Scenario Analysis of Changes in Consumption of Dairy Products Caused by a Hypothetical Causal Link Between *Mycobacterium avium* subspecies *paratuberculosis* and Crohn's Disease

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ABSTRACT

Johne's disease is an infectious disease of cattle caused by *Mycobacterium avium* subspecies *paratuberculosis* (MAP). Crohn's disease (CD) is a human disease of unknown etiology that is characterized by chronic bowel inflammation. No causal link has been scientifically established between MAP and CD, but it is important to understand possible impacts on society should such a causal link be established. The goal of this paper is to analyze the implications and the possible economic impacts that finding such a link would have on milk demand in the dairy industry and to provide a framework for further discussion among stakeholders. Three scenarios were developed based on the effectiveness of possible risk-mitigation strategies. In the first scenario, it was assumed that an effective strategy exists; therefore, a negligible demand decrease in the consumption of dairy products was expected. In the second scenario, it was assumed that new risk mitigation would need to be implemented to minimize the health hazard for humans. In this case, a small milk demand decrease was expected, but larger demand decreases were also possible. The third scenario assumed that no fully effective risk mitigation was available, and this resulted in a considerable demand decrease and a potential reduction in milk supply as a result of regulatory measures. A milk demand reduction of 1 or 5% resulted in a reduction in consumer surplus of \$600 million and \$2.9 billion, and a reduction in dairy farm income of \$270 million and \$1.3 billion, respectively. A decrease in milk supply would cause a slight increase in total losses, but would cause the greatest losses to test-positive dairy farms. Given the current scientific knowledge about MAP and CD, we conclude that if a link were established, it is most likely that the first or second scenario would occur. Thus, consumer response and economic consequences to the discovery of such a link

are expected to be limited, but could be large if the consumer's perception of risk is large or if risk-mitigation strategies were ineffective.

Key words: *Mycobacterium avium* ssp. *paratuberculosis*, Crohn's disease, scenario analysis, economic analysis

INTRODUCTION

Johne's disease (**JD**) is an infectious disease of cattle caused by *Mycobacterium avium* subspecies *paratuberculosis* (**MAP**). The disease manifests with a variety of pathological changes, the most relevant being chronic bowel inflammation (Johne and Frothingham, 1895). Crohn's disease (**CD**) in humans is a disease of unknown etiology that is characterized by chronic bowel inflammation.

Soon after the first description of the disease in the late 19th century, the pathological and clinical similarity between JD and CD led to the hypothesis that CD was also caused by MAP (Chiodini, 1989). After more than 100 yr of significant research efforts, this hypothesis is yet to be substantiated or rejected [NRC (US) Committee on Diagnosis and Control of Johne's Disease, 2003]. Although recent meta-analysis studies suggest MAP is detected more frequently among CD patients compared with control patients (Feller et al., 2007; Abubakar et al., 2007), no causal link between MAP and CD has been proved (Van Kruiningen, 1999, Rudoler, 2004), nor is there consensus about this link among medical gastroenterologists and epidemiologists.

Since 1998, 3 authoritative bodies (National Institute of Allergy and Infectious Diseases, 1998; European Commission, Scientific Committee on Animal Health and Animal Welfare, 2000; Rubery, 2002) have tried to answer the question of whether MAP is a human pathogen and a cause of CD, and all reached the same conclusions [NRC (US) Committee on Diagnosis and Control of Johne's Disease, 2003]:

- Insufficient evidence to prove or disprove that MAP is a significant human pathogen;

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- Insufficient evidence to prove or disprove that MAP is a cause of CD;
- The problem is of such importance and the hypothesis sufficiently plausible to warrant increased research to resolve the questions.

Regardless of whether a causal link between MAP and CD in humans is discovered in the future, it is important to identify the implications and the possible economic impact that finding such a link would have on the dairy industry.

The main goal of this study is to examine the potential economic impact of a reduction in milk demand in the dairy industry because of a discovered causal link between MAP from dairy cattle (hereafter called MAP for simplicity) and CD in humans. Whereas this paper takes the causal link as a given, we emphasize that no such link has been scientifically established. This paper aims to provide a framework for further discussion about the consequences of a potential link between MAP and CD among members of the dairy industry, consumers, regulators, academia, and other stakeholders. The study focuses on the effects through dairy and dairy products without discussing alternative routes of potential consumer exposure to MAP from cattle.

MATERIALS AND METHODS

Given the very limited number of relevant and comparable historical cases in which scientific evidence becomes available on the zoonotic nature of a disease in farm animals, it is impossible to predict the exact consequences of a potential link between MAP and CD. Therefore, the focus of the study is on evaluating a range of plausible scenarios. First, we discuss possible effects from a conceptual perspective, based on previous experience with other food safety issues having a real or perceived public health effect. Second, we estimate the magnitude of loss by using a model that evaluates the economic effects that a causal link between MAP and CD could have on the US dairy industry and consumers.

Scenario Analysis

Many scenarios could develop should a link between MAP and CD in humans be established. The impact on the dairy industry will depend on many factors, including the degree of regulatory reaction to the newly found link (e.g., from no response to complete and permanent ban of the affected product) and the attitude of the consumers toward the newly discovered findings. Whereas regulatory reaction is expected to be based on current scientific evidence of the potential risks to

consumers, predicting consumer reactions is more difficult.

