = \beta_k + \sigma_k w_{k,ir} \qquad w_{k,ir} \sim N(0,1) \quad (4.13)$$

Then the individual-specific parameters are defined where $\beta_{k,i} \sim N(\beta_k, \sigma_k^2)$. It has been common practice in standard random parameter choice models to assume independence of the random parameters. This assumption, however, is often excessively restrictive for situations in which the modeled effects may indeed be correlated within individuals. Thus, we allow for such correlation by estimating a correlated RPOL, assuming joint normal distribution of the random parameters. The simulated maximum likelihood estimation is achieved by drawing values from the assumed distribution of the random parameter, calculating a simulated probability from each value and averaging those probabilities over the multiple draws (Lee, 1992; Hajivassiliou & Ruud, 1994; Sarrias 2016). We utilize 1000 Halton draws in our estimation to ensure stability and precision of the parameters (Hensher & Greene, 2003; Sarrias, 2016). The estimation is carried out using NLOGIT 6 (Greene, 2016).

Data was collected with a survey mailed to dairy farmers in six states in February and March of 2020. Farmers were randomly drawn from licensed dairy farm lists from the Departments of Agriculture in California, Michigan, Minnesota, New Mexico, Vermont and Wisconsin. Together, these states represent over 47% of national milk production and cover major regions of production nationwide (NASS, 2020). Following the tailored design method, an initial survey was mailed, followed by a reminder postcard two weeks later, and a second survey sent two weeks after the postcard (Dillman et al., 2014). Surveys were sent to 2000 farmers with 534 returned resulting in a gross response rate of 26.7%. Of the 534 returned responses, 384 completed the experimental vignette methodology (EVM) portion of the survey used in this analysis, making the effective response rate 19.2%. Of the 384 participants, 361 observations provided full responses to all eight vignettes, resulting in a final, usable sample of 361 farmers.

The survey was comprised of three sections, designed to ensure that earlier questions did not influence subsequent questions and sections. The first section elicited farm and farmer information, including gender, education, years of farming experience and herd size, as well as information relevant to non-pecuniary motivating factors in a farmer’s potential decisions over an animal welfare-improving technology. These included a past history of biotechnology use (rbST), consideration of technologies at the forefront of the industry (robotic dairying technologies), farm history of and plans for planting genetically modified organisms, and Johne’s disease experience and current management. Farmers with over 500 head of milking cows were designated as ‘large farms’ (MacDonald et al., 2007). The intention to plant at least one type of genetically modified crop in the 2020 season was used as a proxy for farmers who already employ genetic biotechnology on farm. The second section of the survey specifically focused on awareness and attitudes towards biotechnology in the industry as well as the additional non-pecuniary motivation of animal welfare concerns. Responses to two statements were analyzed using principal components analysis and a single positive animal welfare attitude factor was identified using parallel analysis. Additionally, farmer attitudes towards the use of gene-editing in animals were elicited using a single Likert-style question. The third section of the survey contained the EVM questions.

The EVM presented a series of scenarios to the farmer in which the same question was posed over varying situational contexts. The scenarios focused on the farmer’s choice to maintain their current breeding program or elect to adopt the hypothetical gene-editing technology which provides cattle with increased resistance to Johne’s disease. Two attributes, each with two levels were selected for the hypothetical technology: the technology’s efficacy and market acceptance. Attributes and levels were selected based on the dairy and biotechnology literature. For efficacy, the technology either reduced the risk of Johne’s disease by 25% or by 75%. Market acceptance was denoted by either the same milk price being received or a 10% reduction in milk price. This variable accounts for the pecuniary considerations which invariably are included in a farmer’s decisions. Two situational variables were also included: veterinary encouragement to adopt the technology compared to veterinary indifference to the technology and a low proportion of peers planning to adopt (20%) compared to a high proportion of peers planning to adopt (60%). An orthogonal design was used for four variables with two levels, resulting in eight scenarios being presented to every farmer.

Prior to being presented with the scenarios, the farmer was given a short description of gene-editing technology (Appendix C). To frame the scenario evaluations, farmers were first told to suppose they were making their breeding decisions and now have the opportunity to purchase semen which offers the gene-edited attribute of resistance to Johne's disease. Due to the interest in identifying non-pecuniary motivations, the cost of the gene-edited technology was assumed to be the same as maintaining conventional genetics. Moreover, given the already-present market resistance to genetic biotechnology, it is reasonable to assume that any gene-edited genetics which become commercially available will need to be priced competitively relative to conventional genetics.[16] The vignette scenarios followed an identical format with only the attribute or situational variables varied and were presented as follows:

*Fully adopted, the effectiveness of the gene-edited genetics will reduce the risk of new Johne's cases in your herd by [**25%, 75%**]. When selling milk from GE cows, you will receive [**the same, a 10% decrease in**] milk price [**as before**]. Your operation's veterinarian [**encourages, is indifferent toward**] adoption of GE and [**20%, 60%**] of the dairy farmers in your area are planning to adopt GE genetics. Under these circumstances, what is your most likely decision?*

[16] Furthermore, recent work on the predicted costs of developing genetically modified traits in crops has demonstrated a capacity for GE technologies to substantially reduce research and development costs relative to traditional genetic engineering technologies (Bullock et al., 2021). Hence, it is reasonable to assume that GE genetics would be closer in cost to traditional genetics than genetically engineered genetics produced using conventional GMO techniques.

