Effects of a Traceability System on the Economic Impacts of a Foot-and-Mouth Disease Outbreak

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Abstract: The research reported in this paper created an epidemiological foot-and-mouth disease (FMD) spread model for the Canadian province of Ontario. Disease simulations were constructed to reflect three levels of the cattle identification and movement recording system. The outputs generated by the epidemiological model were used to calculate the direct disease control costs a FMD outbreak. In addition, welfare effects caused by a FMD outbreak were also calculated for each level of cattle traceability using an equilibrium displacement model. Parameter sensitivity was tested for both the epidemiological and economic model results. It was found that the benefits to the beef cattle industry of increasing the ability to trace direct animal contacts during a FMD disease outbreak in Ontario were less than the lowest annual cost estimate of a cattle traceability system.

Introduction

The Canadian and several provincial Governments have financially committed to extensive animal identification and livestock movement recording programs. Producers in all affected livestock supply chains are currently experiencing new costs associated with these programs and related regulations. According to the Canadian Dairy Commission's (CDC) 2005 Annual Report, design of an optimal and uniform traceability system for the dairy industry, including full product tracing from farm to final consumer is an important goal for the entire industry. The comparison of the benefits provided by the system to the costs of adopting and maintaining a livestock identification and recording system has important implications for the development of an informed animal identification related government policy.

The economic value of a livestock identification and recording system during a contagious disease outbreak is of extreme importance to both livestock producers and policy makers. Saatkamp et al (1995) state the control and eradication of foot-and-mouth disease is the primary benefit of a livestock identification and recording system. Zhao, Wahl, and Marsh (2006) affirm that from an economic perspective, FMD is the most devastating type of disease outbreak in the livestock sector. Consultation with the Manitoba representative of the National Agriculture and Food Traceability Task Team also identified contagious disease control as the primary benefit of the cattle animal identification system (Hunt 2009).

The livestock sector has recently undergone significant food safety-related transformations relating to traceability. Factors within the beef and dairy supply chains subject these industries to both milk-borne pathogen and animal disease risk. Following the detection of an animal disease outbreak, government officials are required to discover how and where the disease entered the supply chain, in order to identify which animals and products have been affected by the outbreak and to adopt pre-emptive measures to avoid the occurrence of future livestock disease outbreaks. In addition to the benefit of improved management of disease outbreaks, functioning traceability systems improve supply management and allow for product differentiation in products with undetectable quality attributes (Golan et al 2004). These benefits enable the producer to realize commercial value of a functioning traceability system.

The objective of the research reported in this paper is to calculate the economic impacts of a traceability system in the event of an animal disease outbreak. A spatial, stochastic disease simulation model is employed to generate disease outbreak statistics for several livestock traceability system scenarios. An explanation of the epidemiological disease spread model is provided, along with a detailed description of the framework used to evaluate economic outcomes. Parameterization and data sources for both the epidemiological and economic models are also described. Impacts upon the feeder and fed cattle as well as wholesale and retail beef markets are determined, and welfare changes associated with each livestock traceability scenario are analyzed. The final section of the paper discusses findings, draws conclusions, identifies limitations of the approach taken, and suggests directions for future research.

Epidemiological-Economic Modeling

Epidemiological-economic modeling is becoming increasingly popular within the agricultural economics literature. Rich, Miller, and Winter-Nelson (2005) focused on reviewing the economic tools for the assessment of animal disease outbreaks. They created the typology shown in Figure 1 to illustrate the scale of analysis for each economic framework, in addition to a description of which is best suited for the information desired from the economic model. The economic models included are benefit-cost analysis, linear program, partial equilibrium, input-output, multi-market and computable general equilibrium. The paper lists the information provided by, appropriate scale for each, and the data required for each model. Ekboir (1999) states that a complete analysis of the economic implications of a FMD outbreak is comprised of four components. These components include; the direct cost of controlling an outbreak, production losses, induced price changes, and the effects across sectors in the economy.

Zhao, Wahl, and Marsh (2006) utilize a partial equilibrium approach when interpreting disease spread simulation results. This methodology derives price change information, linkages across markets, and welfare measures of the market participants. Similarly to the previous studies, the epidemiological model utilizes the traditional Markov-Chain state transition process however the economic consequence analysis adopts an alternative approach. Dynamic livestock production, domestic consumption and trade models are included in the framework. Consumer and producer behavioral responses to the outbreak are calculated as well as the groups resulting welfare for each control strategy. Similarly to both Saatkamp et al (1996a) and Disney et al (2001), different scenarios are tested for various tracing and surveillance efforts, vaccination plans, and depopulation methods.

Equilibrium Displacement Models

The use of an equilibrium displacement model (EDM) originated with Muth (1964), who extended Hicks' (1948) analysis of the factors affecting the elasticity of derived demand for the case of variable input proportions. The term "equilibrium displacement model" was first used by Sumner and Wohlgenant (1985) who calculated the economic impacts of a cigarette tax increase on manufacturers and tobacco producers. A notable example of applying an EDM framework to the cattle/beef industry comes from Brester, Marsh and Atwood (2004), who estimated the economic impacts of country-of-origin labeling in the US meat industry across four beef and cattle marketing levels. Pendell et al (2010) use an EDM to determine the economic impacts of adopting animal identification and recording systems on the US cattle, swine, lamb, poultry, and meat sectors. Exogenous shifts to supply are included in the model to account for the increased costs of the livestock traceability system, independent from a livestock disease outbreak. These shifts are imposed on the farm level markets and vertical market linkage parameters to convey the effects of the supply shift on the other marketing levels. In addition, horizontal linkages in the form of cross-price elasticities capture these effects across sectors. Potential increases in export demand were also investigated within the study, also using the EDM. The authors assumed that an animal livestock traceability system would have a positive effect on the retail demand for beef. Demand shift scenarios were included in the model to determine the percentage increase in beef demand necessary to justify the costs of the livestock traceability system. Assuming the livestock traceability adoption rate was 90% in the US, it was found that a retail beef demand increase of 1% would be sufficient to cover all costs associated with animal identification.