Predicting Consumer Reactions. The economics of information theory is regularly used to predict and explain consumer reactions, and states that consumers will consider the costs and benefits of collecting (additional) product information. For example, this theory helps explain why the controversial introduction of the use of recombinant bST (**rbST**) in the United States in 1994 had limited effects on milk demand (Aldrich and Blisard, 1998). Basically, the consumer could either believe the US Food and Drug Administration (**FDA**), which stated that rbST is not a food safety issue, or research the rbST issue at considerable cost and time. Because no negative consequences from milk consumption with rbST were reported, consumers may have been comfortable relying on government regulation to protect them. The economics of information theory suggests that in case of a discovery of a causal link between CD and MAP, the FDA's reaction to such a discovery is likely to affect the consumers' reaction.

In addition, it is important to understand the link between consumer risk perception, consumer behavior, and consumer demand for specific food items. For example, Zepeda et al. (2003) found that the availability of labeled rbST-free milk not only increased the proportion of consumers who purchased labeled milk, but also that its availability reduced the perception of the risk, regardless of whether consumers purchased the labeled milk. In other words, the availability of rbST-free milk resulted in a lower risk perception of milk produced with rbST. If a causal MAP-CD link were established, labeling of milk from MAP low-risk herds may possibly be used to reduce the risk perception of milk produced on test-positive herds and therefore limit the reduction in demand. However, unlike for rbST, if disagreement exists among regulatory agencies, the labeling of milk from low-risk MAP herds may actually increase consumer concerns, reducing consumer demand.

Scenarios. Three main scenarios were developed to consider the impact that a hypothetical MAP-CD causal link would have. Two levels of effectiveness of possible mitigation strategies are considered (Figure 1) to draw parallels between the defined scenarios and the consequences of diseases with zoonotic potential observed in the past. In the first scenario, it is assumed that very effective risk-mitigation strategies exist, whereas in the second it is assumed that mitigation will be only partially effective. The third scenario represents a situation in which no effective risk mitigation is available.

Economic Analysis

US Dairy Industry. The US dairy industry is a complex system in which the prices dairy producers receive

Figure 1. Flowchart summarizing scenarios 1, 2, and 3.

for raw milk are determined by supply and demand, and by 4 main dairy policy programs (Miller and Blayney, 2006). Price and income support is provided through 3 programs: 1) a dairy product purchasing program, 2) a direct payment program, and 3) a subsidized dairy product export program. Market stability, the fourth main dairy policy program, is the main focus of both state and federal milk marketing orders. Overviews of the US dairy policy and its federal and state dairy programs are presented in 2 recent reports (USDA Economic Research Service, 2004; Miller and Blayney, 2006).

Economic Model. A model was developed to estimate the economic effect of a possible change in consumer demand and producers' supply on the price of milk and on consumer and producer surplus resulting from a hypothetical causal link between MAP and CD.

Consumer surplus is the difference between the maximum that consumers would be willing to pay for a good and what they actually pay. Producer surplus is the difference between the revenue of producers and marginal production cost. The changes in consumer and producer surplus are standard economic measures that, together with the change in government costs, result in the total economic effect ("welfare change") of a certain event or policy change on a society (Boardman et al., 2006).

Given the large uncertainties associated with the scenarios evaluated in this paper, a detailed model would suggest an unrealistic sense of precision; therefore, the economic model was kept fairly general. The model was constructed in Excel and is available for download from <http://www.voseconsulting.com/JDCDGoenendaal&Zagmutt2008>. Boardman et al. (2006) provides a de-

Table 1. Summary of the main assumptions used in the calculation of economic impacts

Model feature	Assumption
Demand and supply	Linear
Demand and supply relationship	Remains appropriate after demand or supply "shock"
Consumer surplus	No consumers drop out of market
Demand and supply effect	Nonrecoverable
Secondary market	Not distorted
Economic impact	Calibrated for 2007 forecasts
Economic impact	Annual effect

scription of the general approach and methods used in the economic model. The model (Figure 2 and Table 1) determines the short-run (annual) economic impacts calibrated for forecasted 2007 data and estimates changes in producer and consumer surplus and government payments, assuming that demand and supply are linear and that the estimated demand-supply relationships remain equal. Demand and supply effects were also assumed to be nonrecoverable, meaning that if, for example, consumption declined during a certain period, consumers would not compensate their demand during the next period.

In the model, a decrease in milk demand (Figure 2, step 1) is assumed to cause a homogeneous parallel

shift to the left of the demand curve. This causes a decrease in quantity demanded from Q_0 to Q_1 . After this (Figure 2, step 2), the demand change results in a decrease in price from P_0 to P_1 . In case of a price drop below \$0.218/kg, the oversupply of milk is assumed to be bought by the USDA Commodity Credit Corporation (CCC; as described in Collins, 2006). Finally (Figure 2, step 3), the model determines what effect the price decrease has on milk supply. If the price decreases to levels below the USDA CCC support price P_s , the price will stay at P_s (Figure 2). As a consequence, total supply will increase to Q_s (from Q_1) while consumer demand will decrease to Q_c . The difference between Q_s and Q_c is the amount bought by USDA CCC.

Figure 2. Graphic display of the effects caused by a decrease in demand (i.e., decrease in consumption). Q_0 = quantity demanded before a decrease in demand; Q_1 = quantity demanded after a decrease in demand; Q_s = total supply resulting from the price decreasing to levels below the USDA Commodity Credit Corporation (CCC) support price P_s , and thus staying at P_s ; Q_c = consumer demand resulting from the price staying at P_s . P_0 and P_1 are prices corresponding to Q_0 and Q_1 .

