Available online at www.centmapress.org

Int. J. Food System Dynamics 11 (5), 2020, 482-502

DOI: http://dx.doi.org/10.18461/ijfsd.v11i5.69

INTERNATIONAL JOURNAL ON FOOD SYSTEM DYNAMICS

Economic Effects of a Potential Foodborne Disease: Potential Relationship between Mycobacterium Avium Subs. Paratuberculosis (MAP) in Dairy and Crohn's in Humans

Leslie J. Verteramo Chiu[1], Loren W. Tauer[2], Rebecca L. Smith[3], and Yrjo T. Grohn[4]

[1]College of Veterinary Medicine and Charles H. Dyson School of Applied Economics and Management, Cornell University
[2]Charles H. Dyson School of Applied Economics and Management, College of Agriculture and Life Sciences, and SC Johnson School of Business, Cornell University, Ithaca, NY, 14853
[3]Department of Pathobiology, College of Veterinary Medicine, University of Illinois, Urbana, IL, 61802
[4]Section of Epidemiology, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853
ljv9@cornell.edu; lwt1@cornell.edu; rlsdvm@illinois.edu; ytg1@cornell.edu

Received March 2020, accepted October 2020, available online November 2020

ABSTRACT

Welfare costs of a potential food shock were estimated by disseminating information to milk drinkers on the prevalence of *Mycobacterium avium sub. paratuberculosis* (MAP) in the U.S. milk supply, its potential linkage to Crohn's disease in humans, and subsequent government intervention to minimize MAP in the milk supply. We found that 19.6% of milk consumers exposed to MAP information would stop milk consumption at current market prices, and that only 5% of those would return to their original milk consumption levels after the government intervention. Societal costs of the food shock after the intervention were estimated at $18.2 billion.

Keywords: *Food Shock; Crohn's Disease; Food Contamination; Milk Demand; Food Scare.*

1 Introduction

Foodborne diseases spreading through a country's food supply chain pose serious public health risks. It is estimated that more than 100,000 people are hospitalized and about 3,000 people die in the U.S. from foodborne diseases each year (Center for Disease Control and Prevention, 2018). In the European Region, it is estimated that foodborne diseases cause about 5,000 people deaths per year and that more than 400,000 disability-adjusted life years (WHO, 2017). Foodborne diseases also occur economic costs from treatment and controlling the disease, and from industry losses due to decrease in demand of the infected food.

Foodborne diseases of livestock origin can originate from infected production animals or their infected environment. Examples of such foodborne pathogens include bovine tuberculosis, trichinosis, salmonella, Bovine Spongiform Encephalopathy (BSE), and *E. coli*.

One potential foodborne pathogen that has not received as much public attention as other foodborne pathogens is (MAP). MAP is the agent causing Johne's disease in ruminants. Johne's disease is a chronic disease that affects the lower intestines of ruminants, resulting in wasting, milk loss, and eventually death. It is estimated that about 68% of all U.S. dairy herds are affected by MAP, while large U.S. dairy operations have a herd prevalence of about 95% (USDA:APHIS:VS, 2008). MAP can be present in the milk produced by infected cows, but there are few studies estimating the prevalence of MAP in raw milk and commercially pasteurized milk, and their results vary significantly. It is estimated that up to 27.5% and about 8% of the raw milk produced in the U.S. (Jayarao et al., 2004) and U.K. (Grant et al., 2002), respectively, test positive to MAP with PCR. Ellingson et al., (2005) estimated that about 3% of retail pasteurized milk samples in three states of the U.S. (CA, MN, and WI) tested positive to MAP with PCR. Millar et al., (1996) estimated that about 28% of the whole pasteurized milk sampled in England tested culture positive, and Grant et al., (2002) estimated that about 12% of commercially pasteurized milk in the U.K. tested PCR positive. MAP has also been detected in powder infant formula produced in some European countries (Botsaris et al., 2016). Commercial pasteurization may not eliminate MAP completely from milk (Chiodini and Hermon-Taylor, 1993;Grant et al., 2002; O'Reilly et al., 2004). MAP has been identified in milk ultra-pasteurized at high temperature (Paolicchi et al., 2012). Donaghy et al., (2004) found that MAP can persist in the cheddar cheese manufacturing processes. Even milk produced from subclinically infected cows can contain MAP (Ayele et al, 2005).

A similar disease in humans is Crohn's disease (CD), for which the cause(s) are unknown. Crohn's disease is a chronic disease that causes inflammation of the small and sections of the large intestines. Abdominal pain, diarrhea, and weight loss are common symptoms of CD. Although Crohn's disease is not a terminal disease, it cannot be cured, and results in permanent lifestyle changes. MAP has been identified in CD patients; however, the causal link between drinking MAP contaminated milk and CD has not been widely accepted (Feller et al., 2007). In a meta-analysis of MAP and CD, Feller et al. (2007) found that the causal link between MAP and CD is inconclusive (cannot be rejected nor accepted given the evidence). They conclude that any knowledge on association should be updated as new evidences accumulate. Recently, Bognár et al. (2019) discussed the potential routes of transmission, including the food chain, of MAP to humans, and concluded that herd level control programs should be implemented to minimize MAP infection and the potential zoonotic risk.

Consequently, the objective of this paper was to analyze the economic effects of a potential food shock caused by milk consumers' awareness of MAP in milk, and of a subsequent implementation of a government MAP elimination program. We estimated changes in milk demand and its corresponding welfare changes using a partial equilibrium framework, the cost to eliminate MAP from the milk supply, milk supply changes due to implementing a MAP elimination program, and the likelihood of restoring consumer demand to the initial level. To estimate the effect of information on MAP in the milk supply, we conducted a difference-in-difference analysis from an online survey of milk consumers representative of the U.S. population. We also collected personal information on these consumers and analyzed factors that contribute to their response of MAP information in milk and to a MAP elimination program.

The results of this paper have important policy implications and contributes to the debate in understanding the potential costs of a food shock of a foodborne pathogen present in the food supply, and the ability to restore consumers' confidence in the food supply. Our study centers on the dissemination of information of a potential zoonotic pathogen in the food supply, where the presence of the pathogen has been known to the scientific community but has been largely unknown to the rest of the population. Our results can help policy makers in deciding the scope of the intervention, based on the expected costs of the shock.

2 Literature Review

Studies on the effects of food shocks on consumer behavior are numerous. Smith et al. (1999) estimated that the bovine spongiform encephalopathy (BSE) scare of 1996 in Scotland reduced consumer trust in information from expert sources, including the government, about food safety. Kaiser, Scherer, and Barbano (1992) analyzed the potential response of consumers to milk produced with recombinant bovine somatotropin (r-bST) hormone in the U.S., and found that about 18% of milk consumers would decrease milk consumption if r-bST was used in the production of the milk they purchase, even though bST is a naturally occurring hormone in cows. Estimates of the effect of a hypothetical Salmonella food scare on chicken demand were conducted in five European countries by Mazzocchi et al. (2008), they found that consumer trust is important in estimating the effect of the food scare, thereby suggesting that priority should be on building trust after a food scare.

Some studies on food shocks include the implementation of government programs, such as culling infected animals, quarantine, or total depopulation of a country's livestock. Examples include the outbreak of bovine spongiform encephalopathy (BSE or mad cow disease) in the U.K. decreased beef consumption in Europe in that same year by 11% (Powell, 2001), costing the U.K. more than £4 billion.

Changes in consumer demand from a food shock can occur quickly. From the start of the BSE outbreak in Japan in September 2001 to the end of November 2001, sales of domestic and imported beef dropped by 70%, even though only three cases of BSE were confirmed (McCluskey et al., 2005). These authors found that Japanese consumers were willing to pay up to 50% premium for BSE-tested beef.

Consumer reaction to food shocks depends on many factors, including risk communication of the pathogen or the agent perceived to be harmful, and individual characteristics (Mazzocchi et al., 2008). In a study of risk perception of avian influenza on Chinese consumers, Zhou et al. (2016) found that providing any information on the pathogen (H7N9 virus), either positively or negatively, led to an increased perception of risk and lower consumption of chicken, suggesting low trust in positive information. Trust in authorities moderates the impact of the food shock, while high education amplifies the effect of trust (Lobb, Mazzocchi, and Traill, 2007). Piggott and Marsh (2004) found that poultry is more responsive to safety concerns than beef or pork.