Pendell (2006), used the NAADSM epidemiological software and employs an EDM to assess welfare consequences. The equilibrium displacement model is derived from a partial equilibrium framework; however, exogenous shocks can be included in the former. An epidemiological-economic model is employed to derive the local economic impact of a hypothetical FMD outbreak in southwest Kansas. A partial equilibrium model that included US beef, pork and poultry markets was used in conjunction with the equilibrium displacement model framework. The model included four marketing levels for beef, three marketing levels for swine and two marketing levels for poultry. Quantity transmission elasticities were used in the model to permit variable input proportions across marketing levels. Welfare measures and trade impacts at each of the marketing levels were derived in the study.

Epidemiological Model

An epidemiological livestock disease spread model is required to generate estimates of the scale and duration of a FMD outbreak; for this research the North American Animal Disease Spread Model (NAADSM) was selected. NAADSM is a is a stochastic simulation model, allowing for the inclusion of probabilistic parameters to predict the disease spread and is commonly used to model FMD outbreaks at the regional level. It becomes a working epidemiological model when specific disease parameters, animal movement information, a disease control strategy and herd demographic data is integrated into the framework. The non-deterministic framework requires numerous disease outbreak iterations to provide robust model outputs. Disney et al (2001), Dubé et al (2009), Pendell (2006), and Pendell et al (2007) have used 1,000 iterations of the disease spread to provide sufficient convergence of the output values' statistical means; the same number of iterations was selected for the research reported here.

The NAADSM framework requires extensive herd demographic, disease attribute, and livestock movement data. In addition, parameter estimates are also needed to model disease detection, disease control strategies and animal tracing capabilities. Although disease spread models have been previously used by the CFIA to model disease outbreaks in the Ontario livestock population, the parameters employed were not publically available. Many of the disease spread model parameters are spatially sensitive, prompting the need for Ontario-specific data.

Herd demographic data is required by NAADSM to incorporate spatial considerations in the models' indirect contacts, direct contacts, zone controls, and the probability of airborne disease spread. The specific demographic data required by the model is the geographical coordinates and herd size of every; cow-calf, feedlot, dairy and swine operation. This data was only available in Ontario for dairy operations, provided by the Dairy Farmers of Ontario organization (Lane 2009). Therefore, an estimation procedure was needed to approximate the distribution of both beef cattle and swine operations, as well as the distribution of animals among these operations. An approximation technique that utilized 2006 Census of Agriculture data combined with geographical information system software was implemented. This technique required data on the total number of operations and animals within each of Ontario's census division districts. The 2006 Census of Agriculture divided Ontario into over 250 districts, providing the number of operations (for each operation type) and the total number of animals for each district. Statistics Canada also provides geographical information system boundary files that create a layer of polygon shapes that represent each of these census districts in geographical space. Using the geographical information system software package ArcGIS®, the boundary file and the number of operations within each district, a random point generator created a number of geographical points in each boundary equal to the number of operations for each production type. This process was further refined using an ArcGIS® add-on program called "Hawth's Analysis Tools" that enabled the inclusion of a geographical layer where points could be excluded. Due to the inclusion of several large bodies of water in the Statistics Canada census division boundary file, a "lakes, rivers and streams" layer was used to prohibit the creation of geographical points in major bodies of water. Although the use of census divisions limit the number of points generated in urban areas, future research should use a geographical information systems program that can include multiple geographical layers that restrict the creation of data points in areas where cattle farms cannot exist (urban areas, national parks, etc.).

Following the creation of a number of geographical points equal to the number of operations in each census division, an assumption was required that the number of animals on each operation is equal to the average number of animals per operation within each census division. The 2006 Census of Agriculture included several regional data amalgamations for the purpose of respecting farmer privacy. A total of 70 census divisions were amalgamated into 20 representative regions; however, the data regarding the number of operations in each individual region was still available. Since only the total number of animals in these amalgamations was provided, the average number of animals in the amalgamated district was used for each component of the amalgamation. This is the most commonly used practice within the CFIA and USDA for estimating livestock demographic data at the time of writing; however, improvements can be made. If statistical measures were available concerning the distribution of animals within each region, the uniformity created by assuming the number of animals on each operation is equal to the average could be relinquished.

The parameters used in NAADSM to determine the rate of disease spread include the direct animal contact rate, the indirect contact rate, and the herd-level disease state durations. The direct animal contact rates were obtained from an average of a survey of Ontario livestock auction houses and the parameters used by the CFIA in a NAADSM model of a FMD outbreak in the Maritimes. Due to the non-existence of a formal publication of the CFIA Maritime FMD model, the parameters adopted from this model have been referenced as personal communication with the model designer, Dr. Emery Leger, a senior veterinarian with the CFIA. The data used in the CFIA Maritimes study were obtained based on expert opinion within the Canadian animal health community and industry personnel. The Ontario livestock auction house survey obtained estimates from four of the seven auction house managers surveyed. The questions regarded the frequency of animal shipments between different operation types. The survey was implemented to account for differences in livestock industry practices between the Maritimes and Ontario. Further details pertaining to the NAADSM model can be found in Jones (2010).

The probability of successfully tracing an indirect contact was held constant across all traceability scenarios at 50% for all production types, equal to the parameter chosen for the CFIA Maritime model. Pendell (2006) assumed that the level of animal identification and recording system would affect the tracing of indirect contacts. The current study assumes that the probability of a successful indirect contact would be impacted by individual farm-level and farm-related personnel record keeping practices rather than by the animal identification and movement recording system. NAADSM is a herd-based model, and indirect contacts between herds are modeled as contact between premises that do not directly involve the movement of animals. When a veterinarian, milk-truck, or maintenance individual completes an indirect contact between an infected and susceptible herd, this study assumes that the probability of successfully tracing that contact would be independent of the animal identification system. This implies that the animal identification system only stores information regarding individual animals' current and previous premises. If the traceability system also linked indirect contacts with the premise, the animal identification and movement recording system would impact the ability to trace indirect contacts. This assumption significantly reduces the impact of the traceability system on controlling the disease outbreak. Three scenarios were used in this study to represent different levels of animal identification and recording systems. The NAADSM parameter that reflects the probability of a successful trace following an animal movement between herds was set to; 30% for low, 60% for medium and 95% for high.