Table 2. Main input quantities used in the calculation of economic impacts

Input parameter	Value
Milk demand increase, %	x^1
Milk supply decrease, %	y^1
Milk produced, cwt/yr	$1.83E + 11^2$
Mean milk price, \$/cwt	14.00^2
Price elasticity of demand	-0.40^3
Price elasticity of supply	0.80^4
Minimum price of milk (USDA Commodity Credit Corporation), \$/cwt	9.90^5

¹Value dependent on the scenario examined.

²USDA-National Agricultural Statistics Service (2006).

³Gould et al. (1990).

⁴Wohlgenant (1989).

⁵Collins (2006).

The model also estimates the effects of a shift in milk supply (i.e., milk production) if dairy producers are not able to sell their milk for consumption (i.e., scenario 3). In such a situation, the supply curve would shift to the left (lower production at a given price), causing an increase in the equilibrium price. This would subsequently affect producer and consumer surplus. In the model, it is assumed that secondary markets (substitute and complement goods) such as soy beverages, bottled water, soft drinks, and others are not distorted; therefore, a change in the supply and demand for beverages other than milk is accounted for in the supply and demand of milk. As a result, the opportunity cost of changes in demand is reflected in the estimate of the change in consumer surplus and producer surplus, and the economic analysis is thus complete.

Table 2 lists the input data and sources used in the economic assessment. Milk production was assumed to be 83 billion kg/yr (1.83 billion cwt/yr; USDA-National Agricultural Statistics Service, 2006). Milk price was set at \$ 0.31/kg (\$14.00/cwt), which is in the middle of the forecasted all-milk price range for 2007 (USDA-National Agricultural Statistics Service, 2006). The model contains 2 additional modules with calculations for a low and high base year milk price scenario of \$0.24/kg (\$11.00/cwt) and \$0.38/kg (\$17.00/cwt), respectively. The shifts in milk demand and supply assumed in this study depended on the particular scenario considered and are discussed in the next section.

SCENARIOS

The scenarios were developed by drawing parallels between the general potential effects of a MAP-CD causal link and past events that consumers have or may have perceived as food safety issues. The scenarios cover a range of possible situations and, more importantly, provide a framework to evaluate other potential consequences.

Scenario 1

General Description. The first scenario assumes that a causal link is proven, but no real health risk exists to humans from consuming dairy products because the exposure to MAP from pasteurized dairy products would be negligible or insufficient to cause CD (i.e., the infective dose is far greater than the exposure of MAP attributable to regular human consumption of dairy products). Simple mitigation practices, including current pasteurization methods and other food safety measures, would significantly reduce the bacterial loads of MAP from dairy sources, thereby reducing the risk of human infections from dairy products to negligible levels.

Parallels can be drawn between this scenario and an outbreak of foot-and-mouth disease (**FMD**) in a country with intensive animal agriculture. Foot-and-mouth disease is a highly contagious vesicular viral disease of acute course, affecting domestic and wild cloven-hoofed animals. Although FMD is innocuous to humans (only a handful of proven FMD infections in humans have been reported throughout the world) and is not recognized by USDA as a zoonotic disease (see http://www.aphis.usda.gov/publications/animal_health/content/printable_version/fs_foot_mouth_disease07.pdf), this disease is used for this scenario because its presence can change consumer consumption patterns. It also represents a disease that usually receives extensive media attention when present in a nonendemic country, making consumers aware of the disease outbreak, thus potentially changing their consumption patterns even though the disease poses no health risks to humans. Nevertheless, in case of slowly accumulating evidence of a causal link between MAP and CD, the media attention may not be as great.

Also, *Escherichia coli* O157:H7 can be used as a parallel for this scenario. *Escherichia coli* O157:H7 and other strains that can cause illness in humans can be found

in milk and have been associated with food-poisoning events. However, milk consumption has not been significantly affected by food-poisoning events involving *E. coli* in milk although between 29.4 and 53.9% of dairy operations have at least one *E. coli* O157:H7 culture-positive cow (National Animal Health Monitoring System, 2003a).

Reaction of Regulators. Given that current risk mitigations are effective, regulatory agencies (i.e., FDA, USDA) would likely not change regulations, although they would likely increase monitoring efforts for compliance.

Reaction of Industry. Industry reaction in this case may be fairly limited because there would be no food safety concern for consumers. It will be important that industry provides ample evidence that the consumer is protected sufficiently, based on current industry practices. In addition to research efforts that establish this scientifically, industry may increase efforts to establish monitoring programs to ensure the safety of dairy products against MAP. For a review of diagnostic tests for the detection of paratuberculosis in cattle, we refer to Collins et al. (2006). Industry might also consider increasing resources in JD certification programs and possibly start marketing milk from certified low-risk MAP-certified producers—for example, either negative at level 3 or 4 of the test-negative component of the Voluntary JD Control Program [NRC (US) Committee on Diagnosis and Control of Johne's Disease, 2003] or infected herds at low-prevalence whole bulk-tank milk tests negative on a rapid test such as PCR—although this approach is very unlikely given its logistical challenges. This situation would be comparable to the moment the use of rbST was approved in the United States in 1993, when milk produced by “rbST-free” cows was differentially offered to the public, even though US federal agencies agreed that the commercial use of rbST in dairy cattle posed no risk to consumers.

