Modeling Ontario's Beef Sector:
A University of Guelph-OMAFRA Policy Model
MANUAL

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Acronyms

AAFC Agriculture and Agrifood Canada

CANSIM Canadian Socioeconomic Database from Statistics Canada

CCIA Canadian Cattle Identification Agency

FARE Department of Food, Agricultural & Resource Economics, University of Guelph

FAPRI Food and Agricultural Policy Research Institute

IASFAP The Institute for the Advanced Study of Food and Agricultural Policy

OCA Ontario Cattlemen's Association

OMAF The Ontario Ministry of Agriculture and Food

SSM The Static Simulation Model

SSM-L The Long Static Simulation Model

Chapter 1

Introduction

This manuscript documents the structure, function and limitations of the policy model of Ontario's beef sector jointly developed by the Ontario Ministry of Agriculture and Food (OMAF) and the Institute for the Advanced Study of Food and Agricultural Policy (IASFAP) at the University of Guelph. It's main uses are as follows:

- provides a framework with which to identify the key structural relationships which govern the industry;
- it allows policy makers to identify estimated demand and supply elasticities for an improved understanding of the relationships between variables of interest at various stages of the supply-chain; and
- it permits comparative statics to be preformed - i.e. it allows for counterfactual scenarios to be contrasted with a representation of what occurred over a given time period.

The first point is beneficial in that it illuminates the linkages between the farm-level, processing and retailing stages of the provincial beef supply chain. This required identifying the linkages between cattle and beef markets in Ontario, the U.S. and Western Canada, as well as the capacity constraints which restrict supply responses to price changes in the short-run. This was central to the model's development as how accurately these relationships are captured dictates the accuracy of the model's estimates. An secondary benefit of this process is that it serves as a pedagogical tool for policy analysts with limited understanding of the provincial beef sector.

The second point – the estimation of price elasticities – is crucial for economic analysis. Elasticities are a unitless measure of how responsive changes in output are to changes in prices and income. If elasticities are assumed rather than estimated, selection of elasticities in effect become analogous to using a second-best approach of arbitrarily choosing the appropriate relationship, which can detract from the validity of the results (even if the assumed relationship is identical or close to the actual one) and/or result in inaccurate estimates of the degree to which a change in a variable will influence output would be over/understated. In short, the empirical estimation of elasticities from data is preferable, as it allows for the relationships between outcome and independent variable to be obtained in a way that is free of potential subjective biases.

The third benefit identified above is the fundamental driver behind the initiative to develop the model. This model allows us to estimate the impact of shocks or policies for "what if?" questions. What it allows us to do is impose an exogenous shock on the model and examine how the resulting market outcome compares to what occurred in the baseline scenario.[1] The baseline scenario is a calibrated representation of what actually occurred in each of the quarters in the most recent year(s), which is then contrasted with the outcomes arising in the counterfactual scenario when a shock is applied. Thus, throughout this report, one may notice constant reference to the baseline and counterfactual estimates, this is analogous to us referring to the state of the industry if no shock is applied (the baseline scenario), and the state of the industry if a exogenous shock imposed on the model (the counterfactual scenario). In order to cross-validate the model's predicative capacity, a section entitled *Predicative Error* is included in the model to compare how well the baseline scenario represents the actual observed outcome for the year in question. Taking this approach allows us to isolate the change in the endogenous variables attributable to the variation in a (exogenous) variable affecting the industry at given stages. Discussion of how the outcomes are contrasted will be discussed further in section seven: *Application of the model*.

There are two versions of this model. The first is the *Static Simulation Model (SSM)* which offers a simplified version of the model intended for quick assessment of shocks or policy changes. The second model is referred to as the *Long Static Simulation Model (SSM-L)*. The latter is differentiated from the former, in that the SSM only examines shocks which occur in a single year. While this simplifies the analysis, it fails to capture long-term consequences (benefits) of a shock to the industry. In contrast the SSM-L contains a dynamic component, which looks at a three year period and accounts for the dynamic relationships which characterize the beef sector. The relationships between various stages of production are complex and occur over time, and the cumulative effects of a shock may not be revealed for several years. Relative to the latter model, the SSM-L captures these long-term, dynamic relationships, where the SSM would not.