This paper is different from most papers on food shocks. While most papers studied consumers' reaction to a pathogen, or to a risk factor, that is introduced in a food product, this paper studies consumers' reaction to bacteria that is already present in the milk supply. In this paper, consumers are given information about the presence of the bacteria and the potential, not confirmed, link to Crohn's disease.

3 Methodology

3.1 Survey

The data used in this analysis were collected through an online survey on a random sample of 604 milk drinkers across the U.S.[1]

Survey participants were randomly assigned to three mutually exclusive groups: control-control (CC), treatment-control (TC), and treatment-treatment (TT). Each of these groups had a version of the survey with different information on MAP. The survey included two interventions, I_1 and I_2. Each intervention provided unique information to participants. After the intervention information was presented, participants were asked a willingness to purchase (WTP) question. This question asked participants whether they would continue to buy the same amount of milk they normally buy or reduce their purchase. The answer to the WTP question was a dichotomous yes/no choice.

Details on the survey questions are found in the appendix.

[1] Sample subjects were aged 21 years old and older, who participate in their household's milk purchasing decisions. The survey was created and distributed to a random sample using the online survey platform Qualtrics® between Oct. 2nd and 15th, 2018. The survey included standard demographic questions, questions validated to capture level of trust in institutions and level of risk aversion, and additional questions to gauge familiarity with CD, and experience with food borne epidemics.

3.2 Analysis

The effect of MAP information on consumers' willingness to purchase milk, and the restoration of consumption with government intervention to reduce the incidence of MAP in milk production were estimated using difference-in-difference (DID) analysis. There is no initial difference between treatment and control groups pre-intervention.

A detailed explanation on the model used in the analysis is found in the appendix.

3.3 Economic Welfare

The economic impact on society caused by a MAP food shock was analyzed in two parts. First, we estimated the welfare effect of the decrease in demand for fluid milk caused by consumers' reaction to MAP milk. Next, we estimated the costs of government strategies to eliminate MAP from the milk supply and restore consumer confidence and the effect in restoring consumer demand. Changes in supply caused by government controls were also estimated.

The change in milk demand was estimated from the survey by the number of people that responded that they will not purchase the same amount of milk at current prices after reading the information on MAP in fluid milk. We assumed that respondents will not buy any amount of milk. Although it is possible that consumers may partially decrease the consumption of a product that poses a hazard to their health, it is difficult to estimate a reliable decrease in consumption from surveys. We estimated the change in total milk demand as a parallel shift of the demand curve for fluid milk. Consumer and producer surpluses were estimated for each equilibrium price after each intervention.

Similar to Lhermie et al. (2018), P_0 was calculated as the average U.S. national fluid milk price for a five year period. We used the period from 2014-2018. Q_0 was the average yearly U.S. milk production over the same years (USDA:ERS, 2020a).

The price elasticity of demand, E_D, and price elasticity of supply, E_S, were obtained from Andreyeva et al. (2010), and Bozic et al. (2012), respectively. We used linear supply and demand functions

$$Q_S = \alpha_S + \beta_S P_S, \text{ and } Q_D = \alpha_D - \beta_D P_D$$

The elasticities used are assumed to hold at equilibrium price, P^*, and quantity, Q^*, from the formula $E = \beta \frac{P^*}{Q^*}$ where α_S, α_D, β_S, and β_D were estimated from the elasticity values and the equilibrium price and quantity.

Values of the parameters used to estimate welfare changes are shown in Table A1 in the appendix. The formulas to estimate consumer and producer welfare changes are presented after Table A1 in the appendix.

The response of consumers to a government program to reduce MAP was measured as the effect of the second treatment in the survey. In this analysis we consider a national program of herd testing, and those herds that test MAP positive would be required to implement a MAP elimination protocol to reduce MAP prevalence to safe levels. Studies that estimate the efficacy of MAP test and cull protocols in infected herds conclude that it is very difficult to completely eliminate MAP from an infected herd (Lu et al., 2010; Mitchell et al., 2008; Smith et al., 2017; Verteramo Chiu et al., 2018). However, some test and cull protocols can reduce the prevalence of MAP positive animals in a herd to 3% (from a prevalence of 12%) (Verteramo Chiu et al., 2018). This reduction in prevalence has been shown to be sufficient to decrease the amount of MAP in milk to undetectable levels. Beaver et al. (2017) found no traces of MAP in the milk produced in a dairy herd with 2.9% MAP prevalence. Khol et al. (2013) found that in a herd with 5% MAP seroprevalence, no MAP was detected in bulk milk tanks. Milk produced from a dairy herd with 3% MAP seroprevalence is unlikely to have detectable levels of MAP.

A government intervention to eliminate or reduce MAP prevalence from the milk supply chain to safe levels would decrease the supply of fluid milk in the U.S. No international milk trade is assumed when the government program is in place. Milk supply may return to its pre-MAP control levels after cow repopulation; however, we do not analyze the dynamics of milk supply and demand. We focus on the comparative statics of the change in demand and supply.

The estimation of the change in supply after the government intervention follows the analysis by Verteramo Chiu et al., (2018). The authors found that testing and culling all cows in an endemically MAP infected herd, starting in their first parity and higher, can reduce MAP prevalence, from the U.S.

estimated endemic prevalence of 12% to 3%. The tests used in MAP controls do not have perfect sensitivity[2], leading to undetected MAP positive animals left in the herd. We assumed that the government intervention to control MAP is testing and culling all cows parity one and higher. The costs associated with implementing this intervention were obtained from Verteramo Chiu et al., (2018).

The change in milk supply resulting from implementing the MAP control strategy was estimated from loss in milk production from the culled cows that tested MAP positive. For the period 2014-2018, the average number of dairy cows in the U.S. is estimated at 9.34 million (USDA:ERS, 2020b), and the average annual milk production per cow in the U.S. is 10,295 kg (USDA:ERS, 2020b). From the milk production analysis by Smith et al., (2016), we estimated the milk production from an average MAP infected cow to be about 8.5% lower than the production of an average cow in the U.S. The shift in supply of milk due to the control strategy is the product of the expected number of cows with MAP (1.121 million) times its expected milk production per year (9,420 kg). The estimated change in supply is 10.6 billion kg of milk, or 11% of the U.S. annual production.

The total welfare change was calculated after the government intervention to reduce MAP in the milk supply.

The hypotheses tested are presented in the appendix.

4 Results

Five sets of results are presented: demographic composition of the survey participants, Difference-in-Difference results of the treatment effects, factors affecting the first and second treatment, and welfare analysis.

4.1 Demographic Summary

The results of the demographic characteristics of the survey participants, by group and total, are shown in Table A2 in the appendix.

The distribution of demographic values between groups TC and TT are similar. Group CC has a lower proportion of male participants (26%) compared to groups TC (64%) and TT (61%). We tested for gender effects and WTP responses at the first intervention in the CC group and found no significant effect, with a p-value of 0.25. The demographic characteristics of our sample, although not identical to the national average, provide external validity. The effect of some demographic factors on the treatment effect were also tested and the results are shown in the subsections that follow.

4.2 DID results

The results of the logistic regression on the DID effects are presented in Table 1. The variables *T1* and *T2* are indicators of the first and second treatment, respectively. In this paper we define treatment as the time when information is given to the individual followed by the WTP question. The information in the treatment can be neutral (for the control group), or not (interventions for the treated groups). *GT1* and *GT2* are the interaction effects of the treated groups and T1 and T2, respectively, and represent the effects of the two interventions on WTP.

The marginal effect of *GT1* on WTP milk is 0.196, indicating that the first treatment (MAP information in the milk supply) would result in 19.6% of milk drinkers reducing their milk purchases. This is the proportion of the milk consumers that respond negatively to the first treatment. Because this parameter is positive and statistically significant, Hypothesis 1 (H1) is rejected in favor of the null. The effect of the second treatment, *GT2*, captures the efficacy of government interventions to restore confidence in milk consumers. Its value represents the percentage of milk consumers that decreased milk purchases in *GT1* that would continue consuming their normal amount of milk if the intervention takes place. The coefficient value of the marginal effect of *GT2* is -0.053. The negative sign indicates that on average, 5.3% of the people responding negatively to *GT1* would restore their milk purchases to their pre-*GT1* level. This is equivalent to 1.04% of equilibrium quantity of the initial state (pre-treatment). Although the sign is what we would expect (-0.053), the results are not statistically significant at the 5% level. Our results cannot reject Hypothesis 2.

[2] Sensitivity for fecal culture test is 0.90 for clinically infected animals (Collins et al., 2006), and 0.50 for subclinically infected animals with MAP (Whitlock et al., 2000). Specificity of fecal culture test is 1 (Sweeney et al., 2014).