Reaction of Consumers. Although consumer behavior is very difficult to predict, very minor or no demand reaction by consumers is expected, given that the zoonotic potential in this scenario is negligible. Parallels can be drawn between this scenario and the impact of the FMD outbreak on the demand for beef in 2001 in the United Kingdom. Despite the fact that this is arguably one of the best documented FMD outbreaks, no changes in consumer demand for beef or milk are described in the UK's Department for Environment, Food and Rural Affairs official publications (Thompson et al., 2002). Although some studies on the economic impact of an FMD outbreak (Paarlberg et al., 2002) assume a 5 to 10% decrease in consumption for hypothetical outbreaks, none of these values is based on empirical data. In addition, several recent *E. coli* O157:H7-

related outbreaks caused by the consumption of raw milk in California did not result in a reported decrease in milk consumption. In addition, when first introduced in the United States, rbST was perceived by some consumers as a potential food safety issue but was concluded to be safe by FDA, and no measurable effect on milk demand was observed.

It is also unlikely that a sudden “consumer demand shock” would occur because the potential for a link has long been recognized (Chiodini, 1989; Hermon-Taylor and Bull, 2002; Greenstein, 2003; Greenstein and Collins, 2004; Sartor, 2005). In addition, there are already many other zoonotic diseases in farm animals (Centers for Disease Control, 2006) and MAP might be viewed by the consumer as just one more. The consumer may therefore be indifferent to a newly proven link, considering that MAP has been prevalent in dairy cattle worldwide for many decades. Finally, CD in humans is not a totally new disease [as compared with variant Creutzfeldt-Jakob disease (**vCJD**), for example]. Therefore, a possibly slowly growing body of evidence could result in little change to consumer demand and minimal economic effects. Thus, a limited decrease in milk demand is expected in the first scenario, but although unlikely, a great amount of attention and coverage of the MAP-CD link by the media could decrease demand more sharply.

Scenario 2

General Description. In this scenario, when a MAP-CD link is proven, there would be a potential health hazard for humans consuming processed dairy products, unless appropriate risk management measures are taken. Thus, by implementing sufficient measures, the food safety risk of MAP would be very low or negligible. Some parallels can be drawn with the *Salmonella* scare in eggs in 1989 in the United Kingdom (Yeung and Morris, 2001) and with pathogens that can be found in milk and are zoonotic, such as *Salmonella* and *Listeria*. In a survey carried out by USDA (National Animal Health Monitoring System, 2003b), 2.7% of operations presented bulk-tank milk sample tests positive for *Salmonella*, and 6.5% of operations had a single bulk-tank sample test positive for *Listeria monocytogenes*. Human infections have been associated with consumption of raw milk and milk products. However, as with *E. coli*, those events have not had a real long-term impact in the dairy industry. Given their ubiquitous presence in dairies, neither *Salmonella* nor *Listeria* can be fully eliminated from the environment or from cows. Hence, correct pasteurization methods are essential to eliminate the agents from milk in the food chain. Because this scenario assumes the availability of effective risk-

mitigation strategies against MAP exposure through consumption of dairy products, we first review the evidence for the effectiveness of MAP reduction via pasteurization of milk.

Pasteurization of Milk. An often-debated issue is the potential for pasteurized milk to contain viable MAP and therefore be a potential source of human exposure. A comprehensive review of the effect of pasteurization on the presence of MAP in milk can be found elsewhere (i.e., Grant et al., 2001). Cows with clinical JD or at late stages of asymptomatic infection can shed low concentrations of MAP in milk (Taylor et al., 1981; Sweeney et al., 1992; Streeter et al., 1995). Feces from infected cows can contain large concentrations of MAP, so milk contaminated with feces can present significant concentrations of viable MAP (Nauta and van der Giesen, 1998). Under laboratory conditions, most MAP is killed by the standard HTST pasteurization process (Stabel et al., 1997), but some MAP bacteria may still remain in milk that had a high initial (prepasteurization) bacterial load (Grant et al., 1998). Although there is some disagreement on what these results indicate (Paratuberculosis Awareness and Research Association, 1999–2003), a few studies have successfully cultured significant numbers of MAP from cow's milk pasteurized under commercial conditions (Hope et al., 1996; Gao et al., 2002; Grant et al., 2002b). For instance, Hope et al. (1996) performed their experiment by using small-scale pasteurizers and milk with artificially high concentrations of MAP. They found small amounts of viable colony-forming units of MAP in a subset of batches loaded with high concentrations of MAP, but no MAP in milk batches with more realistic concentrations of MAP. Furthermore, viable MAP were found only in milk batches treated with lower temperatures and shorter times than those recommended for the pasteurization equipment used. The authors assertively pointed out that given the study design limitations, their study could not be directly extrapolated to commercial pasteurization of naturally infected milk in dairy plants. In another study, researchers took 312 samples of retail pasteurized cow's milk in the United Kingdom and detected MAP DNA in 7% of the samples (Millar et al., 1996). However, the PCR assay used does not differentiate between live and dead MAP; hence, the authors were not able to determine whether the MAP found was present in a viable form (i.e., that could be transmitted to other animals or to a human). Other studies on the subject present similar difficulties (Chiodini and Hermon-Taylor, 1993).