[1] An exogenous shock is defined here as a change in an independent variable. The word exogenous is used to describe a variable which is determined outside the model. For example, an increase in the provincial corn price from $7.00/bushel to $8.00/bushel.

Despite differences in the length of time they look at, the basic structure is identical for both. Each model is comprised of a series of structural equations and identities. The structural equations represent each variable of interest (e.g. the supply and demand of cattle, carcass weights, etc.) as a function of various explanatory variables (e.g. price of the good, price of inputs, previous output, etc.). The structural equations are then used to estimate the statistical relationship between each of the explanatory variables and the variable of interest. In other words, through use of regressions we are able to parameterize or estimate how the dependent variable changes if there is a change in one of the explanatory variables.

The second structural component of the models are the identities. Identities are axioms – relationships which are assumed to hold true. For example, we expect the sum of the provincial supply of calves and the imports of feeder calves from other provinces to equal the demand for feeder calves in a period (assuming there are no exports of calves from Ontario). Establishing these identities ensures that the values and quantities we seek to estimate do not yield unrealistic results.

As a final comment, this approach while predicative in nature is not a forecasting exercise. As we are estimating outcomes for a year which has occurred, we can ignore the potential influence of any unforeseen structural changes in the industry – that is unless we impose the change on the model. Forecasting requires making strong assumptions in order to predict what will or could occur, here we simply look at what **would have** occurred if the observed independent variables had different values.

This manual is organized as follows. The next section briefly describes the relevant characteristics of the Ontario beef sector. The third section lists the specifications of each structural/behavioural equations used to estimate the relationships identified in the previous section. The fourth section identifies the estimators and statistical tests used to generate the model's parameters. Section five lists the identities and equilibrium conditions imposed on the model. The sixth section provides examples of how the model is applied to questions which may arise in policy analysis. Section seven identifies any limitations of this approach, with the final section concluding.

Chapter 2

Overview of Ontario's Beef Sector

Developing a policy model of the Ontario beef sector first requires the identification of the structural relationships underlying the supply-chain. The first step was to identify the level of analysis that was to be undertaken. Previous studies (e.g., **?**, **?**, **?**, etc.) predominantly focus on what occurs at a national-level, as well as ignoring what occurs at the cow-calf and backgrounding sectors choosing to solely focus on what occurs in the fed and non-fed cattle markets. The limitation of this approach is evident when one is attempting to dissect the effect of a shock at each stage of the supply-chain. This latter point is not a moot one; especially since each stage of the supply-chain can represent different groups of producers, which is an important distinction to make since the purpose of the model is to assist in the development and assessment of different market-level policies.

Furthermore, as mentioned in the introduction, if one is assessing a shock in one period, say the first quarter of 2008, then the effects of the shock have both immediate and long-term effects. For example, an exogenous shock which harms the demand for fed cattle, say the closure or reduced capacity of Cargill, will result in a reduction in the provincial demand for feeder cattle at both the cow-calf and backgrounding stages. In the short-run, there is a reduction in the prices of fed cattle and in turn feeder cattle, this causes farmers at the cow-calf and backgrounding stages to reduce their production. In the long-run, there will be a reduction in herd sizes, the interprovincial imports of cattle, fewer fed animals, and less beef being processed provincially. As such, it was decided that disaggregating between the three stages of production at the industry-level would allow the model to be more versatile and useful, as this provides a venue for more detailed analysis. In other words, by estimating the demand, supply,