Results

Summary statistics for the sample are presented in Table 4.1. The sample consisted of 361 dairy farmers from Michigan (18.0%), Minnesota (29.9%), Vermont (12.2%), New Mexico (1.7%), Wisconsin (32.4%), and California (5.8%). The sample was comprised of approximately 10.2% female farmers, with a mean age of 53.6 years and an average of 33.3 years of farming experience. Approximately 36% of the sample had received any form of college education, ranging from some undergraduate courses to a postgraduate or professional degree. The average herd size was 370 head of milking dairy cows, with a minimum of 2 and a maximum of 12,000. This is larger than the average U.S. herd size but representative of modern, conventional dairy farms. Of the sampled farms, 11.9% were certified organic.[17]

Model Estimation and Results

A traditional (fixed parameter) ordered logit was first estimated and subsequently used as the starting values for the iterative simulation approach of the RPOL. The estimates for both this base model and the RPOL are presented in Table 4.2. Additionally, to fully understand the implications of persistent and situational non-pecuniary variables, marginal effects were derived for the RPOL and presented in Table 4.3. These effects indicate the impact of a unit change in each variable on the probability of a farmer having responded in each category with all other variables held at their means.

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[17] This represents a higher proportion than expected in the market. We elect to keep organic producers in the analysis for two reasons. First, while GMOs are disallowed in organic production, several countries, including Brazil, Argentina, Australia, Canada and Japan; have already determined not to or are considering not treating gene-edited plants and animals with the same regulatory approach as has been used for traditional GMOs. This could mean gene-edited livestock may eventually face different restrictions in the organic industry than current GMOs. Second, our survey contained several responses from organic producers who expressed varying degrees of interest in the technology, implying that organic producers themselves do not assume their preclusion from the technology, nor do they unilaterally reject the possibility of adoption.

In both the base model and the RPOL, the constant is negative, indicating that, at the mean, farmers intended to maintain their current breeding program as opposed to adopting disease-resistant GE genetics (Table 4.2). This, coupled with the relatively high threshold values of $\mu 2$ and $\mu 3$, demonstrates the general resistance among farmers toward adopting GE genetics. This is further supported by the marginal effects (Table 4.3), which were strongest for a farmer definitely keeping their current breeding program and weakest for definitely adopting GE. Overall, while some variables may have increased the probability of a farmer accepting GE, in most cases farmers became uncertain between their current breeding program and adopting GE. This reflects both a general resistance to GE genetics among farmers and possibly a preference for the status quo as well as the potential for additional situational influences on the decision which may not have been accounted for in the vignettes.

Nearly all of the evaluated variables had a significant influence on a farmer's probability of intending to adopt GE and the degree of certainty with which they hold that intent, albeit a very small influence in some cases. Farm and farmer characteristics were highly significant in both the base and RPOL models with the exception of having a college education and a large farm (with 500 head of milking cows or more) in the base model (Table 4.2). In the RPOL, women were less likely to adopt GE genetics while more experienced farmers and those with a college education were more likely to adopt. Additionally, farmers who had experienced a case of Johne's firsthand on their farm were more likely to intend to adopt GE genetics which reduce the likelihood of the disease occurring. Farmers with larger herds were also less likely to adopt GE genetics. The negative effect for large farms is contrary to expectations, given larger operations tend to employ more technology than smaller ones. However, this result may indicate that farmers with larger herds view genetic biotechnologies differently from other technologies, with the cost of both adoption and disadoption or eradicating the genetic biotechnology from a large herd likely being much greater than for smaller operations. Alternatively, as these farms generally have a larger cull rate for detected cases of Johne's, the benefit of this specific application of the technology may be insufficient in the context of a large operation as to merit adoption.

The mean effects of the attribute and situational variables, as well as the persistent non-pecuniary variables, were all statistically significant and as expected. When the GE genetics are more effective, reducing the risk of Johne's disease by 75% rather than the base 25% (High Efficacy), the probability of intending to adopt GE increases. This was also true of an encouraging recommendation to adopt from the farm veterinarian (Veterinary Encouragement) as opposed to an indifferent opinion, as well as having much higher percentage of neighboring dairy farmers adopting, 60% compared to 20% (High Peer Adoption). In contrast, poor market acceptance as evidenced by a decrease in milk price (Price Discount) significantly reduced the likelihood of adoption. This is consistent with the findings of Marra et al. (2004) with respect to farmers placing a negative value on genetic biotechnology due to uncertain consumer acceptance. Price Discount had the greatest marginal effect, resulting in a 31.8% increase in the probability of absolute rejection of GE genetics (Table 4.3). As the estimate for the mean on the price variable was of the greatest magnitude, it is clear that pecuniary concerns still have the strongest effect in farmer decisions. But while the most pecuniary variable did have the greatest individual effect, the non-pecuniary variables exerted a multitude of smaller effects.

Unsurprisingly, farmer attitudes played a significant role in influencing the intent to adopt the novel biotechnology. Farmers who particularly value animal welfare in the production context were less accepting of GE, despite the technology's potential to address a disease concern. The marginal effects showed that farmers with greater concern for animal welfare were more than 2% more likely to definitely intend to keep their current breeding program. This is contrary to the expectations of the animal welfare benefit of disease resistance, however it is possible that this indicates a belief amongst some farmers that GE use in and of itself could reduce the welfare of an animal and so is to be avoided. In contrast, farmers who had a more favorable attitude toward the general use of GE in animals were more likely to adopt GE genetics which reduce the incidence of Johne's disease. These farmers were 7% less likely to have definite opposition to adopt GE. Having used rbST in the past resulted in a farmer being 3% more likely to be unsure between adopting or not, as did having considered robotic machinery. This indicates that both these characteristics are associated with individuals more amenable to the prospect of adopting GE genetics. Similarly, having planted GMO crops reduced the probability of definite rejection of GE genetics by nearly 5%.

The situational variables of Veterinary Encouragement and High Peer Adoption also reduced the probability of staunch opposition to GE by 2 to 3%, respectively. While these effects individually pale in comparison to the larger pecuniary effect of a price discount, they demonstrate the potential for an aggregated effect which could ultimately overrule the pecuniary consideration. While part-whole bias should be considered in such an aggregate effect, where the total aggregate effect may be less than the sum of the individual effects (Marra & Piggott, 2006), the overall effect of non-pecuniary considerations can be substantial. Excluding such variables from empirical analysis can thus produce an incomplete picture of the farmer's considerations within the adoption decision and oversimplify the farmer's decision-making process.