Economic Model

Calculation of the economic impacts of a traceability system in the event of an animal disease outbreak involves the implementation of an equilibrium displacement model within a partial equilibrium framework of the Canadian live cattle and beef markets. Two exogenous shifts generated by a FMD outbreak are incorporated into the model: (1) a negative supply shock to feeder and fed cattle markets, dependent on the number of animals destroyed and the outbreak control costs realized by the producer, and (2) the loss off export markets is included as a negative demand shift. The welfare changes at each marketing level is determined using annual baseline quantity values based on the length of the FMD outbreak as determined by the epidemiological model. The length of time required after the destruction of the last FMD infected animal for Canada to be judged a disease-free country and international trade to be resumed is also considered in the welfare calculation. The determination of the value of the animal traceability and recording systems in mitigating the economic consequences of the disease outbreak are ascertained using scenarios that reflect different levels of livestock tracing abilities. These traceability scenarios are compared to determine what effect traceability has on the epidemiological and economic results.

Table 1 defines the model variables used in economic analysis. The retail beef, wholesale beef, fed cattle and feeder cattle marketing levels are denoted by the superscript j, defined as r, w, s, and f, respectively. Markets are depicted by the subscript i; CAN denoted as the domestic Canadian market, E denoted as the export market, and NE denoted as the net export market. When a subscript is not included, it is assumed that the parameter represents the total Canadian output level or price. Exogenous parameters also included in the model are domestic demand and supply elasticities denoted as η^{j}_{CAN} and ε^{j}_{CAN} for each market level *j*, respectively. Lastly, as described in the two previous sections, the exogenous demand and supply shifts parameters are included denoted as z^{j}_{CAN} and w^{j}_{CAN} for each market level *j*, respectively.

Consumer surplus, defined as the difference between consumers' willingness-to-pay and the actual price paid at each output level, is calculated only at the retail level. Producer surplus, defined as the difference between marginal cost and price for each level of output, is calculated at each marketing level. Producer surplus at the retail level is representative of the surplus generated by the beef retailer, most commonly the grocery store. Alston, Norton, and Pardey (1995) show changes in surplus using the equations in Table 2. The E term in the change in surplus equations denotes a relative change operator (i.e. $EQ^{r}_{CAN} = \partial Q^{r}_{CAN}/Q^{r}_{CAN} = \partial \ln Q^{r}_{CAN}$).

The research reported in this study uses an EDM framework that follows the approach used by Pendell (2006). In this research, supply and demand equations are created for each marketing level within the beef supply chain. The equations in Table 3 outline the structural model. Previous studies included pork and poultry markets; however, this study will only include a beef market model. Pork and poultry markets were excluded from this analysis due to the unavailability of primary supply elasticities for the Canadian hog and poultry markets; the implications of this exclusion are discussed in the final section of this paper.

Vertical linkages between Canadian feeder cattle, fed cattle, wholesale beef and retail beef markets are incorporated into the model through the use of quantity transmission elasticities. The quantity of exports within the structural model is treated as exogenous, due to the model's trade demand shock assumption, which assumes all exports will equal zero immediately following a FMD outbreak. A primary supply equation is specified for the feeder cattle market; this equation is not dependent on any other marketing level. The derived supply equations for all other marketing levels require downstream relationships that link the supply of each marketing level to the quantity domestically available in the underlying market. For instance, fed cattle supply is related to the quantity of feeder cattle available domestically. Therefore, supply linkages in this model relate market supply to the total quantity supplied in the underlying market minus the quantity provided to that marketing level's export market. Vertical market linkages also exist on the demand side; however, total demand (domestic + exports) is included in the intra-market demand relationships for all cases. All upstream demand linkages are related to the primary demand function for beef at the retail level. Transmission elasticities are also included to relate the output quantities in each marketing level. In the wholesale beef market, where both exports and imports are present in the market, instead of an 'exports' measure a 'net exports' term is included that subtracts the level of imports from the quantity exported. In order to treat the 'net exports' quantity as exogenous to the model, an assumption regarding effects upon imports in the case of a FMD outbreak is required. This model assumes that following a FMD outbreak, all wholesale beef imports are immediately substituted with domestic beef.

The supply shift parameter, W^{j}_{CAN}, represents the negative production effects generated by the FMD outbreak at the *j*th market level. This shift is comprised of two primary impacts: the direct disease control costs that are assumed to be borne by the producer and the percentage of feeder and fed cattle destroyed. The direct disease control costs are the summation of all costs associated with disease containment and eradication. This analysis focuses on the short-run economic impacts of a FMD disease outbreak, thus in order for direct disease control costs to shift the supply curve of the entire industry, several assumptions are required. Current policy in Canada does not require firms in the cattle industry to internalize the monetary risks of controlling a foreign disease outbreak. However, if firms were expected to internalize these uncertain costs into their production decision, the marginal cost of production would be affected due to the fact that exposure to this risk increases with the number of animals owned. The direct outbreak cost scenarios discussed in this section do not assume that a single fixed cost shock would alter the short-run marginal cost of production but reflect situations in which producers were to internalize these risks into their production decisions. The expected direct disease control costs are used, implying that all producers are risk neutral.

A partial budgeting framework will be developed to aggregate the direct short-run costs of the hypothetical disease outbreak. These direct costs include surveillance, disinfection, slaughter, and government reimbursement. In a similar framework used by Disney et al. (2001), the mean output values generated by the contagious disease spread model were used to compute these direct outbreak costs. The disease outbreak model outputs are multiplied by the per-unit costs for disinfection, slaughter, government reimbursement and surveillance costs. For clarification, slaughter costs include the removal, euthanasia and disposal of the infected herds and surveillance costs. The contagious disease spread model provides 28 output parameters in both per-animal or per-herd form, and when combined with the disease eradication procedures in the Canadian FMD hazard specific plan, these costs are easily calculated.

The direct disease outbreak cost shock is required by the EDM framework as a percentage change of the total market. The percentage change in the cost of supplying output in the *j*th market level, $EW^{j}_{CAN,}$ is calculated using the methodology of Pendell (2006), separately for both the disease outbreak costs and culled animal costs. Firstly, the direct disease outbreak cost impact is calculated. The total industry value is approximated for both feeder and fed cattle markets using the average animal weight multiplied by the price per animal type in $/cwt. The percentage change in cost is calculated as the direct cost of the disease outbreak divided by the total value of the industry.