Table 1.
Logistic regression results of the DID effects and their marginal effects.

Variable	Log Odds Ratio	Marginal Effect
T1	-1.869***	-0.339***
	(0.207)	
GT1	1.085***	0.196***
	(0.233)	
T2	-1.046***	-0.189***
	(0.161)	
GT2	-0.291	-0.053
	(0.237)	

Standard errors in parenthesis. Significance: *** .01, ** .05, * .10. Marginal effects are estimated at mean values and represent changes in probability of decreasing milks purchases. *T1*, first treatment; *T2*, second treatment; *GT1*, treated on the first treatment; *GT2*, treated on the second treatment.

We estimated another logistic regression similar to that described in Table 1, but included demographic variables interacting with each of the treatment groups. The results are shown in Table 2.

Table 2.
Log-odds ratio and marginal effects of demographic variables for the treatment effects on the treated.

Variable	**Log Odds Ratio**	**Marginal Effect**
T1	-1.869***	-0.332
	(0.207)	
GT1	2.647***	0.470
	(0.552)	
GT1xMale	-1.019***	-0.181
	(0.246)	
GT1xAge	-0.020**	-0.004
	(0.009)	
GT1xHSchool	-0.233	-0.041
	(0.250)	
GT1xLowIncome	0.413*	0.073
	(0.236)	
GT1xYoung	-0.473*	-0.084
	(0.261)	
GT1xPCMilkCons	0.065	0.011
	(0.138)	
T2	-1.046***	-0.186
	(0.161)	
GT2	1.153	0.205
	(0.813)	
GT2xMale	-0.973**	-0.173
	(0.391)	
GT2xAge	-0.023	-0.004
	(0.014)	
GT2xHSchool	-0.062	-0.011
	(0.386)	
GT2xLowIncome	0.363	0.064
	(0.375)	
GT1xYoung	-0.570	-0.101
	(0.404)	
GT1xPCMilkCons	0.267	0.047
	(0.200)	

Standard errors in parenthesis. Significance: *** .01, ** .05, * .10. Marginal effects were estimated at the mean values and represent changes in probability of decreasing milks purchases. *T1*, first treatment; *T2*, second treatment; *GT1*, treated on the first treatment; *GT2*, treated on the second treatment. Interaction terms *Male*, indicator if male; *Age*, age in years; *HSchool*, maximum level of studies is high school or less; *LowIncome*, annual household income is $50,000 or less; *Young*, indicator if people age 18 or younger live in the household; *PCMilkCons*, per capita milk consumption, truncated at 4 gal/week.

Males are more likely to be unresponsive to treatment 1 than females. This is consistent with previous studies on risk attitudes **(**Tonsor et al., 2009**)**. Similarly, older people and people living in households with people age 18 and under, are also less likely to reduce milk purchases because of the MAP information on milk. Households with low income (≤ $50,000) are more likely to decrease milk purchases due to treatment 1. Demographic variables are less important for the second treatment. Only gender is statistically significant on responding to the second treatment (government controls to eliminate MAP from the milk supply). Males are more likely to restore their milk purchases once the control is in effect. Older people are also more likely to restore their milk purchases after treatment 2, however, the result is marginally significant. Milk consumption has no significant effect in either treatment.

4.3 Factors affecting the first treatment

The following sets of results are the effects of various factors on the likelihood of decreasing WTP milk from the first treatment on the treated. We tested the rest of the hypotheses by including the variables described in the hypotheses section in the logistic regression model that estimates the DID effects. For each hypothesis tested, the corresponding variables used to test that hypothesis were interacted with a treatment dummy on the treated. Each hypothesis was tested independently from the rest.

To test hypothesis 3, we included a variable that measures whether a person trusts news from newspapers, TV, radio, or internet. The value of the variable is 1 if the person trusts any of these information sources. Trust among these sources is highly correlated (> 0.8). An additional variable included trust of government. Both variables have negative marginal effects (-0.014 and -0.018, for trust of government and trust in news sources, respectively) but are not statistically significant (p-values > 0.64).

Hypothesis 4 tests the preference for milk production and the effect of decreasing WTP milk due to MAP information. We tested the preferences for locally produced milk and organic milk. Additionally, we tested if consumer's agreement that pasteurization is important to have healthy milk influences treatment 1. For each of these three statements, we created a binomial variable of value 1 if the individual strongly agrees or somewhat agrees to the following statements: I prefer milk from local farms, I prefer organic milk, pasteurization is important to have healthy milk.

Preference for milk from local farms does not have a significant effect in treatment 1. Knowing that pasteurization is important for healthy milk has a negative effect in treatment 1 (marginal effect -0.08, with a p-value of 0.10). These people are 8% more likely to continue drinking the same amount of milk despite the information of MAP in milk, than the people who do not think pasteurization is important for healthy milk. Consumers that prefer organic milk, however, are more likely to reduce purchases of milk because of the information on MAP in milk. These people are 25% more likely to reduce milk purchases due to the MAP information.

Hypothesis 5 tests the effect of the perception that foodborne epidemics are difficult to control in treatment 1. To measure that perception, we used the level of agreement to the following statements: The government can cope with a disease outbreak effectively, food borne epidemics requiring government intervention are increasing, a food borne epidemic requiring government intervention is difficult to control, food producers can cope with a disease outbreak effectively, and a food borne epidemic requiring government intervention would affect my food purchases. We also asked if they have experienced a food borne epidemic. Consumer risk perceptions on food has been found to depend on their personal and indirect food safety experiences (Tonsor et al., 2009). The correlation among these variables ranged from 0.21 to 0.62.

Believing that government and producers can cope with a food borne epidemic decreases the effect of treatment 1. Only the effect of believing that the government can cope with a food borne epidemic is significant; those responding positively to that question are 10% less likely to be affected by treatment 1 (p-value of 0.03), although they are still less likely to purchase milk. Believing that food borne epidemics are increasing, and that a food born epidemic would affect their purchases, have a positive effect in treatment 1. These variables correlate with 8% and 12% increase in probability of being affected by treatment 1. We tested if having experience an epidemic affects the reaction to treatment 1. We asked participants whether they experienced an epidemic, like the H1N1 epidemic, and found that experiencing an epidemic like the H1N1 does not have any effect in treatment 1.

Hypothesis 6 tests whether being familiar with Crohn's disease, or also if knowing a person affected by Crohn's disease, increases the probability of being affected by treatment 1. In our survey, no one answered that they were familiar with Crohn's disease before this survey, despite people answering that they know someone with Crohn's disease. Thus, we only tested the second statement, knowing a person affected by Crohn's disease. We found that people who know anyone who suffers from Crohn's disease are 7% less likely to be affected by treatment 1. That is, they are less likely of decreasing milk purchases due to MAP in milk.

A summary of the results of the hypotheses 3-6 (H3-H6) are shown in Table 3.

Table 3.
Marginal effects of the variables of the hypotheses tested for treatment 1.

H3		H4		H5		H6	
TrustGvmt	-0.015	*LocalFarm*	-0.042	*GvmtCope*	-0.108**	*KnowPat*	-0.076*
	(0.754)		(0.356)		(0.034)		(0.069)
TrustNews	-0.019	*Organic*	-0.083***	*ProdCope*	-0.031		
	(0.644)		(0.000)		(0.546)		
		Pasteur	0.288*	*FEpiIncr*	0.081*		
			(0.100)		(0.051)		
				FEpiDCont	0.028		
					(0.506)		
				FEpiAffPur	0.123**		
					(0.018)		
				FEpiExper	0.018		
					(0.714)		

Results are marginal effects of a logistic model. P-values in parenthesis. Significance: *** .01, ** .05, * .10. Marginal effects were estimated at the mean values and represent changes in probability of decreasing milk purchases due to treatment 1. The column names starting with an H refers to the hypothesis number. The variables of each model are described in the hypothesis section and the section above. *TrustGvmt*, trust the government; *TrustNews*, trust a news source (TV/Radio, newspaper, online news); *LocalFarm*, prefer products from local farms; Organic, prefer organic products; Pasteur, agree that pasteurization is important for healthy milk; *GvmtCope*, agree that government can cope effectively with a food borne epidemic; *ProdCope*, agree that food producers can cope effectively with a food borne epidemic; *FEpiIncr*, agree that food borne epidemics are increasing; *FEpiDCont*, agree that food borne epidemics are difficult to control; *FEpiAffPur*, agree that food borne epidemics may affect their food purchases; *FEpiExper*, have experience food borne epidemics in the past; *KnowPat*, know a person with Crohn's disease.