Heterogeneity of Adoption

While the estimated means and marginal effects of these variables show their mean impact on the adoption decision, the model results also evince considerable heterogeneity amongst farmers as to the degree of these impacts. Though more widely used random parameters models tend to report estimated standard deviation parameters, such estimates in a correlated random parameters model may not be independent. To account for this, we evaluate the estimated Cholesky matrix, which identifies the contributions to the standard deviations from correlations with other random parameters and the isolated heterogeneity about a random parameter's mean, resulting in unconfounded estimates of total heterogeneity (Hensher et al., 2005). The presence of significant elements of the Cholesky matrix provides evidence for the goodness of fit of the RPOL specification.

Results from the RPOL displayed evidence of considerable heterogeneity in farmer response to attributes and situational variables on intent to adopt GE genetics (Table 4.4). This evidence is in line with the results of Useche et al. (2009) in finding significant heterogeneity in farmer preferences over biotechnology. Estimates for the diagonal elements of the Cholesky matrix indicate the degree of variance in effect of each variable, excluding any confounding effect of correlated variables. The magnitude of significant heterogeneity was largely consistent with the magnitude of the mean effect, where Price Discount had the widest range of effect, followed by High Efficacy and Veterinary Encouragement. There was no significant variation in the effect of High Peer Adoption alone. Even so, the significant heterogeneity in the other attribute and situational variables demonstrates the importance of accounting for variation in farmer response to these variables in empirical evaluation.

The importance of modeling heterogeneity is further evidenced by the significant correlations between the random parameters, as presented in the full Cholesky matrix in Table 4.4 and the implied correlation matrix in Table 4.5. The below diagonal elements of the Cholesky matrix showed that the constant is significantly related to both High Efficacy and Price Discount, though in opposite ways (Table 4.4). The positive relationship between the constant and High Efficacy could indicate that farmers who place a greater weight on the efficacy of the GE disease-resistance are also inherently more amenable to adopting the technology. In contrast, farmers who are more sensitive to the potential of market rejection through a milk price discount may also be more hesitant toward GE technology than the mean. As we might expect, there was a positive significant correlation between High Efficacy and Price Discount. This could reflect an economizing attitude of maximizing returns, both in terms of profit potential and product value for GE genetics. While High Peer Adoption by itself lacks statistically significant heterogeneity, the below diagonal elements of the Cholesky matrix indicated a significant positive relationship between Veterinary Encouragement and High Peer Adoption. This could indicate that some farmers are generally more responsive to the social environment in which they make a choice, including both professional and peer opinion. This responsiveness could come from a desire to keep up with industry trends as measured by peer actions, or could be driven by a presumed learning effect as has been observed in other studies of farmer response to social environments (Conley & Udry, 2010). The implied correlation between these variables indicated a strong relationship. Veterinary Encouragement was significantly negatively correlated with High Efficacy. This is somewhat counterintuitive, though it could indicate that the clearer the benefit of the technology, the less weight a farmer places on the veterinarian’s opinion.

Individual-Specific Parameter Estimates

In addition to mean effects and random parameters, we derived individual-specific or conditional parameters for each observation in the sample (for details on methods, see Train (2009)). This allowed us to better identify differences in effects of the random parameters across farmers with varying characteristics. To explore the relationship between observable farmer characteristics and the magnitude of influence of attribute and situational variables, we identified the top and bottom deciles of each variable and test for significant differences in the types of farmers who were most and least influenced by each variable against the bottom 90% or top 90% of the sample, respectively. [18] Results are presented in Table 4.6. While several of the variables did significantly differ amongst the farmers most or least influenced by attribute or situational variables, the most important are those which are most easily identified. These are the traits which might outwardly signal those farmers whose decisions are most strongly influenced by veterinary opinion or peer adoption or who may most heavily weigh the market reaction and subsequent price changes in their decision-making process.

Farmers who responded most strongly to High Efficacy and the two situational variables were significantly more likely to have experienced a case of Johne's on farm and to have considered robotics. This is evident from the proportion of farmers who had experienced a case of Johne's on farm or considered robotics in the group of farmers in the top 10% of individual-specific parameters for each of these variables being significantly greater than the proportion in the lower 90%. This could be because farmers who have adopted or expressed interest in adopting robotics may pay greater attention to trends in the industry and are thus more sensitive

[18] An alternative approach, presented in Appendix D and Table 4.D.1, is to calculate the means of the estimated individual-specific parameters and compare them across groups of farmers with differing persistent non-pecuniary or farm characteristics

to situational variables in the decision-making process. Unsurprisingly, those farmers most influenced by High Efficacy and Price Discount were more likely to have large farms. Farmers most sensitive to the efficacy of the technology on average had fewer years of farming experience, potentially indicating a greater sensitivity to risk than more established farmers. Having a college education was also more common amongst individuals most sensitive to Price Discount and Veterinary Encouragement. The inverse was seen for those individuals who were least influenced by or sensitive to High Efficacy, Price Discount and Veterinary Encouragement, with those farmers all significantly less likely to have had a college education. Farmers who were least sensitive to the decisions of other farmers in their community, on average, had more years of farming experience. Altogether, these results demonstrate that the heterogeneity amongst farmers in response to these variables is, at least in part, associated with identifiable characteristics. By considering which groups of farmers are more sensitive to situational variables or more responsive to the attributes of an alternative, it could be possible to substantially improve our understanding of why some novel technologies are successfully adopted industry-wide and others face widespread rejection.