The presence of MAP in milk after different commercial pasteurization methods has been evaluated in the United Kingdom, United States, and Czech Republic (Grant et al., 2002a,b; Ayele et al., 2005; Ellingson et

al., 2005). Studies have used commercial-grade pasteurization equipment on naturally MAP-infected milk (Grant et al., 2002b) and tested both bulk raw milk and cartons of pasteurized milk collected from the production line (Grant et al., 2002a). Investigators have also used both bulk and retail milk (Ayele et al., 2005), whereas the US study used samples from retail milk from the largest milk-producing states in the United States (Ellingson et al., 2005). The results from all 4 studies suggested that under certain conditions, low levels of viable MAP may be found in a small proportion of samples taken from commercially pasteurized naturally infected milk. The proportion of the retail milk samples (i.e., cartons and bottles) with viable MAP was consistent among studies and ranged from 1.6 to 2.8% of the samples. Finally, others used a custom-built pilot plant pasteurizer and milk artificially spiked with MAP to study the effect of different HTST treatments under controlled conditions (Hammer et al., 2002), obtaining results similar to those obtained from the aforementioned studies. Nonetheless, time increase in the current HTST treatments (Grant et al., 1999) combined with adequate homogenization procedures (Grant et al., 2005) may kill a significant proportion of MAP in milk, making it a preemptive strategy that could be implemented if there is a need to further reduce the MAP load in milk. However, there is currently no agreement about the exact time and treatments that should be applied to ensure a proper reduction of the MAP load in milk.

It is important to note that researchers performing pasteurization studies, as described above, frequently use nontypical methods (resuscitation and very long-term incubation as well as PCR assays) relative to the methods usually used for bacterial culture of the pathogen in cattle. Although studies have usually not quantified the bacterial load in naturally infected or contaminated milk, the practice of using such sensitive testing methods would tend to indicate a low concentration of MAP in milk (S. J. Wells, University of Minnesota, St. Paul; personal communication).

Cheese made from raw or pasteurized milk can also present trace amounts of viable MAP. Some cheese varieties made from raw milk can have low concentrations of viable MAP after 4 mo of ripening (Spahr and Schafroth, 2001). Similar results have been obtained for Hispanic-style cheese (Sung and Collins, 2000), Feta and other cheeses from retail markets in Greece and the Czech Republic (Ikonomopoulos et al., 2005), and pasteurized Cheddar cheese from artificially spiked milk in the United Kingdom (Donaghy et al., 2004). Soft cheeses presented some of the highest concentrations of MAP among the studies. Nonetheless, a combination of heat treatment and low pH inactivated large quanti-

ties of MAP per milliliter (Sung and Collins, 2000), suggesting that preventive measures could be implemented to reduce the concentrations of MAP in cheese. Nonetheless, although the reduction of MAP loads in milk and cheese has been studied intensively, the concentration of MAP in raw milk needs further study to truly ensure negligible MAP exposure to consumers. The current scenario assumes that, should a MAP-CD causal link be found, pasteurized milk products would present negligible risk of MAP exposure from consumption of commercial fluid milk and dairy products given that the appropriate mitigation strategies would be taken.

Reaction of Regulators. In this scenario, regulatory agencies would implement more stringent regulations, such as increased duration and temperatures of pasteurization, to minimize the risk of consumer exposure to negligible levels. It is further assumed that it would also be scientifically established and supported by the FDA that the risk measurements in place (e.g., pasteurization of milk) are effective in protecting consumers against any risks. Retail and on-farm sales of raw milk and milk products could be suspended in states that currently allow for it (e.g., California, Arizona). Several food-safety pathogens can be present in raw milk, but retail of raw milk still exists in some states (usually with a warning label), suggesting that sales of raw milk could remain.

Reaction of Industry. The industry would either show consumers that the new risk-mitigation procedures are sufficient or raise milk-processing standards to minimize the risk of MAP surviving pasteurization procedures. If scenario 2 occurs, additional evidence of the effectiveness of pasteurization under commercial circumstances would be required. In addition, tighter milk pasteurization regulations set by regulators and industry would aim to minimize the risk of MAP exposure to consumers through commercial milk. An unlikely longer term consequence would be that milk from JD-certified low-risk farms would be labeled separately for consumers willing to pay a higher price for this milk. The availability of milk from low-risk MAP herds may result in a lower risk perception of milk produced on both certified low-risk MAP and noncertified herds, similar to the situation observed after the introduction of rbST (Aldrich and Blisard, 1998). However, the labeling of milk from low-risk MAP may actually increase consumer concerns about milk in general and, as a result, increase the potential reduction of consumer demand.

Reaction of Consumers. The assumed effectiveness of the mitigation strategies under this scenario suggests that rational consumers would not have a strong reaction against dairy products. However, consumer reaction is not necessarily related to the real risk as

understood by scientists, but rather is an issue of risk perception that may vary greatly among demographic or cultural groups, or both (Frewer, 2000). Consequently, a range of possible consumer reactions can occur under this scenario, from no reaction to long-term changes in consumer demand.

In this scenario (similar to scenario 1), very limited long-term change in consumer demand could occur if strong evidence for a link would slowly accumulate (i.e., no sudden consumer demand shock). In addition, consumers may consider JD as simply another zoonotic disease and may therefore be fairly indifferent about a newly proven link, particularly considering that MAP has been prevalent in dairy cattle worldwide for decades.