4.4 Factors affecting the second treatment

Hypotheses seven and eight (H7, H8) test various factors that may affect the likelihood that a person responds positively to government controls to eliminate MAP from the milk supply in the U.S. Similar to the hypotheses testing for the first treatment, the variables used to measure and test a hypothesis is interacted with the treatment effect on the treated for the second treatment. The results of testing H7 and H8 are shown in Table 4.

Hypothesis 7 states that trust in government (local government and Health Department) and dairy producers does not have an effect in treatment 2. The measure of local government trust is the same used in the hypothesis 3; trust in the Health Department and in dairy producers is measured in the same way from the survey response. We found that trust has no effect in returning to pre-MAP levels of milk purchases after government intervention. However, we found significant effects for not restoring milk purchases to original levels when individuals are self-described as liberals. They are 21% more likely, compared to the people that do not described themselves as either liberal or conservative, of not responding to the government interventions to eliminate MAP from the milk supply. Being self-described as conservative has no statistically significant effect.

Hypothesis 8 tests the effect of the perception that food borne epidemics are difficult to control. The result of this test was not statistically significant.

Table 4.
Marginal effects of the variables of the hypotheses tested for treatment 2.

H7		H8	
TrustGvmt	-0.027	*FEpiDiffContr*	-0.042
	(0.720)		(0.739)
TrustHealthD	0.0512		
	(0.511)		
TrustFarmers	-0.053		
	(0.525)		
Conservative	0.059		
	(0.443)		
Liberal	0.218***		
	(0.006)		

Results are marginal effects of a logistic model. P-values in parenthesis. Significance: *** .01, ** .05, * .10. Marginal effects were estimated at the mean values and represent changes in probability of decreasing milk purchases due to treatment 1. The column names, with prefix H, refers to the hypothesis number. The variables of each model are described in the hypothesis section and the previous section. *TrustGvmt*, trust in government; *TrustHealthD*, trust in the Health Department; *TrustFarmers*, trust in farmers; *Conservative*, identified as a conservative political ideologist; *Liberal*, identified as a liberal political ideologist. *FEpiDCont*, agree that food borne epidemics are difficult to control

4.5 Welfare effects

The welfare effects of the public response to the information about MAP in the milk supply and on the subsequent government control to eliminate MAP from the milk supply are presented in this section following a partial equilibrium model for the dairy market in the U.S.

Consumers who withdrew milk consumption due to the effect of MAP information may seek milk substitites, thus restoring some but not all of the consumer surplus, or they would consume the substitute over milk initially. Our analysis focuses on the losses in the dairy market alone, thus a partial equilibrium model is warranted.

This welfare analysis is divided in two parts. First, we estimated the change in consumer and producer surplus from the shift in demand of fluid milk caused by the first intervention. Fluid milk marketed is estimated to represent 23% of total milk marketed (USDA:ERS, 2020a). We calculated that 19.6% of consumers would stop consuming fluid milk after the first intervention. We found that widespread news of MAP in the milk supply decreases the equilibrium quantity of milk by 2.16% to 94.078 billion kg of milk. This shift in demand would decrease the average price of milk received by 4.07%, with the resulting equilibrium price of $0.387/ kg. Change in consumer surplus and producer surplus were estimated at -$1,403 million and -$1,562 million, respectively. Total welfare effect from the decrease in fluid milk demand was estimated at -$2,966 million.

The second part of the welfare analysis looks at the change in fluid milk demand resulting from the government control. The government control was modeled as a test and cull program for all dairy cows. We assumed that the government compensates farmers for every culled cow in the program. The culling of cows will decrease milk supply by an amount equals to the number of culled cows times the average milk production of a MAP infected cow. The MAP test and cull program was assumed to have a specificity of 1 (Verteramo Chiu et al., 2018), thus, no culling of healthy cows is expected. MAP elimination in a herd by test and cull controls is unfeasible. A reduction of MAP infected cows to 3% is possible with test and cull controls, and with this percentage of infected cows in a herd, the amount of MAP in the herd's milk tank becomes undetectable. Reducing the number of infected MAP cows from 12% to 3%, in a 9.34 million cow population requires testing all cows at a cost of $42 per cow and culling 840 thousand cows. The total cost of implementing the program was estimated at $897 million, out of which $392 million is the cost of testing for MAP and $504 million is the compensation given to producers for culling MAP positive cows. These costs are conservative since they do not include other costs like production loss and veterinary salaries, among others. The MAP control program is expected to reduce national milk supply by 10.6 billion kg, or 11% of the equilibrium quantity after the first intervention. This shifts the supply curve to the left, setting the new equilibrium price and quantity to $0.427/ kg and 88.6 billion kg, respectively. Changes in consumer and producer surpluses after the second intervention from the initial equilibrium state were estimated at -$4,942 million and -$4,998 million, respectively, with a total welfare change of -$9,940 million from the initial state. Summary of the welfare effects when only demand for milk is assumed to decrease are shown in Table A3 in the appendix.

Consumers who stated withdrawal from fluid milk consumption may also stop consuming dairy products in general for fear of infection, since consumers were informed that pasteurization does not eliminate MAP from milk. We thus calculated welfare changes if consumers who indicated they would cease consuming fluid milk would stop consuming all dairy products.

In this scenario, we estimated that demand curve for all marketed milk would shift to the left by 19.6% of consumption at the initial state. After the first intervention, the equilibrium price and quantity are estimated to decrease by 17.5% and 9.28%, respectively, with a welfare loss estimated at $12,278 million. After the second intervention, equilibrium price and quantity were 6.77% and 14.57%, respectively, lower than the initial case. Changes in consumer and producer surpluses after the second intervention from the initial equilibrium state were estimated at -$8,873 million and -$9,374 million, respectively, with a total welfare change of -$18,247 million from the initial state. Results are shown in Table 5.

Table 5.
Welfare effects of the interventions. Demand for all dairy products (fluid milk and processed milk products) are assumed to decrease in the same proportion as fluid milk.

	Initial state	First Intervention	Second Intervention
Equilibrium Price ($/kg)	0.403	0.333	0.376
Equilibrium Quantity (mill. kg)	96,155	87,237	82,147
Consumer Surplus[a]	32,845	27,035	23,972
Producer Surplus[a]	36,564	30,096	27,190
Welfare Change from Initial State[a]	-	-12,278	-18,247
Government Cost	-	-	897

[a] in millions of dollars. Price is at farmgate, quantity is total milk production. First intervention refers to the shift in demand of all marketed milk due to MAP information. Second intervention refers to the government program to control MAP and its effect in partially restoring lost demand. Producer surplus in the second intervention includes a $504 million transfer to producers as part of the government control program. Government cost is the cost of implementing the control program: testing costs plus transfer to producers.

A sensitivity analysis of the results is presented in the appendix.

4.6 Limitations of the study

This study has several limitations. The data were obtained from an online survey distributed to a random sample of the U.S. population. This sample, although demographically similar to that of the U.S. population, may not be representative. The people sampled in this survey are part of a list of survey takers of Qualtrics, which may result in selection bias. Realistically, it is difficult to eliminate this potential problem from mail or online surveys. Second, in all surveys it is difficult to assess the veracity of the answers, which may not reflect participants' actual behaviors. We included several questions in the survey aimed at filtering out nonsensical responses, including a filter that discards surveys that took a very short time to complete. These filters and quality checks resulted in 23% of the responses meeting the quality standards, the rest were discarded.

5 Conclusion

We estimated the welfare effects of a food shock in the U.S. milk market caused by dissemination of information on *Mycobacterium avium sub. paratuberculosis* (MAP) present in the milk supply and its presumed association with Crohn's disease in humans. We surveyed, via the online survey platform Qualtrics, 604 regular milk drinkers above 21 years old that participate in their households' milk purchase decision. We did a difference-in-difference analysis of the effects of willingness to purchase milk on the information of MAP in the milk supply, as well as of the effect of a government program to eliminate MAP from the milk supply.

Our results show that about 19.6% (p-value < 0.001) of the people exposed to the MAP information would stop purchasing fluid milk at current market prices, and that 5% (p-value < 0.21) of those people would return to their initial milk purchasing levels under a government control to eliminate MAP from the milk supply.