Conclusion

Neo-classical approaches to explaining producer behavior have historically worked well in approximating several key factors in farmer decision-making. This analysis makes clear the necessity for a broader view of the variables of influence on the farmer's decision-making process, variables which include non-pecuniary motivations. These motivations may be persistent, impacting farmer decisions across a variety of contexts and choices, or situational, arising in the specific circumstances in which a choice is presented. And while our results demonstrate that the effects of these non-pecuniary influences can be small in magnitude (relative to the traditionally evaluated profit motives), their aggregate effects may shift a farmer's decisions away from the neo-classically-explained outcome. Thus, the addition of non-pecuniary variables when modeling a farmer's decision problem more accurately represents farmer behavior. Additionally, we find that situational non-pecuniary variables, in addition to attribute variables relevant to the choice alternatives, have varying degrees of influence for different farmers. Hence, heterogeneity of effects among farmers is an essential element to include in evaluations of decisions to adopt or intend to adopt new technologies. Furthermore, our results show this heterogeneity may be tied to other observable characteristics which may help to identify groups of farmers more or less receptive to adopting novel practices or technologies.

While our results demonstrate broad lessons for the future of evaluating farmer technology adoption decisions, they are especially relevant for the important potential context of disease resistance gene-edited genetics in US dairy. Overall, our findings point to a general resistance among American dairy farmers towards GE genetics in their herds, even with an animal welfare-improving application of increased disease resistance. Farmers can become more amenable to the prospect of adopting GE genetics through situational variables such as high peer adoption rates or veterinary encouragement of adoption. Poor market acceptance, and consequent price discounts, however, will strongly strengthen farmer resistance to adoption. Our results indicate that if disease-resistant GE genetics are to receive widespread adoption in the US dairy industry, they should effectively reduce or eliminate a disease which is commonly experienced by dairy farmers and seamlessly integrate into the consumer market without rejection. Additionally, if high adoption rates are to be achieved, the adoption decision should be presented with cognizance to the situational influences, such as social atmosphere and expert opinions, and the persistent non-pecuniary traits of farmers, such as motivation to stay on the frontiers of technology in the industry or moral objection to GE use in animals. Currently, our findings indicate that these technologies face a difficult battle for acceptance among farmers and fully understanding every facet of the farmer’s decision could mean the difference between success and failure for GE in animal agriculture.

While our results are foundational for work in gene editing adoption in animal agriculture, there are some limitations which future research can address. As genetic biotechnologies in livestock are in their nascent stage with regards to commercial availability, the hypothetical nature of our study is a limitation. As GE applications proliferate with the development of the technology, uses of GE genetics more relevant or of interest to farmers may arise and should be researched further to understand the influence of the application on potential adoption. Even variations in the disease resistance application could impact the adoptability of the technology, as, for example, some farmers in our study may have been satisfied in their alternative means of managing Johne’s so as to make the technology moot. Future research which addresses a variety of potential applications can help address this limitation by helping to more effectively identify the extent to which a farmer is influenced by the nature of the biotechnology as opposed to the relevance of its application to his or her operation. Additionally, while our investigation incorporated several situational and other non-pecuniary variables, the decision-making process is undoubtedly even more complex and can be informed by additional research. Moreover, evaluating consumer responses and market acceptance of a variety of GE applications in animal products could bolster the understanding of market opportunities for these technologies and more accurately frame the adoption decision for farmers. Finally, as our work demonstrates the potential importance of situational variables in the adoption decision, the role of situational influences in adoption decisions over other technologies or practices beyond gene editing and the dairy industry can be informed by future research.

APPENDICES

Appendix A: Tables

Table 4.1: Summary Statistics for Dairy Farmer Sample

Variable	**Full Sample**	**rbST Used**	**rbST Not Used**	**GMOs Grown**	**GMOs Not Grown**	**Robotics Considered**	**Robotics Not Considered**
Female	10.2%	8.6%	11.2%	7.5%	14.9%	11.1%	9.2%
Age	53.6 (12.2)	53.5 (11.4)	54.0 (12.5)	54.0 (11.4)	53.3 (13.3)	53.3 (12.1)	54.0 (12.3)
Years Farming	33.3 (14.9)	32.3 (13.2)	34.2 (15.8)	34.2 (14.0)	32.0 (16.2)	33.7 (14.8)	33.0 (15.1)
College Educated	35.7%	49.2%	28.3%	37.4%	32.8%	41.8%	27.5%
Avg Herd Size (milking cows)	370	697	190	420	285	448	264
Organic	11.9%	1.6%	17.6%	0.4%	31.3%	7.7%	17.6%
Tested for Johne's before	57.6%	68.0%	51.9%	59.0%	55.2%	64.9%	47.7%
Experienced Johne's on Farm	40.2%	57.8%	30.5%	43.2%	35.1%	47.1%	30.7%
Johne's Management Program	22.2%	30.5%	17.6%	22.9%	20.9%	24.0%	19.6%
Used rbST in the past	35.5%			41.0%	26.1%	43.8%	24.2%
GMO use (current)	62.9%	72.7%	57.5%			70.7%	52.3%
Considered robotics	57.6%	71.1%	50.2%	64.8%	45.5%		
N	361	128 (35.5%)	233 (64.5%)	227 (62.9%)	134 (37.1%)	208 (57.6%)	153 (42.4%)

Standard deviations are in parentheses for Age and Years Farming.