If a MAP-CD link were established, a short-term decrease in the demand for milk could occur. For example, during the week following the first reported case of bovine spongiform encephalopathy (BSE) in the United States in December 2003, cattle prices fell by approximately 16%. Consumer surveys at that time suggested that US domestic beef demand may have fallen by as much as 15%. However, prices recovered in early 2004, showing that consumer demand was affected only minimally, if at all (Kuchler and Tegene, 2006; Vickner et al., 2006).

Although this scenario assumes that the health hazard could be prevented with basic measures (i.e., changes in pasteurization methods), the consumption of dairy products could still decrease considerably should consumers perceive dairy products as risky. This scenario could be similar to the *Salmonella* outbreak in eggs in the United Kingdom, although a comparison between UK and US consumers must be taken carefully, given the differences in confidence in the food safety system and government regulatory officials in the 2 countries. In addition, eggs are supplied to consumers as a raw product, whereas milk is largely sold in pasteurized form. For *Salmonella*, the perception of the food safety risk as a result of the outbreak was significant, creating a long-term change in people's egg demand. For example, retail sales of eggs in the United Kingdom decreased from 8,270 million in 1988 to 6,556 million in 1989 (a 21% decrease) after the emergence of *Salmonella* (Yeung and Morris, 2001). Since that outbreak, the consumption of eggs in the United Kingdom has shown a downward trend, which may partially be explained by the *Salmonella* outbreak.

Scenario 3

General Description. This scenario assumes that a MAP-CD link is found and represents a significant food safety hazard (i.e., that a significant number of

people exposed to a sufficient dose of MAP will develop CD). The risk mitigation available would not be highly effective to protect consumers from MAP exposure through commercial dairy products. This unlikely scenario can occur if current and enhanced pasteurization and risk-mitigation methods would be proven as not fully effective.

Given its current importance in global food safety, and the consequences the disease has had on affected patients, parallels can be drawn between this scenario and the global BSE outbreak and its relationship to vCJD affecting humans. Conversely, important differences exist. First, variant vCJD is a lethal neurological disease that is more likely to be feared by consumers than a chronic inflammatory bowel disease such as CD. Second, BSE and vCJD were relatively new diseases, whereas both JD and CD have been recognized for many years. Third, CD is a multifactorial disease and, in case a link between MAP and CD is established, it will likely be a relatively weak epidemiological link (not a one-to-one cause-and-effect relationship).

Reaction of Regulators. The regulatory reaction may take either of 2 non-mutually exclusive forms. First, FDA may withdraw all potentially infected milk and milk products from the market and ban all MAP-infected herds from supplying milk for human consumption. This could result in a considerable decrease in milk supply given the great herd prevalence in the United States (i.e., 93.3% in Colorado; Hirst et al., 2004). Although milk from MAP-infected farms may potentially be sold for animal consumption (i.e., processed milk replacement) or perhaps as powdered milk, in the economic assessment it is assumed that this milk would be removed from the food chain. Given the worldwide occurrence of JD [NRC (US) Committee on Diagnosis and Control of Johne's Disease, 2003], no other countries could supply guaranteed MAP-free milk. Alternatively, FDA could define MAP limits on bulk-tank milk on the farm. These MAP limits could be tested periodically and producers exceeding the MAP threshold may be given penalties or may be excluded from the milk supply.

Reaction of Industry. The banning of MAP test-positive herds would provide a great economic incentive to producers to become certified as MAP low-risk. Therefore, under this scenario, industry is expected to work with regulators to increase control efforts considerably on test-positive farms and to increase certification efforts for JD low-risk farms. Although a range of certification programs are used worldwide, the certification efforts are likely to have increased focus on milk quality and MAP concentration in milk. For example, Weber et al. (2008) showed that bulk milk quality assurance programs would be feasible for closed herds and

could result in much lower costs to producers than certification programs that test individual animals.

Reaction of Consumers. The consumer reaction is expected to be strong, given the high food safety risk assumed. For example, some estimates of the beef demand impact resulting from the BSE crisis include a 36.4% short-term decrease in expected beef sales in a region of Turkey (Miran and Akgungor, 2005), an average decrease in beef consumption of 27% for January 2001 in the United States (Sancton et al., 2001), and a 40% drop in sales of beef products as a result of the 1996 BSE outbreak in the United Kingdom (Agriculture and Agri-Food Canada., 2007). The FDA estimated a loss of \$15 billion in sales revenue, resulting from, among others, a 24% decline in domestic beef sales (as cited in Pritchett et al., 2005). Although impacts in other countries are not necessarily representative of potential impacts in the United States, it is expected that the reduction of short-term consumer demand could be large.

Past Milk Demand Effects. In the past, US milk consumption has not been greatly affected by real or perceived food safety-related issues. For example, after the 1985 *Salmonella* outbreak, when 200,000 people became ill from contaminated milk distributed by Jewel Food Stores, the affected milk was quickly taken out of commerce and no long-term milk demand effects were found (R. Byrne, J. S. Jonker, and P. Vitaliano, National Milk Producers Federation, Arlington, VA, and D. Pelzer, Dairy Management Incorporated, Rosemont, IL; personal communications, 2006). In addition, when rbST was approved by the US FDA in 1993, a very limited or no negative impact on demand for dairy products was evident (Aldrich and Blisard, 1998). This is perhaps the case because milk is, in general, considered a safe product by the US consumer.