It is assumed that the view of Canada's FMD-free status as a public good among producers is the rationale that supports government funded animal health programs. However, this ignores the fact that consumers are excluded from realizing the benefits from these government funded programs. FMD-free status allows all producers in Canada the ability to trade with other FMD-free status countries regardless of their individual concern for animal health, signifying a non-excludability characteristic. An individual producer's trade with an FMD-free status country is minimally affected by the actions of other producers. However, this would not be the case if Canadian exports did affect world prices. The perception that Canada's FMD-free status is a public good among producers does not justify government funded programs that benefit animal health. The required non-rivalrous and non-excludability characteristics only exist among producers, whereas taxpayers are expected to subsidize the industry. This sensitivity analysis is constructed to demonstrate the economic effects of producers having to internalize the realized monetary risk of experiencing an FMD outbreak.

The portion of the supply shock caused by the destruction of animals is computed by calculating the percentage change in total animals before and after the disease outbreak. Unlike the direct cost estimates, where costs were assumed to be split equally between feeder and fed cattle producers, the NAADSM disease spread framework allows for the number of feeder and fed animals destroyed during the FMD simulation scenarios to be separated. The percentage of feeder and fed cattle destroyed in a particular traceability scenario outbreak relative to the total Canadian feeder and fed cattle supply is calculated.

A negative trade demand shift is included in the model to portray the effects of losing export markets at the feeder cattle, fed cattle and wholesale beef market levels. This model assumes an FMD outbreak in Canada would immediately halt all Canadian exports of live cattle and beef. In the feeder and fed cattle markets, the total quantity demand at each market level is assumed to equal the quantity exported to the United States plus the quantity used in the domestic market. This assumption ignores the small number of feeder animals imported from the US each year, totaling less than 0.5% of the Canadian total feeder cattle supply (Canfax 2010). For the case of the wholesale beef market, the negative trade demand shock is set equal to the total quantity of exports minus total imports, totaling net exports. Using the measure of net exports in this situation implies that domestic wholesale beef prices will drop below international market clearing prices, and imports will be completely replaced by domestic production.

The export demand price and elasticity are not included in the export demand equation due to the complete loss of this market following the disease outbreak. Previous partial equilibrium models involving a country whose trading practices impact the international price incorporate the export price as an endogenous variable. In this case, the exogenous shock of a FMD outbreak is assumed to immediately set the export price and quantity equal to zero. When EDMs incorporate international trade, a new export quantity would be computed based on the relative changes in foreign and domestic prices. In a situation where exports are disallowed entirely, the production decision, domestic price, export quantity and domestic demand are not correlated to the international price. This renders the inclusion of an export price and the subsequently required export demand elasticity as irrelevant in the current model. If domestic prices were to increase to a level higher than the international price following a FMD outbreak, foreign prices would then become a factor due to the existence of imports into the supply chain. In addition, in many countries such as China, India and Russia, FMD is endemic to the domestic livestock population. This model also assumes that trade with countries that have a positive FMD status will not occur.

It is important to note that since the export market is not modeled in this framework, an accurate calculation of the change in consumer demand is possible at the retail level only because of the absence of exports in this market. By excluding information regarding the slope of the total demand curve from feeder, fed and wholesale beef markets, changes in welfare can only be computed beneath the price line. The initial baseline quantity in the feeder, fed and wholesale beef markets is included only as a point of reference to compute producer surplus. For these markets, only the slope of the domestic demand function is needed to determine the changes in price and quantity. In the retail beef market, the total demand function is required to determine consumer surplus changes; however, total demand is equal to domestic demand in this market.

Within the percentage change equations, the domestic and export market quantity fractions are exogenous to the EDM. These fractions represent the portion of the total demand either consumed domestically or exported as a fraction of total market output. These fractions are included for the purpose of relating percentage changes in either situation to the total demand. The percentage change equations were derived from total differentiating the structural model. The E term represents a percentage change operator, e.g. $EQ^r_{CAN} = \partial Q^r_{CAN}/Q^r_{CAN} = \partial \ln Q^r_{CAN}$. It is important to note that the percentage change equations relate changes among the model's endogenous variables. As an example for clarification, the first equation in the framework below asserts the percentage change in the quantity of retail beef is equal to the domestic demand elasticity multiplied by the percentage change in the domestic price of retail beef. The system of supply and demand equations (rearranged to matrix form) in Table 4 represents the EDM framework.

In order to construct the relative change system of equations, supply, demand and quantity transmission elasticities are required. Quantity transmission elasticities are simply a statistical relationship between output levels across marketing levels. The derivation of these parameters is conducted using time-series output data from two marketing levels in a regression framework. The choice to use short-run supply and demand elasticity estimates in this study is made due to the dynamics of the FMD outbreak economic consequences. Preliminary results from the FMD spread model have produced disease outbreaks with durations that do not exceed six months. The World Organization for Animal Health (OIE) has recommended that no FMD-susceptible products or animals be exported for three months following the destruction of the last infected animal (OIE 2009). Since the supply and trade demand shocks are temporary, a long-run analysis using long-run elasticities cannot be justified. Using a static form of an EDM only depicts the immediate short-run effects of the outbreak.

For the purpose of providing a robust analysis, all elasticities used in the model will be increased and decreased by fifty percent. This analysis will create four elasticity scenarios, including; all supply functions become 50% more inelastic, all demand functions become 50% more inelastic, all supply functions become 50% more elastic, and all demand functions become 50% more elastic. The value of 50% was arbitrarily chosen to represent the relative importance of the accuracy of the elasticity measures used in the EDM. This sensitivity analysis will be conducted due to discrepancies in the time-frames used to derive each elasticity estimate.

The primary domestic beef demand equation implies that the cross-price elasticities between the direct substitutes of beef are zero. This is a limiting assumption due to the fact that a FMD will also affect the pork market, surely resulting in changes of the pork retail price. According to Statistics Canada (2006), over 5 million head of swine were exported to the US in 2003, a shock in domestic demand similar to that investigated in this study. Pendell (2006) and Brester, Marsh, and Atwood (2004) both included both pork and poultry markets to include this effect. The effect of not including these cross market effects in this research depends on the severity of the expected decline in retail pork prices in the event of a FMD outbreak. In addition, in the case that beef prices experience a substantial decline, consumers would alter their consumption bundle by reducing the quantity of poultry consumed and increasing the amount of beef consumed. This would result in a positive shift of the primary domestic beef demand function. The retail price changes modeled in this framework ignore this effect.