Table 4.2: Fixed (Base) and Random Parameter Ordered Logit Model Results

Variable	Fixed Parameters Ordered Logit (Base) Coefficient	S.E.	Random Parameters Ordered Logit Coefficient	S.E.
Female	-0.42***	0.13	-0.48***	0.18
Years Farming	0.02***	0.01	0.04***	0.00
rbST Use	0.35***	0.08	0.77***	0.12
Johne's Case on Farm	0.51***	0.07	2.64***	0.12
Robotics Considered	0.28***	0.07	0.91***	0.11
Positive Animal Welfare Attitude	-0.26***	0.04	-0.40***	0.05
Positive GE Attitude	0.27***	0.03	1.19***	0.05
College Educated	0.10	0.08	1.16***	0.11
Large Farm	0.03	0.11	-1.75***	0.16
Uses GMOs	0.37***	0.07	0.75***	0.11
Means				
Constant	-0.91***	0.14	-3.60***	0.25
High Efficacy	0.48***	0.07	1.81***	0.13
Price Discount	-1.16***	0.07	-3.95***	0.14
Veterinary Encouragement	0.14**	0.07	0.48***	0.13
High Peer Adoption	0.11*	0.07	0.37***	0.13
Diagonal Elements of Cholesky Matrix				
Constant			6.27***	0.20
High Efficacy			1.45***	0.09
Price Discount			3.14***	0.11
Veterinary Encouragement			0.19**	0.09
High Peer Adoption			0.04	0.07
Below Diagonal Elements of Cholesky Matrix				
Constant : High Efficacy			0.52***	0.15
Constant : Price Discount			-0.72***	0.15
High Efficacy : Price Discount			2.27***	0.10
Constant : Vet. Encouragement			0.02	0.18
High Efficacy : Vet. Encouragement			-0.22**	0.10
Price Discount : Vet. Encouragement			-0.16	0.10
Constant : High Peer Adoption			0.07	0.12
High Efficacy : High Peer Adoption			-0.14	0.11
Price Discount : High Peer Adoption			0.01	0.10
Vet. Encouragement : High Peer Adoption			0.19**	0.09
Mu 1	1.59***	0.04	5.81***	0.14
Mu 2	2.77***	0.05	9.01***	0.18
Mu 3	4.78***	0.11	13.81***	0.28

Statistical significance is denoted for the 1% ($p < 0.01$, ***), 5% ($p < 0.05$, **) and 10% ($p < 0.1$, *) levels.

Table 4.3: RPOL Marginal Effects

Variable	**At Means** Y=0 Definitely keep current breeding program	Y=1 Probably keep current breeding program	Y=2 Unsure	Y=3 Probably adopt GE genetics	Y=4 Definitely adopt GE genetics
Female	0.033***	-0.017	-0.158***	-0.001***	-5.98E-06***
Years Farming	-0.002***	0.001**	0.002***	0.001***	-5.91E-07***
rbST Use	-0.042***	0.006	0.034***	0.002***	1.32E-05***
Johne's on Farm	-0.149***	-0.014	0.155***	0.008***	6.77E-05***
Robotics Considered	-0.058***	0.023***	0.034***	0.002***	1.32E-05***
Positive Animal Welfare Attitude	0.023***	-0.007**	-0.016***	-0.001***	-5.95E-06***
Positive GE Attitude	-0.071***	0.022**	0.047***	0.002***	1.79E-05***
College Educated	-0.061***	0.004	0.055***	0.003***	2.16E-05***
Large Farm	0.183***	-0.139***	-0.042***	-0.002***	-1.58E-05***
Uses GMOs	-0.049***	0.020***	0.027***	0.001***	1.05E-05***
High Efficacy	-0.116***	0.034**	0.078***	0.004***	3.10E-05***
Price Discount	0.318***	-0.080**	-0.225***	-0.013***	-1.10E-04***
Veterinary Encouragement	-0.028***	0.009**	0.019***	0.001***	7.23E-06***
High Peer Adoption	-0.022***	0.007*	0.014***	0.001***	5.51E-06***

Statistical significance is denoted for the 1% ($p < 0.01$, ***), 5% ($p < 0.05$, **) and 10% ($p < 0.1$, *) levels.

Table 4.4: RPOL Cholesky Matrix and Implied Standard Deviations

	Constant	High Efficacy	Price Discount	Veterinary Encouragement	High Peer Adoption	**Implied Standard Deviations**
Constant	6.27***					6.27
High Efficacy	0.52***	1.45***				1.54
Price Discount	-0.72***	2.27***	3.14***			3.94
Veterinary Encouragement	0.02	-0.22**	-0.16	0.20**		0.33
High Peer Adoption	0.07	-0.14	0.01	0.19**	0.04	0.25

Statistical significance is denoted for the 1% ($p < 0.01$, ***), 5% ($p < 0.05$, **) and 10% ($p < 0.1$, *) levels.

Table 4.5: Implied Correlation Matrix of Random Parameters

	Constant	High Efficacy	Price Discount	Veterinary Encouragement	High Peer Adoption
Constant	1.00	0.34	-0.18	0.04	0.27
High Efficacy	0.34	1.00	0.48	-0.60	-0.44
Price Discount	-0.18	0.48	1.00	-0.77	-0.34
Veterinary Encouragement	0.04	-0.60	-0.77	1.00	0.81
High Peer Adoption	0.27	-0.44	-0.34	0.81	1.00

Table 4.6: Difference in Means and Proportions of Farmer Traits of Top and Bottom Deciles of Individual-Specific Parameters

	Means[a]				**Proportions**[b]					
Group	**Years Farming**	**GE Attitude**	**Animal Welfare**	**Johne's Exp.**	**rbST Use**	**Robotics Considered**	**Female**	**College Educated**	**Use GMOs**	**Large Farm**
Constant										
Bottom 10%	35.32	2.74	-0.04	0.53	0.26	0.53	0.16	0.34	0.63	0.13
Upper 90%	33.12	2.66	0.01	0.39	0.37	0.58	0.10	0.36	0.63	0.14
Difference	2.20	0.08	-0.05	0.14*	-0.11	-0.05	0.06	-0.02	0.00	-0.01
Top 10%	34.97	2.08	-0.11	0.27	0.30	0.46	0.14	0.38	0.54	0.27
Lower 90%	33.16	2.73	0.01	0.42	0.36	0.59	0.10	0.35	0.64	0.12
Difference	1.81	-0.65***	-0.12	-0.15*	-0.06	-0.13	0.04	0.03	-0.10	0.15**
High Efficacy										
Bottom 10%	32.76	2.27	-0.18	0.30	0.27	0.35	0.05	0.16	0.59	0.08
Upper 90%	33.42	2.71	0.02	0.41	0.36	0.60	0.11	0.38	0.63	0.15
Difference	-0.66	-0.44*	-0.20	-0.11	-0.09	-0.25***	-0.06	-0.22***	-0.04	-0.07
Top 10%	28.91	3.59	0.10	0.59	0.43	0.78	0.05	0.46	0.73	0.03
Lower 90%	33.86	2.56	-0.01	0.38	0.35	0.55	0.11	0.35	0.62	0.15
Difference	-4.95*	1.03***	0.11	0.21**	0.08	0.23***	-0.06	0.11	0.11	-0.12**
Price Discount										
Bottom 10%	31.43	3.49	-0.15	0.54	0.49	0.78	0.14	0.57	0.68	0.24
Upper 90%	33.57	2.57	0.02	0.39	0.34	0.55	0.10	0.33	0.62	0.13
Difference	-2.14	0.92***	-0.17	0.15*	0.15*	0.23***	0.04	0.24***	0.06	0.11*
Top 10%	32.89	2.69	-0.18	0.31	0.31	0.49	0.03	0.14	0.69	0.09
Lower 90%	33.40	2.66	0.02	0.41	0.36	0.59	0.11	0.38	0.62	0.14
Difference	-0.51	0.03	-0.20	-0.10	-0.05	-0.10	-0.08	-0.24***	0.07	-0.05