The decrease in consumer and producer welfare caused by the food shock affecting all milk demand (fluid and processed milk) and the subsequent government control program was estimated to be $18.247 billion. The MAP control program cost was estimated at $897 million. However, if the food shock only affects the fluid milk market, the welfare cost was estimated at $9.94 billion. Under the scenario of a more elastic demand and supply of milk, welfare losses were considerable smaller at $8,760 and $5,233, when the food shock affects all dairy products demand and fluid milk only, respectively. Welfare losses can represent a substantial share of the market value of milk production in the U.S., estimated at $38.7 billion. Welfare losses to a potential MAP food scare can be substantial.

We analyzed factors that may affect consumer response to the food shock and to the control program. We found that males and younger consumers are less likely to reduce milk purchases due to a food shock of MAP in milk; but low-income consumers are more likely to reduce milk purchases. However, from those who decrease milk purchases due to the information about MAP in milk, males are more likely to restore their initial milk purchases after a government control program to eliminate MAP in the milk supply is in effect.

Consumers that believe the government can cope with a food-borne epidemic effectively are less likely to respond negatively to a food shock, but consumers that believe food-borne epidemics are increasing are more likely to decrease purchases of milk due to MAP information. Consumers that prefer organic milk are less likely to reduce their milk purchases from a food shock. The same is true for people that know someone who has Crohn’s disease: they will not reduce their milk purchases compared to someone that doesn’t know anyone with Crohn’s disease.

People who described themselves as liberals are more likely to not respond positively to a government MAP elimination program. Their milk purchasing levels would not return to their initial levels despite MAP being eliminated from the milk supply.

This study shows that consumers may reduce their consumption levels of a food when information on a potential pathogen present in the food is disseminated, even though it is explicit that there is no scientific evidence that the pathogen can affect humans. We also found that government responses to a food born epidemic may not be effective in restoring consumption to pre-epidemic levels, at least in the short run.

Acknowledgements

This work was funded by USDA-NIFA AFRI grant # 2014-67015-2240 and BBSRC award # BB/M01262X/1 as part of the joint USDA-NSF-NIH-BBSRC-BSF Ecology and Evolution of Infectious Diseases program.

The authors thank Harry M. Kaiser for his comments on the experimental design.

References

Andreyeva, T., Long, M. W., and Brownell, K. D. (2010). The impact of food prices on consumption: A systematic review of research on the price elasticity of demand for food. *American Journal of Public Health*, **100**(2): 216–222.

Ayele, W. Y., Svastova, P., Roubal, P., Bartos, M., and Pavlik, I. (2005). Mycobacterium avium Subspecies paratuberculosis Cultured from Locally and Commercially Pasteurized Cow’s Milk in the Czech Republic. *Applied and Environmental Microbiology*, **71**(3): 1210–1214.

Beaver, A., Sweeney, R. W., Hovingh, E., Wolfgang, D. R., Gröhn, Y. T., and Schukken, Y. H. (2017). Longitudinal relationship between fecal culture, fecal quantitative PCR, and milk ELISA in Mycobacterium avium ssp. paratuberculosis-infected cows from low-prevalence dairy herds. *Journal of Dairy Science*, **100(**9): 7507–7521.

Bognár, B., Farkas, K., Fornyos, K., Zrufkó, R., Baumgartner, W., Khol, J. L., and Jurkovich, V. (2019). Possible Association between Paratuberculosis in Cattle and Crohn’s Disease A Literature Review. *Magyar Allatorvosok Lapja*, **141**(11):659-675.

Botsaris, G., Swift, B. M. C., Slana, I., Liapi, M., Christodoulou, M., Hatzitofi, M., Christodoulou, V., and Rees, C. E. D. (2016). Detection of viable Mycobacterium avium subspecies paratuberculosis in powdered infant formula by phage-PCR and confirmed by culture. *International Journal of Food Microbiology*, **216**: 91–94.

Bozic, M., Kanter, C. A., and Gould, B. W. (2012). Tracing the evolution of the aggregate U.S. milk supply elasticity using a herd dynamics model. *Agricultural Economics*, **43**(5): 515–530.

Center for Disease Control and Prevention (2018). *Estimates of Foodborne Illness in the United States*. Retrieved November 8, 2018, from https://www.cdc.gov/foodborneburden/index.html.

Chiodini, R. J., Hermon-Taylor, J. (1993). The thermal resistance of Mycobacterium paratuberculosis in raw milk under conditions simulating pasteurization. *Journal of Veterinary Diagnostic Investigation,* **5**:629-631.

Collins, M. T., Gardner, I. A., Garry, F. B., Roussel, A. J., and Wells, S. J. (2006). Consensus recommendations on diagnostic testing for the detection of paratuberculosis in cattle in the United States. *Journal of the American Veterinary Medical Association*, **229**(12): 1912–1919.

Dancey, L., Goren, P. (2010). Party Identification, Issue Attitudes, and the Dynamics of Political Debate. *American Journal of Political Science*, **54**(3): 686–699.

Donaghy, J. A., Totton, N. L., and Rowe, M. T. (2004). Persistence of Mycobacterium paratuberculosis during Manufacture and Ripening of Cheddar Cheese. *Applied and Environmental Microbiology*, **70**(8): 4899–4905.

Druckman, J. N., Peterson, E., and Slothuus, R. (2013). How Elite Partisan Polarization Affects Public Opinion Formation. *American Political Science Review*, **107**(01): 57–79.

Ellingson, J. L. E., Anderson, J. L., Koziczkowski, J. J., Radcliff, R. P., Sloan, S. J., Allen, S. E., and Sullivan, N. M. (2005). Detection of Viable Mycobacterium avium subsp. paratuberculosis in Retail Pasteurized Whole Milk by Two Culture Methods and PCR. *Journal of Food Protection*, **68**(5): 966–972.

Feller, M., Huwiler, K., Stephan, R., Altpeter, E., Shang, A., Furrer, H., Pfyffer, G. E., Jemmi, T.,Baumgartner, A., and Egger, M. (2007). Mycobacterium avium subspecies paratuberculosis and Crohn's disease: a systematic review and meta-analysis. *The Lancet Infectious Diseases*, **7**(9): 607–613.

Grant, I. R., Ball, H. J., and Rowe, M. T. (2002). Incidence of Mycobacterium paratuberculosis in Bulk Raw and Commercially Pasteurized Cows' Milk from Approved Dairy Processing Establishments in the United Kingdom. *Applied and Environmental Microbiology*, **68**(5): 2428–2435.

Jayarao, B. M., Pillai, S. R., Wolfgang, D. R., Griswold, D. R., Rossiter, C. A., Tewari, D., Burns, C. M., and Hutchinson, L. J. (2004). Evaluation of IS900-PCR Assay for Detection of Mycobacterium avium Subspecies Paratuberculosis Infection in Cattle Using Quarter Milk and Bulk Tank Milk Samples. *Foodborne Pathogens and Disease*, **1**(1): 17–26.

Kaiser, H. M., Scherer, C. W., and Barbano, D. M. (1992). Consumer perceptions and attitudes towards bovine somatotropin. *Northeastern Journal of Agricultural and Resource Economics*, **21**(1): 10–20.

Khol, J., Wassertheurer, M., Sodoma, E., Revilla-Fernández, S., Damoser, J., Österreicher, E., Dünser, M., Kleb, U., and Baumgartner, W. (2013). Long-term detection of Mycobacterium avium subspecies paratuberculosis in individual and bulk tank milk from a dairy herd with a low prevalence of Johnes disease. *Journal of Dairy Science*, **96**: 3517–3524.

Lavine, H., Johnston, C., and Steenbergen, M. (2012). *The ambivalent partisan: How critical loyalty promotes democracy*. Oxford University Press, New York.

Lhermie, G., Tauer, L. W., and Gröhn, Y. T. (2018). An assessment of the economic costs to the U.S. dairy market of antimicrobial use restrictions. *Preventive Veterinary Medicine*, **160**: 63–67.

Lobb, A. E., Mazzocchi, M., and Traill, W. B. (2007). Modelling risk perception and trust in food safety information within the theory of planned behaviour. *Food Quality and Preference*, **18**(2): 384–395.

Lu, Z., Schukken, Y. H., Smith, R. L., and Grohn, Y. T. (2010). Stochastic simulations of a multi-group compartmental model for Johne's disease on US dairy herds with test-based culling intervention. *Journal of Theoretical Biology*, **264**(4): 1190–1201.

Mazzocchi, M., Lobb, A., Bruce Traill, W., and Cavicchi, A. (2008). Food Scares and Trust: A European Study. *Journal of Agricultural Economics*, **59**(1): 2–24.