Elasticities used in the economic model are shown in Table 5. Several were derived from US market data due to the non-existence of Canadian equivalents, which are limited to the own-price elasticity for retail beef demand and the own-price elasticity for feeder cattle supply. This is important because Canadian retail beef demand and Canadian feeder cattle supply represent the primary functions of the partial equilibrium model, while the remaining supply and demand equations represent derived functions. Furthermore, all derived supply and demand functions are dependent on primary functions, strengthening the model's relationship to the Canadian context.

This research assumes that quantity transmission elasticities are equal between Canada and the US; this parameter is included in the analysis to allow for non-fixed proportions technology. The quantity transmission elasticity relates changes in output quantities at the various marketing levels to the quantity changes in both the primary feeder cattle supply and the primary retail beef demand functions.

The equilibrium displacement model requires baseline price and quantity data for each marketing level; 2008 was chosen as the baseline year due to Statistics Canada export data inconsistencies in 2009. Table 6 displays the baseline prices and annual quantities used in the current study, determined using the same methodology as Pendell (2006). Baseline quantities were derived from Statistics Canada and AAFC (2010). The equilibrium displacement model requires that the transmission elasticities relate the outputs from each marketing level in similar units. Therefore, total quantities in each market level are required to be in kg of beef. Total quantity of retail beef in Canada was determined by multiplying the Statistics Canada measure for beef available in 2008 (of 21 kg per person) by the total Canadian population in 2008. The total wholesale quantity of beef in carcass weight for Canada was determined by multiplying the total number of animals slaughtered in 2008 (3,524,200) by the average cold dressed weight of meat production in 2008 (355 kg). The total wholesale quantity of beef in carcass weight was then multiplied by the percentage of beef weight from carcass weight to determine a measure of total kilograms of wholesale beef. The percentage of beef weight from carcass weight was determined by dividing the Statistics Canada measure for beef available in carcass weight per person for 2008 by the beef available per person in 2008. This calculation determined that 73 percent of carcass weight is translated into beef weight. The total quantity of domestic wholesale beef in Canada was calculated by subtracting wholesale beef exports and adding wholesale beef imports to the total wholesale beef production in Canada. Import and export data for 2008 was provided by AAFC (2010).

Total fed cattle quantities were determined by multiplying the Statistics Canada 2008 estimate for "output of farm production" (4,964,900 head) by the average cold dressed weight of meat production. The number of feeder cattle exports to the US was subtracted from the farm production measure prior to this calculation. This number was then multiplied by the percentage of beef weight from carcass weight. Domestic fed cattle quantity in terms of kg of beef was then calculated by subtracting total fed cattle exports to the US in kg of beef terms from the total. An assumption regarding the average weight of a feeder animal was required to convert feeder cattle into per kg of beef terms. The average weight of a feeder animal was assumed to be 250 kg. In addition, a carcass weight percentage estimate was required to determine the percentage of total animal weight that would be converted into carcass weight; this measure was assumed to be 60 percent. The Statistics Canada measure for total calves under one year in 2008 (4,034,400) was converted into kg of beef terms using the assumed average animal weight, the carcass weight percentage, and the carcass weight to beef percentage. The same procedure was applied to total feeder animal exports to the US for 2008, obtained from AAFC.

Prices for the retail beef, wholesale beef, fed cattle and feeder cattle markets were obtained from Canfax (2010). The feeder cattle price was obtained from the average price of a 550 pound steer in Ontario and Alberta for 2008. The fed cattle price was determined as the average of Alberta and Ontario fed steer and heifer prices for 2008 (Canfax 2010). The average wholesale beef price was attained from the weighted average cutout value of AAA and AA boxed beef. The retail beef price obtained from a Canfax data specialist was the seven price Canadian average for 2008, used by the cattle and beef industry (Grant 2010). Per-unit direct cost parameters of controlling a FMD in Canada were obtained from a 2010 Serecon Management Consulting of the economic impact of several FMD outbreak scenarios for British Columbia. Cost estimates included in the study were disposal, surveillance, euthanasia, indemnity, cleaning, and disinfection, and came from CFIA personnel and equipment cost estimates.

Results

This paper presents epidemiological and economic model results pertaining to the medium direct contact rate scenario; findings for the high contact rate and reduced movement contact rate scenarios can be found in Jones (2010). The epidemiological results for the medium direct contact rate scenario most relevant to the current analysis are displayed in Table 7, which clearly depicts an indeterminate effect of cattle traceability parameters on the disease spread model outputs. The difference in the mean value of the disease outbreak duration after 1,000 iterations between the low and high traceability scenarios is minimal. The low traceability scenario's mean outbreak duration is approximately one day longer than the high traceability scenario. However, the total number of animals destroyed is actually higher in the situation with higher cattle traceability. Much of the ambiguity in the results for the medium contact rate scenario can be explained by the number of farms infected by the different forms of disease spread. As noted in Table 7, the number of farms infected by direct contact is small relative to the number of farms infected through indirect contact and airborne transmission.

The low relative number of direct contact disease transmissions significantly reduces the impact of the traceability system on the model outputs, since the current study assumes that cattle traceability has no direct affect on other forms of disease transmission. When the number of direct animal contacts is compared to the total number of disease transmissions, three percent of the total disease transmissions are impacted by the traceability system in the medium contact rate scenario. The mean value of farms that were directly exposed and successfully traced in each outbreak also explains the minimal impact of cattle traceability within this scenario. Table 7 illustrates that on average, between 0.73 and 2.15 directly exposed farms were successfully traced, across all traceability scenarios.

The direct disease control outbreak costs for the medium contact rate are presented in Table 8. The mean total direct cost of a FMD outbreak in Ontario for this scenario is determined to be between $205 million and $206.6 million Canadian dollars. Approximately 94 percent of these costs are attributed to the cost of enforcing movement restrictions through the setup of infected and restricted control zones. The direct disease outbreak costs for this disease outbreak scenario are not impacted by the level of cattle livestock traceability, shown by the increased costs in the medium traceability scenario relative to both the high and low traceability scenarios. The higher direct disease outbreak control cost in the medium traceability scenario is attributed to a larger number of animals destroyed and a higher number of control zones.