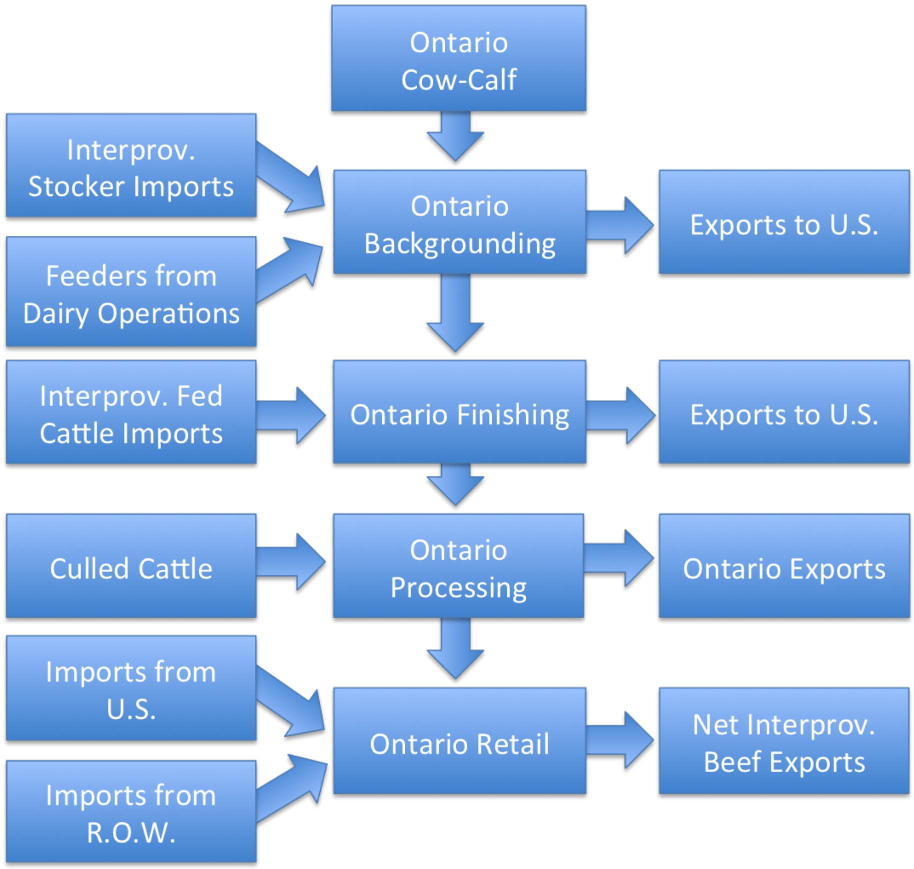

Figure 2.1: Supply Chain and Linkages of the Provincial Beef Sector

export and import equations at the cow-calf, backgrounding and finishing stages the model can be used to answer questions such as: "How would an increase in the Ontario feed price affect the interprovincial imports of feeder cattle?"

A downfall of modelling the sector this way (and a likely reason why no one has attempted to do this recently) is that it requires data on the cow-calf and backgrounding stages which was not previously available. As a result we had to infer any missing data. Much of the data used in this study was not explicitly collected by any agency, but was inferred by the authors using available data and informed assumptions.

Figure 2.1 is a flow chart representing the key relationships that we have identified. These relationships (inflows and outflows into/out of the provincial sector) vary between stages of production. The following sections will discuss the relationships for each stage of production, with specific focus on the generation of data for each of the inflows and outflows in figure 2.1, which are then used in the estimation of the structural/behavioural equations identified in chapter 3.

The remainder of this section is used to describe the various elements which define the provincial supply-chain. It begins by discussing the interprovincial movement of cattle into Ontario, which is then followed by subsections describing each stage in the supply-chain (cow-calf, backgrounding, finishing, and processing/retail).

2.1 Interprovincial Imports

One of the toughest challenges for this project is finding reliable estimates of the interprovincial movement of cattle by quarter and stage. CANSIM reports biannual counts of the total number of cattle imported into the province but fails to distinguish whether the animal is intended for an dairy or beef operation, and the stage of the animal. For simplicity, we assume that trade in dairy cattle between Ontario and other provinces is marginal and only representative of movement in the breeding stock/heifers, therefore, we ignore it here and assume that 100 percent of the reported interprovincial imports are beef cattle (table 2.1).[1]

While it does not explicitly list the disposition of the interprovincial imports of cattle, CANSIM does provide biannual spot counts of cattle by type (cow, calf, etc.) on each type of operation (e.g. cow-calf, backgrounding operations, or feedlots) for beef farms in each province. It is assumed here that the disposition of interprovincial imports into Ontario is indicative of the relative disposition of cattle in the western provinces. While it is plausible that beef cattle come in from the Maritime provinces, due to the small number of calves (Calves are used here as a proxy for the productivity of the provincial beef sectors) in the Atlantic provinces and Quebec relative to Western Canada, the majority of the interprovincial movements of beef cattle into Ontario likely originate from Manitoba, Saskatchewan and Alberta (table 2.2) as they represent the largest beef producing regions in Canada.