McCluskey, J. J., Grimsrud, K. M., Ouchi, H., and Wahl, T. I. (2005). Bovine spongiform encephalopathy in Japan: consumers' food safety perceptions and willingness to pay for tested beef. *The Australian Journal of Agricultural and Resource Economics*, **49**(2): 197–209.

Millar, D., Ford, J., Sanderson, J., Withey, S., Tizard, M., Doran, T., and Hermon-Taylor, J. (1996). IS900 PCR to detect Mycobacterium paratuberculosis in retail supplies of whole pasteurized cows' milk in England and Wales. *Applied and Environmental Microbiology*, **62**(9): 3446–3452.

Mitchell, R. M., Whitlock, R. H., Stehman, S. M., Benedictus, A., Chapagain, P. P., Grohn, Y. T., and Schukken, Y. H. (2008). Simulation modeling to evaluate the persistence of Mycobacterium avium subsp. paratuberculosis (MAP) on commercial dairy farms in the United States. *Preventive Veterinary Medicine*, **83**(3–4): 360–380.

O'Reilly, C. E., O'Connor, L., Anderson, W., Harvey, P., Grant, I. R., Donaghy, J., Rowe, Michael., and O'Mahony, P. (2004). Surveillance of bulk raw and commercially pasteurized cows' milk from approved Irish liquid-milk pasteurization plants to determine the incidence of Mycobacterium paratuberculosis. *Applied and Environmental Microbiology*, **70**(9): 5138– 5144.

Paolicchi, F., Cirone, K., Morsella, C., and Gioffré, A. (2012). First isolation of Mycobacterium avium subsp Paratuberculosis from commercial pasteurized milk in Argentina. *Brazilian Journal of Microbiology*, **43(**3): 1034–1037.

Piggott, N. E., Marsh, T. L. (2004). Does Food Safety Information Impact U.S. Meat Demand? *American Journal of Agricultural Economics*, **86**(1):154–174.

Powell, D. (2001). Mad Cow Disease and the Stigmatization of British Beef. In P. Slovic, J. Flynn, and H. Kunreuther (Eds.), *Risk, media, and stigma: Understanding public challenges to modern science and technology,* 1st ed. 416.

Smith, R. L., Al-Mamun, M. A. A., and Gröhn, Y. T. (2017). Economic consequences of paratuberculosis control in dairy cattle: A stochastic modeling study. *Preventive Veterinary Medicine*, **138**(2017): 17–27.

Smith, R. L., Gröhn, Y. T., Pradhan, A. K., Whitlock, R. H., Kessel, J. S. Van, Smith, J. M., Wolfgang, D.R., and Van Kessel, J. S. (2016). The effects of progressing and nonprogressing Mycobacterium avium ssp. paratuberculosis infection on milk production in dairy cows. *Journal of Dairy Science*, **99**: 1383–1390.

Smith, A.P., Young, J.A. and Gibson, J., (1999). How now, mad-cow? Consumer confidence and source credibility during the 1996 BSE scare. *European Journal of Marketing*, **33**: 1107-1122.

Sweeney, R. W., Gardner, I. A., Hines, M. E. I., Anderson, R., Byrem, T. M., Collins, M. T., and Whitlock, R. H. (2014). Comparison of 3 fecal culture, 2 fecal PCR, 2 serum ELISA, and milk ELISA for diagnosis of paratuberculosis in US dairy cattle. In *12th International Colloquium on Paratuberculosis*. Parma, Italy.

Tonsor, G. T., Schroeder, T. C., and Pennings, J. M. E. (2009). Factors Impacting Food Safety Risk Perceptions. *Journal of Agricultural Economics*, **60**(3): 625–644.

USDA:APHIS:VS. (2008). Johne's Disease on U.S. Dairies, 1991-2007, *NAHMS Dairy 2007 study*, Center for Animal Health Monitoring.

USDA:ERS. (2020a). Dairy Data. *Supply and allocation of milk fat and skim solids by product*. Retrieved February 4, 2020, from https://www.ers.usda.gov/data-products/dairy-data/.

USDA:ERS. (2020b). Dairy Data. *Milk cows and production by State and region (Annual).* Retrieved Retrieved February 4, 2020, from https://www.ers.usda.gov/data-products/dairy-data.

USDA:NASS. (2020) *Quick Stats*. Retrieved February 4, 2020, from https://quickstats.nass.usda.gov.

USDA:NASS. (2017). *Agricultural Prices*. Available at: http://usda.mannlib.cornell.edu/usda/nass/AgriPric//-2010s/2017/AgriPric-03-30-2017.pdf.

Verteramo Chiu, L. J., Tauer, L. W., Al-Mamun, M. A., Kaniyamattam, K., Smith, R. L., and Grohn, Y. T. (2018). An agent-based model evaluation of economic control strategies for paratuberculosis in a dairy herd. *Journal of Dairy Science*, **101**(7): 6443–6454.

Whitlock, R., Wells, S., Sweeney, R., and Van Tiem, J. (2000). ELISA and fecal culture for paratuberculosis (Johne's disease): sensitivity and specificity of each method. *Veterinary Microbiology*, **77**(3): 387–398.

WHO. (2017). *The burden of foodborne diseases in the WHO European Region*. World Health Organization.

Zhou, L., Turvey, C. G., Hu, W., and Ying, R. (2016). Fear and trust: How risk perceptions of avian influenza affect Chinese consumers' demand for chicken. *China Economic Review*, **40**: 91-104.

Appendix

1 Survey questions

Two WTP questions are asked, one after each intervention. The information on the first intervention (I_1) was identical for the TC and TT groups, but different for the CC group. For I_1, the information for all groups is shown next[3].

Control (CC) and Treatment (TC, TT)
The average cow in the U.S. produces about 23,000 lbs of milk per lactation (milk producing period). Lactation occurs after a cow gives birth to a calf, and lasts about 305 days. The gestation period of a cow is 9 months. Dairy cows can weigh about 1,500 pounds. There are many dairy breeds in the U.S., but Holstein cows make about 90% of all dairy cows.

The following information was shown to the treatment group for I_1.

Treatment (TC, TT)
MAP (Mycobacterium avium subs. paratuberculosis) is a bacteria that causes a **non-treatable disease in ruminants (cows)** that affects their lower intestines, resulting in **weight and milk production loss and eventually death**. **A similar disease in humans is called Crohn's disease**. According to the Mayo Clinic: "**Crohn's disease** is an inflammatory bowel disease. It **causes inflammation of your digestive tract**, which can lead to **abdominal pain, severe diarrhea, fatigue, weight loss and malnutrition**. The inflammation caused by Crohn's disease often spreads deep into the layers of affected bowel tissue. **Crohn's disease** can be both **painful and debilitating**, and sometimes may lead to **life-threatening complications**." Currently, **there is no cure for Crohn's disease**. Although some **studies suggest a relationship between MAP and Crohn's** disease through **milk contaminated with MAP**, this relationship **has not been proven**. It is estimated that **5% of the cows** in the U.S. are infected with MAP, and about **30% of the milk sold in the U.S. (of all varieties) contains MAP**. **Pasteurization may not eliminate MAP from milk.**

[3] The information was shown to U.S. milk consumers; thus, it is shown in pounds. Average milk production per cow in the U.S. is about 10,430 kg per lactation. Dairy cows can weigh about 680 kg.

The information shown on the second intervention (**I_2**) was the same for the CC and TC groups, but different for the TT group. For I_2, the following information was shown to all groups.

Control (CC, TC) and Treatment (TT)
The top five milk producing states are: California, Wisconsin, Idaho, New York, and Texas. Together they account for over 50% of the total U.S. milk production. Most milk produced in the U.S. comes from commercial farms, following USDA's strict regulations.

The following information was shown for the treatment group for I_2.

Treatment (TT)
If a link between MAP and Crohn's disease is established, the **government** can establish procedures to **reduce MAP-contaminated milk in the food supply**. These actions include better and more frequent testing of farms, dairy animals, milk tanks, and processing facilities. MAP-positive animals can be identified and culled, and the infected **farms are monitored until no MAP is found on those farms**. The government would assure that **under these procedures**, the risk of drinking MAP-contaminated milk and **getting Crohn's disease is highly unlikely**. Health agencies and non-government organizations support these claims.

In all three survey versions, after the information corresponding to each group was presented, the following question on willingness to purchase milk was asked.

After reading the previous information, would you **continue** to buy **or reduce** your purchases of the **milk of your choice** (**cow's milk** of any fat content, including lactose free and flavored milk) that is normally consumed in your household **at current prices**?