ECONOMIC EFFECTS

Effect of Milk Demand Impacts

The results shown in Table 3 indicate the economic effects of a range of milk demand decreases. Table 3 shows that the decrease in milk demand (Figure 2, step 1) will cause a decrease in price (Figure 2, step 2), which will subsequently partially mitigate the decrease in consumption (Figure 2, step 3). The effects on both consumer and producer surplus increase with a larger decrease in milk demand. Government payments under USDA's CCC program are expected to increase only if milk demand decreases by at least 26% (e.g., see the 30% demand decrease in Table 3). Scenario 1 is expected to have a demand impact that will be fairly small or nil, hence toward the lower end of the ranges shown above. The demand effects and consequential decreases

Table 3. Decrease in annual consumer and producer surplus and government payments (in million \$US) attributable to a decrease in milk demand

Milk demand decrease, %	Price decrease, %	Consumption decrease, %	Decrease in surplus, \$			
			Consumer	Producer	Government	Total
1.0	1.2	1.0	600	270	—	870
2.0	2.4	1.9	1,180	530	—	1,710
3.0	3.6	2.9	1,770	790	—	2,560
5.0	6.0	4.8	2,920	1,310	—	4,230
10.0	11.9	9.5	5,700	2,550	—	8,250
15.0	17.9	14.3	8,340	3,720	—	12,060
20.0	23.8	19.0	10,840	4,820	—	15,660
30.0	29.3	28.6	14,930	5,870	1,120	21,920

in surpluses under scenario 2 are expected to be on the lower end of the ranges shown above, but depending on the risk perception such a discovery would get, it could be on the high end. Finally, given the real risk assumed in scenario 3, the decrease in milk demand can be expected to be large, possibly to the higher end of the losses show above or greater.

Effect of Milk Supply Impacts

In Table 4, price and surplus consequences are shown for a range of supply shocks in which the default structural decrease in milk demand is assumed to be 5%. The results show that the higher the decrease in milk supply, the less milk prices will decrease. In case of a milk demand decrease smaller than 5%, and a milk supply decrease, the milk price may actually even increase. A decrease in milk supply with a concurrent decrease in demand causes a greater decrease in consumer surplus but causes a lower decrease in producer surplus. The decrease in producer surplus is not homogeneous among producers, having the most devastating effects on producers with MAP-infected herds. Finally, no government payments are expected because in all the scenarios the milk price stays above the policy break point of \$0.218/kg (\$9.90/cwt).

DISCUSSION

The 3 scenarios (Table 5) illustrate the great range of possible outcomes in the event that a MAP-CD link is established. Because consequences vary greatly between the 3 scenarios explored in this paper, it is important to explore the likelihood of the different scenarios.

Likelihood of Scenarios

In this paper, it was assumed that a causal link was scientifically demonstrated to exist between MAP and CD in humans. The exact nature of this causal link is not defined in this paper, but varies in the 3 scenarios that were evaluated in this paper. For MAP in dairy cattle to cause or increase the risk of developing CD in humans, transmission of live MAP bacteria will need to take place from dairy cattle through some dairy product to the consumer. Given the current knowledge of the effects of pasteurization and other potentially available risk-mitigation measures on MAP survival in milk, it is feasible that, in case of a discovered MAP-CD link, current procedures either could already be sufficient or could be made effective to minimize the risk of MAP exposure through commercial dairy products to the consumer. However, without knowing infectivity and other

Table 4. Decrease in annual consumer and producer surplus and government payments (in million \$US) attributable to a decrease in milk supply and a 5% decrease in milk demand

Milk supply decrease, %	Price decrease, %	Consumption decrease, %	Decrease in surplus, \$			
			Consumer	Producer	Government	Total
1.0	5.7	1.9	2,980	1,300	—	4,280
2.0	5.5	2.0	3,020	1,290	—	4,310
3.0	5.3	2.1	3,060	1,270	—	4,340
5.0	5.0	2.2	3,150	1,250	—	4,400
10.0	4.2	2.5	3,350	1,190	—	4,540
15.0	3.3	2.9	3,550	1,130	—	4,680
20.0	2.5	3.2	3,750	1,070	—	4,820
30.0	0.8	3.9	4,150	950	—	5,110

Table 5. Summary of 3 main evaluated scenarios

Item	Scenario 1	Scenario 2	Scenario 3
Zoonotic disease	Yes	Yes	Yes
Human health impact	Negligible	Negligible if correct mitigation applied	Yes (100% mitigation impossible)
Preventive measures	Effective	Effective	Not 100% effective
Regulator response	Tighten existing regulations	Application of new regulations where necessary	Either withdrawal of infected milk, milk products, and milk producers or define bulk-tank limits for <i>Mycobacterium avium paratuberculosis</i> (MAP) or both
Industry response	Provide high level of evidence of effectiveness of current risk mitigation	Provide high level of evidence of effectiveness of current risk mitigation for implementation and certify MAP low-risk producers	Find effective risk-mitigation measures and certify MAP low-risk producers
Consumer response	Little	Most likely little, possibly large	Likely large
Economic consequences ¹	Likely small	Small to considerable	Likely considerable
Likelihood	High	Less likely	Not likely

¹See Tables 3 and 4 for estimates of economic consequences.

epidemiological parameters, it is impossible to ensure this would be the case should a causal link be found. Scenario 3 therefore appears unlikely to occur. The difference between scenarios 1 and 2 depends on the effectiveness of current risk-mitigation (e.g., pasteurization) procedures. For example, Dairy UK decided to increase the minimum recommended pasteurization times from 15 to 25 s (Dairy UK, 2005). Although they realized that a link between MAP and CD has not been proven or disproven, they speculated that if the link would ever be established, it would be preferable to have a higher likelihood of being in a scenario similar to scenario 1.