Table 4.6 (cont'd)

Group	Years Farming	**Means**[a] GE Attitude	Animal Welfare	Johne's Exp.	rbST Use	**Proportions**[b] Robotics Considered	Female	College Educated	Use GMOs	Large Farm
Vet Encouragement										
Bottom 10%	33.11	2.27	-0.05	0.30	0.22	0.46	0.05	0.22	0.65	0.05
Upper 90%	33.38	2.71	0.01	0.41	0.37	0.59	0.11	0.37	0.63	0.15
Difference	-0.27	-0.44*	-0.06	-0.11	-0.15*	-0.13	-0.06	-0.15*	0.02	-0.10
Top 10%	33.32	3.43	0.03	0.59	0.41	0.81	0.14	0.51	0.70	0.16
Lower 90%	33.35	2.58	0.00	0.38	0.35	0.55	0.10	0.34	0.62	0.14
Difference	-0.03	0.85***	0.034	0.21**	0.06	0.26***	0.04	0.17**	0.08	0.02
High Peer Adoption										
Bottom 10%	38.75	3.05	0.01	0.54	0.32	0.54	0.11	0.35	0.68	0.16
Upper 90%	32.73	2.62	0.00	0.39	0.36	0.58	0.10	0.36	0.62	0.14
Difference	6.02**	0.43*	0.012	0.15*	-0.04	-0.04	0.01	-0.01	0.06	0.02
Top 10%	35.35	3.05	0.16	0.54	0.32	0.73	0.11	0.43	0.65	0.08
Lower 90%	33.12	2.62	-0.02	0.39	0.36	0.56	0.10	0.35	0.63	0.15
Difference	2.23	0.43*	0.18	0.15*	-0.04	0.17**	0.01	0.08	0.02	-0.07

Statistical significance is denoted for the 1% ($p < 0.01$, ***), 5% ($p < 0.05$, **) and 10% ($p < 0.1$, *) levels.

[a] Mean value of variable is reported for each group.

[b] Proportion of farmers in each group with variable trait is reported.

Appendix B: Derivation of Farmer's Expected Profits

The farmer forms an expectation of profits under each technological regime, 'conventional genetics' and 'gene-edited genetics', as follows:

$$\underset{\boldsymbol{v}}{Max} \; E\left(p_C q_C - C_C - \boldsymbol{vw}\right) \; s.t. \; q_c = f_C(\boldsymbol{v})$$

And

$$\underset{\boldsymbol{v}}{Max} \; E\left(p_{GE} q_{GE} - C_{GE} - D_{GE} - \boldsymbol{vw}\right) \; s.t. \; q_{GE} = f_{GE}(\boldsymbol{v})$$

Each maximization problem assumes the technological framework and maximizes under that regime. p_j represents the price of milk produced using the corresponding technology j. Under uncertainty, this price is subject to the farmer's expected price, which is influenced by farmer perceptions about consumer acceptance or rejection of the technology. $\boldsymbol{v}$ is a vector of inputs required under both regimes with corresponding input price vector $\boldsymbol{w}$. D_{GE} represents the differential reproductive costs of maintaining a gene-edited herd. C_j represents the variable cost of herd health management under the relevant technology j and can account for cost reductions in herd management assuming $C_{GE} < C_C$. The farmer is assumed to maximize profits, getting an optimal vector of inputs $\boldsymbol{v_j}^*(p_j, \boldsymbol{w})$ under each technological regime j which can then be used to calculate expected profits under each case, $E(\pi_{GE})^*$ and $E(\pi_C)^*$. These profit expectations are then used as determinants of the farmer's expected utility under each technological production regime.

Appendix C: Descriptions of GE and Johne's Disease Provided in Farmer Survey

"**Gene editing** (**GE**) is a technique which changes an animal's own DNA to produce desirable traits or remove undesirable traits without adding foreign genetic material. In this section, we are interested in your willingness to adopt gene editing biotechnology through the purchase of semen which will increase resistance to Johne's disease in your herd under a variety of different conditions. The economic cost of Johne's disease is estimated at $200 to $2300 per clinical case, or $200 to $1500 million in the US annually."

*Note that the values presented in the survey were derived from Garcia and Shalloo (2015).