Important information was shown in bold.

2 Econometric model

Data are organized in two repeated cross sections, one observation for each intervention. Since the dependent value is (1, 0), the DID effects are estimated using a logit model. The probability of observing a decrease in WTP after each intervention is,

$$P_{i,j} = E\left(WTP_{i,j} = 1 \middle| I_{i,j}, G_{i,j}\right) = \frac{1}{1+e^{-[\beta_0 I1_i + \beta_1 (I1_i * G1_i) + \beta_2 I2_i + \beta_3 (I2_i * I2_i)]}} \quad (1)$$

Where P_i is the probability that individual i chooses to decrease milk purchases conditional on being in intervention I_j and group G_j, j= 1, 2. In equation (1), $G1$ and $G2$ are two vectors indicating if an individual i is part of the treatment group of the first and second intervention, respectively. The groups in the first treatment are TT and TC, while the group in the second treatment is TT. I_1 and I_2 are indicator vectors for the first and second treatment, respectively.

Similarly, the probability of not decreasing WTP is 1 = $P_{i,j}$ with odds ratio

$$\frac{P_{i,j}}{1-P_{i,j}} = e^{[\beta_0 I1_i I \beta_1 (I1_i * G1_i) + \beta_2 I2_i + \beta_3 (I2_i * G2_i)]}.$$

The natural log of the odds ratio results in the logit model

$$\ln\left(\frac{P_{i,j}}{1-P_{i,j}}\right) = \beta_0 I1_i + \beta_1(I1_i * G1_i) + \beta_2 I2_i + \beta_3(I2_i * G2_i) + \varepsilon_i \quad (2)$$

The output, $\ln\left(\frac{P_{i,j}}{1-P_{i,j}}\right)$, is the log of the odds ratio, and ε_i is the error term vector distributed $N\sim(0,\sigma^2)$. The coefficients to estimate are the βs, which change the log odds ratio. The effect of the first and second treatment are β_1 and β_3, respectively.

The coefficient β_0 measures the change in output of the control group at the first intervention,
$\beta_0 = (WTP \mid I1 = 1, I2 = 0, G1 = 0, G2 = 0)$.
β_1 measures the change in output of the treatment group at the first intervention,
$\beta_1 = (WTP \mid I1 = 1, I2 = 0, G1 = 1, G2 = 0)$.
β_2 measures the change in output for the control group at the second intervention, T2.
$\beta_2 = (WTP \mid I1 = 0, I2 = 1, G1 = 0, G2 = 0)$.
β_3 measures the change in output of the treatment group at the second intervention,
$\beta_3 = (WTP \mid I1 = 0, I2 = 1, G1 = 0, G2 = 1)$.
The hypotheses H_0: β_1 = 0 and H_0: β_3 = 0, capture the effect of the first and second treatments, respectively.

The next step in our analysis was to estimate the effects of factors affecting the conditional probability of changes in WTP milk for each of the treated groups ($G1$ and $G2$) at each treatment ($I1$ and $I2$). Similar to (1), we include matrices of covariates, X_i and Z_i, interacting with each of the interactions of $(I1 * G1)$ and $(I2 * G2)$, respectively. Matrices X_i and Z_i are not identical, they include specific variables that were tested for each treatment effect on the treated. The variables included in each matrix were based on hypotheses described in another section. Description of the variables of each matrix is shown in Table A2. The conditional probability of reducing WTP milk conditional on the covariates for each treatment is

$$P_{i,j} = E(Y_i = 1 | X_i, Z_i, I_{j,i}, G_{j,i}) = \frac{1}{1+e^{-(\beta_0 I1_i + \beta_1(I1_i * G1_i) + \beta_2 I2_i + \beta_3(I2_i * G2_i) + (I1_i * G1_i)X_i\gamma + (I2_i * G2_i)Z_i\delta)}} \quad (3)$$

The resulting logit model is

$$\ln\left(\frac{P_{i,j}}{1-P_{i,j}}\right) = \beta_0 I1_i + \beta_1(I1_i * G1_i) + \beta_2 I2_i + \beta_3(I2_i * G2_i) + (I1_i * G1_i)X_i\gamma + (I2_i * G2_i)Z_i\delta \quad (4)$$

The effects of the covariates in X_i and Z_i were estimated by the vectors of coefficients γ and δ, respectively.

3 Hypotheses

This section lists the hypotheses tested in our study. Hypotheses *H1* and *H2* were tested from the DID regression (1). Hypotheses *H3* through *H9* were tested from equation (3). The variables used to test the hypotheses were obtained from the survey. Some of these variables are the result of the level of agreement with certain statements. Responses were given over a Likert-type scale, where the values ranged from 1 to 5, indicating level of agreement with the statement.

H1: milk consumers exposed to information on MAP in the milk supply and the current understanding of its association with Crohn's disease will not change their willingness to purchase milk.

One of the main hypotheses to test is whether information on MAP in the milk supply changes consumers' WTP milk. The information on MAP and Crohn's disease may trigger fear on consumers, potentially creating a food shock. Consumers may be unwilling to take the risk of drinking MAP contaminated milk. This is captured by the parameter β_1. We expect the value of β_1 to be positive.

H2: milk consumers that decrease their willingness to purchase milk due to treatment 1 (information on MAP in the milk supply) will not increase their willingness to purchase milk after exposed to information on policies that minimize the risk of MAP in milk.

During a food shock caused by information on MAP in the milk supply, the government may enforce policies aimed at minimizing MAP in the milk supply chain, and potentially eliminating MAP from the milk supply chain, to restore consumers' confidence. The effect of these policies on changes in consumers' WTP milk is captured by the parameter β_3. If the policy is deemed as sufficient to reduce the risk of MAP contamination, consumers may increase their WTP milk. We expect the value of β_3 to be negative.

The following hypotheses *H3-H6* are estimated for intervention 1 (I_1).

H3: trust in mass media or the government is not correlated with the probability of decreasing milk purchase intent due to MAP information.

Information on MAP through mass media, or any information source, may have a lower effect in decreasing WTP milk if consumers have little trust in the source of information. Skeptical consumers may underestimate the degree of urgency that media conveys. This hypothesis was tested with the variable *TrustNews*. This variable includes responses to trust of newspapers, TV/radio, and internet sources. To test the effect of trust on government information alone we used the variable *TrustGvmt*, which does not include the variables in *TrustNews.* The value of these variables are 0 and 1, where 1 indicates trust in the information source and is recorded when the individual states that they trust an information source included in the variable completely or somewhat. We expect a positive effect of these variables.

H4: preference for milk production processes is not correlated with the probability of decreasing milk purchase intent due to MAP information.

Consumers that care about how the milk they drink is produced may pay more attention to the information related to milk process, and thus may be more responsive to the MAP information in milk. We used the responses on agreement of three statements on preference in milk production: local milk, organic milk, and knowing that pasteurization is important for healthy milk. These results were captured by the binary variables *LocalFarm*, *Organic*, and *Paster*, respectively. We expect the coefficient of these variables to be positive. The correlation among these variables was 0.26 for *Organic* and *LocalFarm*, 0.17 for *Paster* and *LocalFarm*, and -0.02 for *Paster* and *Organic*.

H5: perception that food borne epidemics are increasing and difficult to control is not correlated to the probability of decreasing milk purchase intent due to MAP information.

Knowing that MAP is prevalent in the milk supply may lead people to anticipate a food borne epidemic requiring intervention. People that believe this type of epidemic is increasing and difficult to control may be more likely to respond to MAP information by decreasing purchase intent. The variables *FEpiIncr*, *FEpiDCont*, *FEpiAffPur*, indicate agreement that food borne epidemics are increasing, are difficult to control, and can affect their food purchases. The variable *FEpiExper* indicates if an individual has experienced food borne epidemics before. We expect the coefficient of these variables to be positive. The variables *GvmtCope* and *ProdCope*, indicate whether individuals trust that government or milk producers can cope with a food borne epidemic effectively. We expect the coefficient of these variables to be negative. All variables take value 1 or 0 if they agree to the statement or not.

H6: familiarity with Crohn's disease is not correlated with the probability of decreasing milk purchase intent due to MAP information.

The information on MAP in the milk supply also states the potential association with Crohn's disease, although non-confirmed by the scientific community. People that are familiar with Crohn's disease are believed to be more likely to react to MAP information because they may know that this disease is non-curable and potentially fatal. We included a question that ask if an individual knows anyone with Crohn's disease, the response is captured in the variable *KnowPat*. We expect this coefficient to be positive.