Therefore, we use both the biannual inventory counts on the disposition of cattle on each type of beef operation to determine the relative percentage of stockers, heifers and steers being imported into the province in a given quarter. We calculate, what we refer to as, the 'total number of exportable cattle,' a mea-

[1]Zone Canada – an institution dedicated to the traceability of livestock between provinces – administers a voluntary survey recording the movement of livestock between provinces. Survey results indicate that in July 2011 that only 4.4% of cattle shipments were dairy cattle, between January and July in 2012 2.57% shipments were dairy cattle, and in July 2012 only 5.8% of cattle shipments were dairy cattle.

Table 2.1: Ontario Biannual Interprovincial Imports and Exports of Cattle (2005–2012)*

Year	Period	Interprovincial Imports of Cattle	Interprovincial Exports of Cattle
2012	Jul. to Dec.	138.40	6.40
2012	Jan. to Jun.	79.10	8.00
2011	Jul. to Dec.	140.40	3.40
2011	Jan. to Jun.	81.90	24.90
2010	Jul. to Dec.	125.40	4.00
2010	Jan. to Jun.	92.90	14.40
2009	Jul. to Dec.	210.80	4.00
2009	Jan. to Jun.	111.30	20.90
2008	Jul. to Dec.	174.30	44.40
2008	Jan. to Jun.	100.10	51.50
2007	Jul. to Dec.	184.80	8.60
2007	Jan. to Jun.	123.90	24.50
2006	Jul. to Dec.	181.00	4.80
2006	Jan. to Jun.	132.60	23.80
2005	Jul. to Dec.	180.80	25.50
2005	Jan. to Jun.	132.70	5.50

*Note: CANSIM defines calves as being a year or under.
All figures are in 1000's of head.
Source: CANSIM, table 003-0083.

sure of the number of cattle that could have potentially been moved between provinces. The total number of exportable cattle is defined as the sum calves on cow-calf and backgrounding operations, and heifers and steers on both backgrounding[2] and finishing operations. We did not include any count of non-fed cattle (bulls and cows) as we assume that provincial slaughter plants will not import any non-fed animals as there is substantial supply originating from both the beef and dairy industry in Ontario. We also omit calves on finishing operations from this measure, as it is assume that once a calf has been purchased by a feedlot that it will not be resold, but rather put on feed.

Meetings with OCA board members revealed that the majority of the cattle imported from western provinces were typically between 500-900 lbs., which by our model's assumptions renders them as coming into the backgrounding sector. Thus, while it is quite plausible that some feeder calves come into the province at below 500 lbs., for tractability of the model, we intrinsically ignore this potential and assume that there are no interprovincial imports of feeder calves, just stockers entering in at the backgrounding stage. Before continuing,

[2]CANSIM uses the terminology 'feeding and stocking operations' to refer to the backgrounding stage.

Table 2.2: Provincial Inventory Counts of Calves, Jul. 1 (2005–2012)*

Year	Atlantic Provinces	Quebec	Ontario	Manitoba	Saskatchewan	Alberta
2012	47.6	212.6	306.9	451.6	1075.7	1697.4
2011	48.00	220.20	311.90	453.70	1082.60	1687.90
2010	45.60	226.90	323.80	475.90	1108.30	1699.20
2009	48.30	250.40	321.60	500.80	1123.50	1772.10
2008	56.30	247.40	333.50	533.60	1206.90	1914.90
2007	58.20	244.20	363.30	524.70	1334.30	1949.80
2006	57.30	248.10	376.50	616.90	1377.70	2040.30
2005	58.10	263.10	425.30	624.90	1418.20	2210.30

*Note: CANSIM defines calves as being a year or under.
All figures are in 1000's of head.
Source: CANSIM, table 003-0032.

an important distinction should be made here. In our model we define a feeder calf as one that lies within the weight range of 500-600 lbs., while CANSIM (table 003-0032) defines a calf an animal under one year of age. Since it takes approximately between 7-8 months for a calf to reach 500 lbs., this implies that CANSIM's definition of a calf is at odds with ours; and would include both animals coming in as feeder calves and stockers.