The exogenous supply shocks to the Canadian fed and feeder cattle markets are displayed in Table 9. The values in this table represent a percentage shock to the entire Canadian fed and feeder cattle markets. The results shown in table 9 represent a situation where direct disease control costs are divided equally between producers and the government. These shocks were affected when the assumptions regarding who bears the direct disease outbreak costs were changed to either the producer or government. The number of animals destroyed as a percentage of the entire Canadian markets was minimal for both the fed and feeder cattle markets. The effect of traceability on this type of supply shock represented less than one-hundredth of a percentage point for both markets.

Table 10 illustrates the welfare changes generated by FMD from the medium contact rate scenario, totaling a negative change in welfare of approximately $4.2 billion across all marketing levels. Total consumer welfare, as measured by the change in consumer welfare at the retail level, experienced a larger positive welfare change in the low traceability scenario relative to the scenario with high traceability. This is caused by the slightly longer outbreak duration. The supply shock in this scenario was too small to produce a measurable effect on the entire Canadian market. Relative to the high traceability scenario, the medium traceability situation had a higher number of animals destroyed and had higher direct disease outbreak costs. However, the medium contact rate scenario had a smaller negative total change in welfare. The mean difference in welfare changes between the low and high traceability situations for the medium contact rate scenario was $22 million, a difference of half of one percent.

Conclusions

The research reported in this paper involved the construction of an epidemiological FMD spread model for Ontario using the NAADSM framework. Disease simulations were produced to reflect different levels of cattle traceability. This was accomplished using variations of the parameter that reflects the probability of a successful direct animal trace. The epidemiological model outputs were then used to calculate the direct disease control costs of an FMD outbreak in Ontario. Indirect costs of an FMD outbreak were calculated for each level of cattle traceability using an EDM framework that incorporated negative demand shocks from to the loss of export markets and negative supply shocks caused by the disease outbreak. Parameter sensitivity was investigated within both the epidemiological and economic model.

It was found that under a medium direct contact rate scenario, an FMD outbreak could be expected to last around 81 days, infect approximately 60 farms, and result in the destruction of somewhere in the order of 15,000 animals (beef and dairy cattle as well as swine). Direct disease outbreak costs would total around $205 million with an overall welfare loss of close to $4.2 billion (by comparison Mitura and Di Pietro (2004) estimated the 2002-2003 loss of live beef cattle exports caused an overall loss to the Canadian economy of $5.7 billion). None of these results change much in the presence of a “medium” or “high” vs. “low” traceability scenario, as measured by the probability of a successful trace. The implication of this is that increasingly more sophisticated traceability systems may not be warranted, at least from the perspective of mitigating the effects of an animal disease outbreak.

The research presented in this paper provides a valuable starting point for future epidemiological-economic modeling research in Canada. The stochastic nature of the outputs generated by the NAADSM framework allows for future research to incorporate the statistical properties of the disease spread model outputs, rather than only using the mean model outputs. This approach would allow the economic model to take account of the possibility of worst case disease outbreak scenarios. Incorporating an economic model with stochastic inputs would generate a distribution of direct costs and welfare changes for each scenario. The version of NAADSM used in this analysis only incorporates a trace-forward instrument in the framework. This fails to include the potential benefit generated by a full cattle traceability system with regard to improving the ability to trace the source of an infected herd. Also, future versions of NAADSM want to include more options regarding cattle tracing in the event of a disease outbreak, such as allowing for diagnostic testing of traced herds. Future research should attempt to obtain the most recent version of the software when deriving the benefits of such a traceability system.

In addition, this research demonstrated that model results are highly sensitive to the supply elasticity parameters used in the EDM. Stochastic elasticity parameters can also be incorporated into the current framework to reduce the dependency of model outputs on the accuracy of the elasticity parameters. A major drawback of using stochastic elasticity parameters is that a distributional form must be assumed. Depending on the number of different elasticity estimates available for each marketing level, the selection of this functional form is highly arbitrary and cannot be easily justified. The use of US elasticities as proxies for several of the derived marketing levels should also be listed as a model limitation.

Future EDM models used in a similar context to the current study should include swine and poultry markets. When relative prices change between beef, pork and poultry, product substitution would occur towards products with a reduced relative price. This effect is not incorporated in the current analysis, causing potential overestimates of the reduction in beef market welfare. Lastly, the economic model should optimally include dynamics to incorporate the re-opening of export markets. Rich and Winter-Nelson (2007) used a five year period to capture the impacts of changing access to export markets. The current model is designed to evaluate the economic effects up until the time that the boarder is re-opened. However, as demonstrated by the Canadian BSE crisis in 2003, market distortions caused by the closure of export markets would not be corrected instantaneously.

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Table 1. Parameter definitions used in the economic analysis

Parameter	Definition
Q^j_i	Quantity at the *j*th marketing level in market i
P^j_i	Price at the *j*th marketing level in market i
Z^j_i	Demand shift at the *j*th marketing level in market i
W^j_i	Supply shift at the *j*th marketing level in market i
η^j_i	Own-price demand elasticity *j*th marketing level in market i
ε^j_i	Own-price supply elasticity *j*th marketing level in market i
τ^{jy}	Transmission elasticity between two marketing levels
Markets (i)	**Definition**
CAN	Domestic Canadian market
E	Export market
NE	Net export market
Marketing Levels (j)	**Definition**
r	Retail beef
w	Wholesale beef
s	Fed cattle (slaughter)
f	Feeder cattle

Note: The term y is a marketing level ≠ *j*.

Table 2. Welfare change equations

Economic Measure		Equation
Change in consumer surplus for retail marketing level	=	$-P^rQ^r(EP^r - z^r)(1 + 0.5EQ^r_{CAN})$
Change in total producer surplus	=	$\sum^j(\Delta PS^j)$
Change in producer surplus at marketing level j	=	$P^jQ^j(EP^j - w^j)(1 + 0.5EQ^j)$

Source: Alston, Norton, and Pardey (1995)