Vaccination of cattle may be another possible mitigation strategy. Although vaccination reduces the number of clinical JD cases, field observations suggest that vaccination does not reduce the prevalence of infection (Wentink et al., 1994). If vaccination effectively decreases the shedding levels of MAP-infected animals, it could be used as a potential risk-mitigation strategy. In addition, certification programs can be used as a possible risk-mitigation strategy. For this, it will be important to develop less expensive and faster ways to identify infected dairy herds, such as bacterial culture or PCR of pooled environmental fecal samples (Raizman et al., 2004; Berghaus et al., 2006). The logistics of plant segregation of milk may present a challenge to the marketing of low-risk MAP milk. However, small processors could differentiate their products by demonstrating that their suppliers are 100% test-negative for MAP.

Economic Consequences

The current economic analysis estimates a reduction in consumer surplus of \$600 million and \$2.9 billion,

and a reduction in producer surplus of \$270 million and 1.3 billion for a milk demand decrease of 1 and 5%, respectively. However, the true decrease (“shift”) in milk demand resulting from a hypothetical discovered link between MAP and CD is unknown. In addition to a decrease in demand, milk supply could decrease if milk and milk products from MAP noncertified herds could not be sold to consumers (i.e., a shift in supply). In this case, the price of milk may actually increase, resulting in a smaller reduction in producer surplus but a greater reduction in consumer surplus. No government payments are expected, because in all of the scenarios, market prices stay above the policy break point (\$9.90/cwt). However, given the volatility of milk prices, government payments are likely to occur when milk prices approach the break point. In addition, government payments to producers through the Milk Income Loss Contract (MILC) program are expected to increase in case milk prices decrease. In addition, the economic analysis focused on producer and consumer impacts and assumed negligible costs of policy implementations within the different scenarios. For scenarios 1 and 2, the implementation costs will likely have a relative small effect on consumers and producers. However, the costs of JD control for positive herds in scenario 3 may be considerable.

Marginal price elasticities assume that market conditions otherwise remain the same. In the case of large demand or supply shifts, this may not be the case and they are not included in the analyses. The economic analysis furthermore assumed that trade implications resulting from an established MAP-CD link would be negligible because of the worldwide occurrence of JD.

Limitations of This Study

The scenario and economic effects estimated within the current study are based on many assumptions. In addition, there are limitations on the parallels made between past food safety cases and the scenarios evaluated. Thus, several factors could cause the current estimates to be biased. An overestimation of the consequences and economic effects in this study could arise from several factors, including that CD is considered multifactorial and does not have a short incubation time, such as, for example, *Salmonella* and *E. coli*. Extensive outbreaks of CD in a short time period are then very unlikely. In addition, CD has been recognized for more than a century. A discovered link between MAP and CD might attract less attention and publicity than did the outbreaks of BSE. In addition, given the many years of research and the current lack of a proven causal link between MAP and CD, it is likely that if such a link were established, it would be indirect and of a multifactorial nature, leading to a less drastic consumer reaction.

Conversely, the current results could be an underestimate because the discovery of a link with a widely spread cattle disease and CD could potentially cause a stronger and longer than expected consumer reaction, particularly because CD is also diagnosed in children. In addition, wide media coverage of a proven link may have a much greater short- and long-term demand decrease than expected. The lack of scientific consensus regarding the link between MAP and CD and the efficacy of pasteurization to kill MAP could also increase media attention. In addition, this study focuses only on the impact of a link through milk and dairy products. However, there may not be readily available mitigation strategies to control other routes of potential human exposure (e.g., meat products, contaminated water from farm runoff, direct contact with infected cattle). These routes may represent a more significant economic impact on consumers, producers, and the government.

Role of Regulatory Agencies

The FDA and USDA will likely play an important role, assuming that a zoonotic link is established. First, their reaction to any research is important because a proportion of consumers may not change their behavior if FDA and USDA conclude that consumers are not at risk. Second, in case regulatory agencies conclude that a true link is established and that consumers are exposed to unacceptable food safety risks, they will take appropriate action to minimize consumers' exposure (e.g., remove MAP-contaminated milk from the market). The USDA-Animal and Plant Health Inspection Service (APHIS) might gauge its response on how the

Food Safety and Inspection Service and FDA respond. The greater emphasis FDA or the Food Safety and Inspection Service place on the contaminated product, the greater emphasis and effort APHIS is expected to place on controlling the disease.

CONCLUSIONS

Given the current scientific knowledge about MAP and CD, the effectiveness of pasteurization and other risk-mitigation methods, and past experience with food safety issues related to milk and milk products, it is concluded that in case a link is established between MAP and CD in the future, risk-mitigation methods and regulations are available to protect consumers from exposure to viable MAP through consumption of dairy products. However, the efficacy of this protection (i.e., no viable infective dose of MAP after risk mitigation is applied) is uncertain. In addition, consumer response and economic consequences to the discovery of such a link is expected to be limited, but could be large if consumer perception of the risk is large, for instance, because of great media exposure or if risk-mitigation measures are not fully effective.

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