Appendix D: Individual-Specific Parameters Supplemental Results and Discussion

The means of the estimated individual-specific parameters compared across groups of farmers with differing persistent non-pecuniary or farm characteristics are presented in Table 4.D.1. The significant differences between many of the average effects in different groups of farmers further demonstrates the heterogeneity of the effects of the attribute and situational variables on farmer decisions, with some of this heterogeneity being related to persistent non-pecuniary traits or farmer characteristics. For example, the magnitude of the influence of all four attribute and situational variables is significantly greater for farmers who have considered robotics than those who have not, as well as for those who have a college degree. This would indicate that farmers who have considered adopting another, non-biological technology are more responsive to the attribute and situational variables of the adoption decision. Farmers who have a college education similarly take all of the evaluated variables into greater consideration in determining their intent to adopt GE genetics. Interestingly, there are no significant differences in the influence of these variables on farmers of different genders. While these differences, though significant, are often small, their presence does indicate the potential for accounting for farmer heterogeneity in response to attribute and situational variables. Understanding how observable characteristics relate to a farmer's propensity to respond to various aspects of an adoption decision could improve future evaluations of trends in adoption of novel practices and technologies.

Table 4.D.1: Individual-Specific Parameter Means by Farmer Characteristic

	Constant	**High Efficacy**	**Price Discount**	**Veterinary Encouragement**	**High Peer Adoption**
Full Sample	-3.79	1.83	-3.97	0.48	0.36
No rbST Use	-4.06	1.79	-3.60	0.45	0.35
rbST Use	-3.28	1.90	-4.64	0.52	0.38
Difference	-0.78	-0.11	1.04***	-0.07***	-0.03**
No GMOs Grown	-4.38	1.78	-3.64	0.45	0.34
GMOs Grown	-3.44	1.86	-4.16	0.49	0.38
Difference	-0.95	-0.08	0.52	-0.04*	-0.03**
Robotics Not Considered	-4.17	1.65	-3.24	0.42	0.34
Robotics Considered	-3.50	1.96	-4.50	0.52	0.38
Difference	-0.67	-0.31***	1.26***	-0.09***	-0.05***
No Johne's Experience	-3.70	1.72	-3.53	0.45	0.36
Johne's Experience	-3.92	1.98	-4.63	0.52	0.37
Difference	0.22	-0.25**	1.10***	-0.07***	-0.02
Female	-4.74	1.88	-4.17	0.49	0.35
Male	-3.68	1.82	-3.94	0.48	0.37
Difference	1.06	-0.06	0.23	-0.02	0.01
Less than College	-3.81	1.69	-3.48	0.44	0.35
College Educated	-3.75	2.06	-4.84	0.54	0.39
Difference	-0.05	-0.37***	1.36***	-0.10***	-0.04***
Small or Medium Farm	-4.06	1.83	-3.76	0.47	0.36
Large Farm	-2.08	1.78	-5.28	0.54	0.38
Difference	-1.98**	0.06	1.52***	-0.08**	-0.02

Significant differences in means are denoted at the 1% ($p < 0.01$, ***), 5% ($p < 0.05$, **) and 10% ($p < 0.1$, *) levels.

REFERENCES

REFERENCES

Bullock, D. W., Wilson, W. W., & Neadeau, J. (2021). Gene Editing Versus Genetic Modification in the Research and Development of New Crop Traits: An Economic Comparison. *American Journal of Agricultural Economics, in press*.

Carlson, D. F., Lancto, C. A., Zang, B., Kim, E. S., Walton, M., Oldeschulte, D., Seabury, C., Sonstegard, T. S. & Fahrenkrug, S. C. (2016). Production of hornless dairy cattle from genome-edited cell lines. *Nature Biotechnology*, *34*(5): 479-481.

Clark, B., Stewart, G. B., Panzone, L. A., Kyriazakis, I., & Frewer, L. J. (2017). Citizens, consumers and farm animal welfare: A meta-analysis of willingness-to-pay studies. *Food Policy*, *68*: 112-127.

Conley, T. G., & Udry, C. R. (2010). Learning about a new technology: Pineapple in Ghana. *American Economic Review*, *100*(1): 35-69.

Dillman, D. A., Smyth, J. D., & Christian, L. M. (2014). Internet, mail, and mixed-mode surveys: The tailored design approach. *John Wiley & Sons*, Hoboken, NJ.

Dohoo, I. R., DesCôteaux, L., Leslie, K., Fredeen, A., Shewfelt, W., Preston, A., & Dowling, P. (2003). A meta-analysis review of the effects of recombinant bovine somatotropin: 2. Effects on animal health, reproductive performance, and culling. *Canadian Journal of Veterinary Research*, *67*(4): 252-264.

Foltz, J. D., & Chang, H. H. (2002). The adoption and profitability of rbST on Connecticut dairy farms. *American Journal of Agricultural Economics*, *84*(4): 1021-1032.

Frewer, L. J., van der Lans, I. A., Fischer, A. R., Reinders, M. J., Menozzi, D., Zhang, X., van den Berg, I. & Zimmermann, K. L. (2013). Public perceptions of agri-food applications of genetic modification–a systematic review and meta-analysis. *Trends in Food Science & Technology*, *30*(2): 142-152.

Garcia, A. B., & Shalloo, L. (2015). Invited review: The economic impact and control of paratuberculosis in cattle. *Journal of Dairy Science*, *98*(8): 5019-5039.

Garforth, C. (2015). Livestock keepers' reasons for doing and not doing things which governments, vets and scientists would like them to do. *Zoonoses and Public Health*, *62*: 29-38.

Greene, W.H. (2016). NLOGIT version 6 reference guide. *Econometric Software, Inc.*, Plainview, NY 11803, USA.

Guehlstorf, N.P. (2008). Understanding the scope of farmer perceptions of risk: considering farmer opinions on the use of genetically modified (GM) crops as a stakeholder voice in policy. *Journal of Agricultural and Environmental Ethics*, *21*(6): 541-558.

Hajivassiliou, V.A. & Ruud, P. A. (1994). Classical Estimation Methods for LDV Models Using Simulation. In R.F. Engle & D. McFadden (eds.), *Handbook of Econometrics*, Vol. 4, Ch. 40 (pp. 2383–2441). Elsevier.

Hensher, D.A. & Greene, W. H. (2003). The Mixed Logit Model: The State of Practice. *Transportation*, *30*(2): 133–176.