The following hypotheses were estimated for intervention 2 (I_2).

H7: trust in government and in dairy farmers is not correlated with the probability of increasing milk consumption due to information on the MAP elimination policy.

The perception of the success of government's policies to eliminate a national food borne epidemic are important in restoring confidence. People who have trust in the government may be more likely to increase their WTP milk after a government intervention than people who do not trust the government. This is captured in the variables *TrustGvmt* and *TrustHealthD* (trust in the Health Department). We expect parameters on these coefficients to be positive. Similarly, the success of a MAP elimination policy may be perceived as how much dairy farmers contribute to solve this problem. Dairy farmers contribute directly in eliminating MAP from the milk supply. Trust in dairy farmers may cause consumers to increase milk purchases after an eradication policy. This was tested with the variable *TrustFarmers*, which asks the level of trust in dairy farmers. We expected this coefficient to be positive. In addition, political ideology may also affect the perception of benefits of government programs; especially if the ruling government is of a different ideology. This is consistent with partisan identity, where individuals may adjust their opinions to be consistent, and loyal, with that of the party they are affiliated (Dancey and Goren, 2010; Druckman et al., 2013; Lavine et al., 2012). The variables *Conservative* and *Liberal* are dummy variables that indicate political ideology, or affiliation. We expect that people with ideologies similar to that of the current government to be more likely to trust government policies.

H8: perception that food borne epidemics are difficult to control is not correlated to the probability of increasing milk consumption due to information on the MAP elimination policy.

The perception that food borne epidemics are difficult to control is hypothesized to be negatively related to increasing milk purchases after a MAP elimination policy. This factor was measured by the variable *FEpiDiffContr* which is the belief that food borne epidemics are difficult to control. The variable takes value 1 if the feeling is that these epidemics are difficult to control, and 0 otherwise. We expect the coefficient of this variable to be positive.

4 Tables

Table A1.
Parameter values used in the welfare analysis

Parameter	Description	Value	Source
E_D	Demand elasticity of milk	-0.59	Andreyeva et al. (2010)
E_S	Supply elasticity of milk	0.53	Bozic et al. (2012)
α_D	Intercept of demand function	152,887	Estimated
α_S	Intercept of supply function	45,192	Estimated
β_D	Slope of demand function	-140,747	Estimated
β_S	Slope of supply function	126,433	Estimated
Q_0	Milk production (million kg)	96,155	USDA:ERS (2020a)
P_0	Milk price ($/kg)	0.403	USDA:NASS (2020)
-	Milk production per cow/year (kg)	10,295	USDA:ERS (2020b)
-	Milk production per infected cow/year (kg)	9,420	Estimated from Smith et al., (2016)
-	Number of dairy cows in the U.S. (million)	9.34	USDA:ERS (2020b)
-	Culled price of MAP infected cow ($)	600	USDA:NASS (2017)
-	Cost of MAP tests ($ per cow)	42	Verteramo Chiu et al. (2018)

Changes in consumer surplus were calculated by the inverse demand function, $P_D = \frac{\alpha_D}{\beta_D} + \beta_D Q_D$, and for supply as $P_S = \frac{\alpha_S}{\beta_S} + \beta_S Q_S$. The change in consumer surplus is $\Delta CS = CS_1 - CS_0$, where the consumer surplus is $CS = \frac{Q^*}{2}(-\frac{\alpha_D}{\beta_D} - P^*)$. Similarly, the change in producer surplus is $\Delta PS = PS_1 - PS_0$. The producer surplus is $PS = \frac{Q^*}{2}(P^* - \frac{\alpha_S}{\beta_S})$. Total welfare change is $\Delta W = \Delta CS + \Delta PS$.

Table A2.
Demographic Characteristics of Survey Participants and National Average for Comparison.

Variable	CC	TC	TT	All Groups	National Average*
Observations	202	200	202	604	N/A
Male (%)	0.26	0.64	0.61	0.50	0.50
Age (years, mean)	41	46	46	44	35[a]
Education (%)					
High School or Less	0.38	0.30	0.35	0.34	0.56[b]
Associate Degree	0.19	0.18	0.18	0.18	0.10
Undergraduate Degree	0.26	0.35	0.31	0.31	0.21
Postgraduate Degree	0.17	0.17	0.16	0.17	0.13
Household Income (%)					
< $25k	0.20	0.15	0.16	0.17	0.18
$25-$50k	0.19	0.25	0.22	0.22	0.22
$50-$75k	0.14	0.22	0.21	0.19	0.19
$75-$100k	0.07	0.15	0.16	0.13	0.14
$100-$150k	0.18	0.13	0.15	0.15	0.15
> $150k	0.20	0.08	0.09	0.13	0.12
Race (%)					
Non-Hispanic White	0.43	0.73	0.72	0.63	0.60
Hispanic	0.27	0.11	0.13	0.17	0.18
Asian	0.05	0.06	0.05	0.05	0.06
Non-Hispanic Black	0.21	0.09	0.09	0.13	0.13
American Indian or Alaskan	0.02	0.00	0.00	0.01	0.01
Other	0.01	0.00	0.00	0.01	0.02
Political Affiliation (%)					
Conservative	0.27	0.35	0.33	0.32	0.36
Liberal	0.28	0.24	0.20	0.24	0.25
Middle-of-the-road	0.38	0.37	0.44	0.40	N/A
Other	0.07	0.03	0.03	0.05	N/A

Values as proportion of the group or population. * United States Census Bureau. [a] median age. [b] includes some college education but no college degree. N/A, not applicable.

Table A3.
Welfare effects of the interventions when only demand for fluid milk is assumed to decrease.

	Initial state	First Intervention	Second Intervention
Equilibrium Price ($/kg)	0.403	0.387	0.427
Equilibrium Quantity (mill. kg)	96,155	94,078	88,626
Consumer Surplus[a]	32,845	31,442	27,903
Producer Surplus[a]	36,564	35,002	31,566
Welfare Change from Initial State[a]	-	-2,966	-9,940
Government Cost	-	-	897

[a] in millions of dollars. Price is at farmgate, quantity is total milk production. First intervention refers to the shift in demand of fluid milk due to MAP information. Second intervention refers to the government program to control MAP and its effect in partially restoring lost demand. Producer surplus in the second intervention includes a $504 million transfer to producers as part of the government control program. Government cost is the cost of implementing the control program: testing costs plus transfer to producers.

5 Sensitivity analysis

We further estimated the welfare effects under a set of supply and demand elasticities that are more elastic than the previous results. Also, the effect of the government program in milk supply depends on the elimination time of the program. When the effects of a program are expected over a longer term, the shape of the supply and demand curves should reflect that time horizon (Just, Hueth, and Schmitz, 1982). We estimated the welfare changes after the both interventions for changes in fluid milk demand as well as for changes in all marketed milk. We used the more elastic demand and supply elasticities values of -1.39 (Davis et al., 2012) and 0.89 (Bozic et al., 2012), respectively. In the initial case, equilibrium price and quantity remain the same as in the previous analysis ($0.403/ kg and 96,155 million kg), but the initial consumer and producer surplus are now $13,942 million and $21,774 million, respectively. The results of changes in demand for fluid milk only and for all dairy products under larger elasticity values are shown in Table A4.

Table A4.
Welfare effects of the interventions for decrease in demand for fluid milk and all dairy products, under larger elasticity values.

	Fluid Milk Only		All Dairy Products	
	First Intervention	Second Intervention	First Intervention	Second Intervention
Equilibrium Price ($/kg)	0.395	0.415	0.368	0.390
Equilibrium Quantity (mill. kg)	94,442	88,095	88,798	82,751
Consumer Surplus[a]	13,449	11,702	11,890	10,325
Producer Surplus[a]	21,005	18,781	18,570	16,630
Welfare Change from Initial State[a]	-1,261	-5,233	-5,256	-8,760

[a] in millions of dollars. Price is at farmgate, quantity is total milk production. First intervention refers to the shift in demand of milk, as described in the column, due to MAP information. Second intervention refers to the government program to control MAP and its effect in partially restoring lost demand. Producer surplus in the second intervention includes a $504 million transfer to producers as part of the government control program. The cost of implementing the control program is $897 million.

The welfare losses under the scenario of larger demand and supply elasticity are significantly lower than the baseline scenario. This is expected since larger elasticities implies that consumers and producers are better able to accommodate the effect of price changes with substitutes in consumption and technologies. This may also occur when looking at market response in the long run.