Table 3. Partial equilibrium model structure

Retail Beef Market			
Primary Domestic Demand	Q^{r}_{CAN}	=	$f_1(P^{r}_{CAN})$
Derived Total Supply	Q^{r}_{CAN}	=	$f_2(P^{r}_{CAN}, Q^{w}_{CAN})$
Wholesale Beef Market			
Derived Domestic Demand	Q^{w}_{CAN}	=	$f_3(P^{w}_{CAN}, Q^{r}_{CAN})$
Net Exports	Q^{w}_{NE}	=	$f_4(Z^{w}_{E})$
Total Demand	Q^{w}	=	$Q^{w}_{CAN} + Q^{w}_{NE}$
Derived Total Supply	Q^{w}	=	$f_5(P^{w}_{CAN}, Q^{s}_{CAN}, W^{w}_{CAN})$
Fed Cattle Market			
Derived Domestic Demand	Q^{s}_{CAN}	=	$f_6(P^{s}_{CAN}, Q^{w})$
Exports	Q^{s}_{E}	=	$f_7(Z^{s}_{E})$
Total Demand	Q^{s}	=	$Q^{s}_{CAN} + Q^{s}_{E}$
Derived Total Supply	Q^{s}	=	$f_8(P^{s}_{CAN}, Q^{f}_{CAN}, W^{s}_{CAN})$
Feeder Cattle Market			
Derived Domestic Demand	Q^{f}_{CAN}	=	$f_9(P^{f}_{CAN}, Q^{s})$
Exports	Q^{f}_{E}	=	$f_{10}(Z^{f}_{E})$
Total Demand	Q^{f}	=	$Q^{f}_{CAN} + Q^{f}_{E}$
Primary Total Supply	Q^{f}	=	$f_{11}(P^{f}_{CAN}, W^{f}_{CAN})$

Table 4. Percentage change equations in matrix form

Cattle Market Equations		
$EQ^{s}_{CAN} - \eta^{s}_{CAN} EP^{s}_{CAN} - \tau^{sw} EQ^{w}$	=	0
EQ^{s}_{E}	=	Ez^{s}_{E}
$EQ^{s} - (Q^{s}_{CAN}/Q^{s})EQ^{s}_{CAN} - (Q^{s}_{E}/Q^{s})EQ^{s}_{E}$	=	0
$EQ^{s} - \varepsilon^{s}_{CAN} EP^{s}_{CAN} - \tau^{sf}(Q^{f}_{CAN}/Q^{f})EQ^{f}_{CAN}$	=	Ew^{s}_{CAN}
$EQ^{f}_{CAN} - \eta^{f}_{CAN} EP^{f}_{CAN} - \tau^{fs} EQ^{s}$	=	0
EQ^{f}_{E}	=	Ez^{f}_{E}
$EQ^{f} - (Q^{f}_{CAN}/Q^{f})EQ^{f}_{CAN} - (Q^{f}_{E}/Q^{f})EQ^{f}_{E}$	=	0
$EQ^{f} - \varepsilon^{f}_{CAN} EP^{f}_{CAN}$	=	Ew^{f}_{CAN}
Beef Market Equations		
$EQ^{r}_{CAN} - \eta^{r}_{CAN} EP^{r}_{CAN}$	=	0
$EQ^{r}_{CAN} - \varepsilon^{r}_{CAN} EP^{r}_{CAN} - \tau^{rw}(Q^{w}_{CAN}/Q^{w})EQ^{w}_{CAN}$	=	0
$EQ^{w}_{CAN} - \eta^{w}_{CAN} EP^{w}_{CAN} - \tau^{wr} EQ^{r}_{CAN}$	=	0
EQ^{w}_{NE}	=	Ez^{w}_{NE}
$EQ^{w} - (Q^{w}_{CAN}/Q^{w})EQ^{w}_{CAN} - (Q^{w}_{NE}/Q^{w})EQ^{w}_{NE}$	=	0
$EQ^{w} - \varepsilon^{w}_{CAN} EP^{w}_{CAN} - \tau^{ws}(Q^{s}_{CAN}/Q^{s})EQ^{s}_{CAN}$	=	Ew^{w}_{CAN}

Note: The term E denotes a percentage change operator, e.g. $EQ^{r}_{CAN} = \partial Q^{r}_{CAN}/Q^{r}_{CAN} = \partial \ln Q^{r}_{CAN}$.

Table 5. Short-run elasticity definitions, sources, and values

Parameter	Definition	Value
η^{r}_{CAN}	Own-price elasticity for Canadian retail beef demand[a]	-0.23
η^{w}_{CAN}	Own-price elasticity for wholesale beef demand[b]	-0.57*
η^{s}_{CAN}	Own-price elasticity for fed cattle demand[c]	-0.6*
η^{f}_{CAN}	Own-price elasticity for feeder cattle demand[c]	-0.887*
ε^{r}_{CAN}	Own-price derived retail beef supply elasticity[d]	0.36*
ε^{w}_{CAN}	Own-price derived wholesale beef supply elasticity[d]	0.28*
ε^{s}_{CAN}	Own-price derived Canadian fed cattle supply elasticity[c]	0.26*
ε^{f}_{CAN}	Own-price derived Canadian feeder cattle supply elasticity[a]	0.2
τ^{rw}	% change in retail beef quantity given a 1% change in wholesale beef quantity[e]	-1.02*
τ^{wr}	% change in wholesale beef quantity given a 1% change in retail beef quantity[e]	-1.03*
τ^{ws}	% change in wholesale beef quantity given a 1% change in fed cattle quantity[e]	-0.94*
τ^{sw}	% change in fed cattle quantity given a 1% change in wholesale beef quantity[e]	-1.02*
τ^{sf}	% change in fed cattle quantity given a 1% change in feeder cattle quantity[e]	-0.97*
τ^{fs}	% change in feeder cattle quantity given a 1% change in fed cattle quantity[e]	-0.78*

Note: * Elasticities were unavailable for Canada and are assumed to be the same as the US.
Sources: [a] FAPRI (2010); [b] Marsh (1992); [c] Marsh (1994); [d] Brester, Marsh, and Atwood (2004); [e] Pendell (2006)

Table 6. Canadian beef market baseline prices and quantities for 2008

Market	Quantity (million kg of beef*)	Price ($/kg)
Domestic Retail Beef	709.2[a]	12.17[c]
Domestic Wholesale Beef	677.3[a]	3.65[c]
Wholesale Beef Imports	151.3[b]	-
Wholesale Beef Exports	387.2[b]	-
Domestic Fed Cattle	891.1[a]	1.98[c]
Fed Cattle Exports	232.1[b]	-
Domestic Feeder Cattle	372.7[a]	2.31[c]
Feeder Cattle Exports	69.0[b]	-

Note: * Prices and quantities for feeder and fed markets converted into per kg of beef terms, the details of this conversion are described in 5.2.2
Sources: [a] Statistics Canada (2010); [b] AAFC (2010); [c] Canfax (2010)