Hensher, D. A., Rose, J. M., Rose, J. M., & Greene, W. H. (2005). *Applied Choice Analysis: A Primer*. Cambridge University Press.

Howley, P., Buckley, C., Donoghue, C. O., & Ryan, M. (2015). Explaining the economic 'irrationality'of farmers' land use behaviour: the role of productivist attitudes and non-pecuniary benefits. *Ecological Economics*, *109*: 186-193.

Ikeda, M., Matsuyama, S., Akagi, S., Ohkoshi, K., Nakamura, S., Minabe, S., Kimura, K. & Hosoe, M. (2017). Correction of a disease mutation using CRISPR/Cas9-assisted genome editing in Japanese black cattle. *Scientific Reports*, *7*(1): 1-9.

Klotz, C., Saha, A., & Butler, L. J. (1995). The Role of Information in Technology Adoption: The Case of rbST in the California Dairy Industry. *Review of Agricultural Economics, 17*(3): 287-298.

Lee, L. F. (1992). On Efficiency of Methods of Simulated Moments and Maximum Simulated Likelihood Estimation of Discrete Response Models. *Econometric Theory*, *8*(4): 518–552.

Lin, W., Ortega, D. L., Caputo, V., & Lusk, J. L. (2019). Personality traits and consumer acceptance of controversial food technology: A cross-country investigation of genetically modified animal products. *Food Quality and Preference*, *76*: 10-19.

Lombard, J. E., Gardner, I. A., Jafarzadeh, S. R., Fossler, C. P., Harris, B., Capsel, R. T., Wagner, B. A., & Johnson, W. O. (2013). Herd-level prevalence of *Mycobacterium avium* subsp. *paratuberculosis* infection in United States dairy herds in 2007. *Preventive Veterinary Medicine*, *108*(2-3): 234-238.

MacDonald, J. M., McBride, W. D., O'Donoghue, E., Nehring, R. F., Sandretto, C., & Mosheim, R. (2007). *Profits, costs, and the changing structure of dairy farming*. USDA-ERS Economic Research Report, (47).

Maertens, A., & Barrett, C. B. (2013). Measuring social networks' effects on agricultural technology adoption. *American Journal of Agricultural Economics, 95*(2): 353-359.

Marra, M. C., & Piggott, N. E. (2006). The value of non-pecuniary characteristics of crop biotechnologies: A new look at the evidence. In *Regulating Agricultural Biotechnology: Economics and Policy* (pp. 145-177). Springer, Boston, MA.

Marra, M. C., Piggott, N. E., & Carlson, G. A. (2004). The net benefits, including convenience, of Roundup Ready soybeans: results from a national survey. *Technical Bulletin, 3*.

Napolitano, F., Pacelli, C., Girolami, A., & Braghieri, A. (2008). Effect of information about animal welfare on consumer willingness to pay for yogurt. *Journal of Dairy Science*, *91*(3): 910-917.

NASS (USDA National Agricultural Statistics Service). (2020). Milk Production. *Agricultural Statistics Board*. Washington, D. C. December 17, 2020. Retrieved December 17, 2020 from: https://downloads.usda.library.cornell.edu/usda-esmis/files/h989r321c/q524kf13h/ws85b748b/mkpr1220.pdf.

Olynk, N., C. Wolf, and G. Tonsor. (2012). Production Technology Option Value: The Case of rbST in Michigan. *Agricultural Economics*, 43(November 2012 Supplement S1): 1-9.

Prokopy, L.S., Floress, K., Klotthor-Weinkauf, D. & Baumgart-Getz, A. (2008). Determinants of agricultural best management practice adoption: Evidence from the literature. *Journal of Soil and Water Conservation*, 63(5): 300-311.

Rasmussen, P., Barkema, H. W., Mason, S., Beaulieu, E., & Hall, D. C. (2021). Economic losses due to Johne's disease (paratuberculosis) in dairy cattle. *Journal of Dairy Science, 104*(3): 3123-3143.

Ribeiro, T. G., Barone, B., & Behrens, J. H. (2016). Genetically modified foods and their social representation. *Food Research International, 84*: 120-127.

Sarrias, M. (2016). Discrete choice models with random parameters in R: The Rchoice Package. *Journal of Statistical Software*, *74*(10): 1-31.

Sinclair, M., Zito, S. & Phillips, C. (2017). The impact of stakeholders' roles within the livestock industry on their attitudes to livestock welfare in Southeast and East Asia. *Animals*, *7*(2): 6.

Train, K. (2009). *Discrete Choice Methods with Simulation.* Cambridge, UK: Cambridge University Press, pp. 259-281.

Ufer, D., Ortega, D. L., & Wolf, C. A. (2019). Economic foundations for the use of biotechnology to improve farm animal welfare. *Trends in Food Science & Technology*, *91*: 129-138.

Useche, P., Barham, B. L., & Foltz, J. D. (2009). Integrating technology traits and producer heterogeneity: A mixed-multinomial model of genetically modified corn adoption. *American Journal of Agricultural Economics*, *91*(2): 444-461.

USDA APHIS (USDA Animal and Plant Health Inspection Service). (2008). *Johne's Disease on U.S. Dairies: 1991-2007*. Veterinary Services - Centers for Epidemiology and Animal Health. April 2008. Retrieved February 17, 2021 from: https://www.aphis.usda.gov/animal_health/nahms/dairy/downloads/dairy07/Dairy07_is_Johnes_1.pdf.

Wolf, C. A., & Tonsor, G. T. (2017). Cow Welfare in the US Dairy Industry: Willingness-to-Pay and Willingness-to-Supply. *Journal of Agricultural and Resource Economics*, *42*(2): 164-179.

Wu, H., Wang, Y., Zhang, Y., Yang, M., Lü, J., Liu, J., & Zhang, Y. (2015). TALE nickase-mediated SP110 knockin endows cattle with increased resistance to tuberculosis. *Proceedings of the National Academy of Sciences*, 201421587.