Table 7. Epidemiological model results for medium direct contact rate scenario

	Traceability Scenario		
Output Statistic	Low	Medium	High
Outbreak duration (days)	81.77	81.46	80.73
Standard deviation of outbreak duration	34.19	35.96	33.58
Number of infected zones	64.37	65.50	63.92
Number of farms directly exposed and successfully traced	0.73	1.46	2.15
Number of farms infected by direct contact	2.37	2.43	2.41
Number of farms infected by indirect contact	5.56	5.55	5.65
Number of farms infected by airborne transmission	55.91	57.30	56.06
Beef cattle destroyed (head)	3,876	3,949	3,895
Dairy cattle destroyed (head)	1,566	1,611	1,608
Swine destroyed (head)	9,512	9,847	9,766
Total animals destroyed (head)	14,953	15,407	15,269
Standard deviation of total animals destroyed	9,843	11,122	9,843

Note: Results display the mean output values of 1,000 iterations of the disease spread.

Table 8. Direct disease outbreak costs generated by the medium contact rate scenario

Disease Outbreak Cost	Operation Type	Traceability Scenario Low	Medium	High
Surveillance	All	193,822,093	197,097,688	192,051,635
Indemnity	Beef	3,682,096	3,751,094	3,699,946
	Dairy	3,131,400	3,222,960	3,216,740
	Swine	1,398,235	1,447,538	1,435,537
	Total	8,211,730	8,421,592	8,352,223
Euthanasia	Beef	387,589	394,852	389,468
	Dairy	156,570	161,148	160,837
	Swine	190,236	196,944	195,311
	Total	734,395	752,944	745,616
Cleaning and Disinfection	Beef	775,178	789,704	778,936
	Dairy	313,140	322,296	321,674
	Swine	237,795	246,180	244,139
	Total	1,326,113	1,358,180	1,344,749
Disposal	Beef	1,550,356	1,579,408	1,557,872
	Dairy	626,280	644,592	643,348
	Swine	380,472	393,888	390,622
	Total	2,557,108	2,617,888	2,591,842
	Total direct outbreak cost	$206,651,439.23	$210,248,291.90	$205,086,065.92

Note: Results displayed are calculated from the mean values of 1000 iterations of the disease spread.

Table 9. Exogenous supply shocks generated by the high contact rate scenario

	Traceability Scenario		
	Low	Medium	High
Direct Disease Control Costs			
Fed cattle	-0.68%	-0.66%	-0.65%
Feeder cattle	-0.08%	-0.08%	-0.07%
Animals Destroyed			
Fed cattle	-0.11%	-0.11%	-0.11%
Feeder cattle	-0.01%	-0.01%	-0.01%

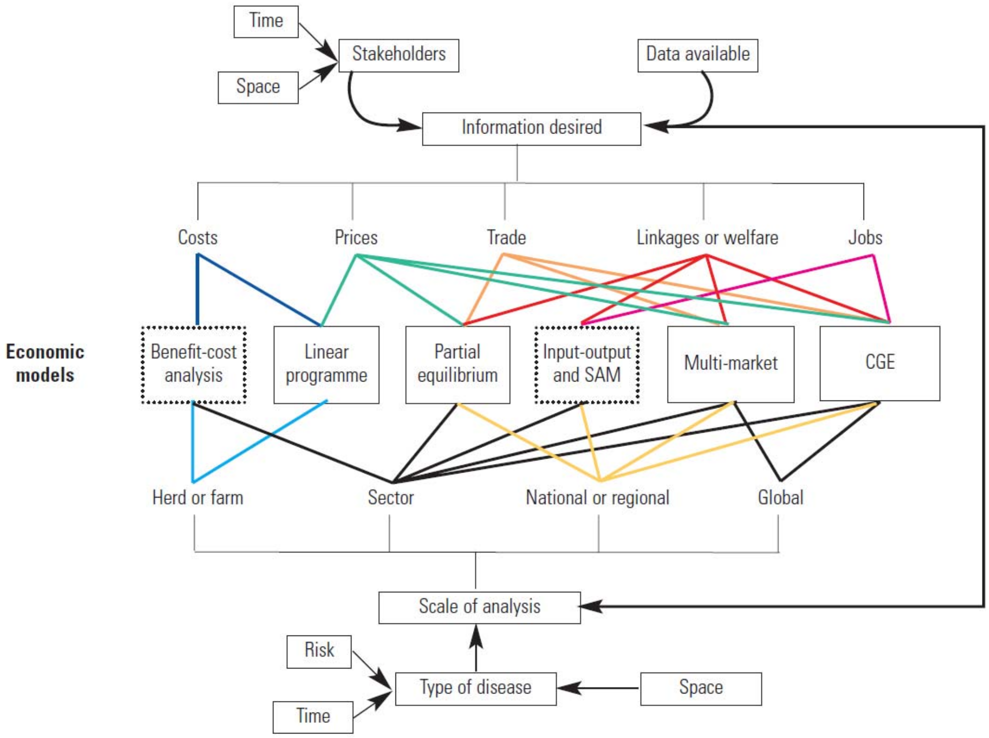
Notes: Results displayed are calculated from the mean output values of 1000 iterations of the disease spread. Outbreak costs are split between producer and government 50-50. Exogenous shocks are displayed as a percentage of the Canadian market.

Table 10. Welfare changes generated by the medium contact rate scenario

	Traceability Scenario		
	Low	Medium	High
Change in consumer welfare	659,478,325	658,546,996	655,030,642
Change in producer welfare			
Retail	-2,413,723,557	-2,408,934,263	-2,400,146,828
Wholesale beef	-851,771,437	-850,067,692	-847,013,136
Fed cattle	-1,143,955,447	-1,141,251,878	-1,138,469,676
Feeder cattle	-415,369,830	-414,794,811	-412,647,119
	-4,824,820,271	-4,815,048,645	-4,798,276,760
Total change in welfare	-$4,165,341,946	-$4,156,501,648	-$4,143,246,117

Notes: Results displayed are calculated from the mean output values of 1000 iterations of the disease spread. Direct disease control costs are barred by the producer.

Figure 1. Typology of economic models for animal disease analysis



Source: Rich, Miller, and Winter-Nelson (2005)