The percentage of interprovincial imports of stockers (feeder cattle) coming into Ontario is calculated as the sum of (according to CANSIM's definition): total number of calves on both cow-calf and backgrounding operations; steers and heifers on backgrounding operations; and the number of steers and heifers on cow-calf operations divided by the total number of exportable cattle for Manitoba, Saskatchewan and Alberta. This may seem convoluted, but again, since CANSIM defines any animal under one year as a calf, then we had to infer that any calf would qualify as a stocker by our definition. Similar intuition follows for why we consider steers and heifers on cow-calf operations as backgrounded animals; they will not have yet been put on feed on these types of operations, and are defined by CANSIM as a heifer or steer as they are over 1 year of age.[3] Considering it takes 24-26 weeks for an animal to complete the backgrounding stage, plus the 7-8 months it took a calf to achieve the 500-600 lbs. (the weight range required to complete the cow-calf stage), it is quite plausible that these animals qualify as stockers under our definition. Put another way, CANSIM would record an heifer as calf if it is 11.5 months old, while a heifer that is only 1 month older (12.5 months old) would qualify as a heifer by the CANSIM data

[3]When heifers are discussed here we are referring to heifers intended for slaughter. CANSIM (table 003-0032) distinguishes between heifers intended for replacement stock and those intended to be put on feed.

even though they would both be classified as stockers by our definition. We then take the weighted average of the ratio across the three Western provinces, and find that stockers typically represent 70-80% of the biannual interprovincial imports depending on the year.

Finally, we calculate the biannual proportion of interprovincial imports of fed heifers and steers as the number of heifers (steers) on feeding operation divided by the total number of exportable cattle. A weighted average of Manitoba, Alberta, and Saskatchewan then reveals that imports of fed heifers and steers on average represent roughly 6-9% and 8-14%, respectively, of interprovincial imports.

The aforementioned ratios for each biannual period are then multiplied by the biannual number of interprovincial imports reported by CANSIM (table 2.1) to generate an estimate of how many cattle at each stage were imported. In order to capture seasonality associated with the calving cycle in the western provinces, each estimate was also multiplied by the proportion of calves born each month as reported by the CCIA survey lagged the appropriate amount of time given the stage under concern. This was then aggregated into quarterly estimates and are reported in the subsection affiliated with their stage of production. The estimated number of interprovincial imports are then reported in the appropriate tables in the following subsections.

2.2 The Cow-Calf Sector

For the cow-calf sector it is assumed that there is only one inflow and one outflow of cattle. The inflow are for those calves born on Ontario cow-calf operations.[4] Unfortunately CANSIM does not report the number of beef calves born each month. This poses a problem as the model requires the quarterly supply of feeder calves (500-600 lbs.) in order to estimate the supply function for the cow-calf sector, which in turn requires knowledge of the monthly number of beef calves born. Thus, the number of beef calves born each month had to be inferred from available data.

While CANSIM (table 003-0083) reports the number of calves born each biannual period, it fails to distinguish between calves born on dairy and beef operations. It does, however, report spot counts of beef cows by operation on January and July 1st of each year; therefore, we calculate the supply of feeder calves as a function of the provincial beef cow inventory on cow-calf operations. Since not all of the cows in Ontario calf at the same time, we need to come up with a measure of the percentage of the herd which calves in the first and second

[4]Note: Due to the small size of the Ontario beef veal sector it is ignored here. The provincial veal industry is largely driven by the dairy industry, rather than entire operations devoted to producing calves for veal.

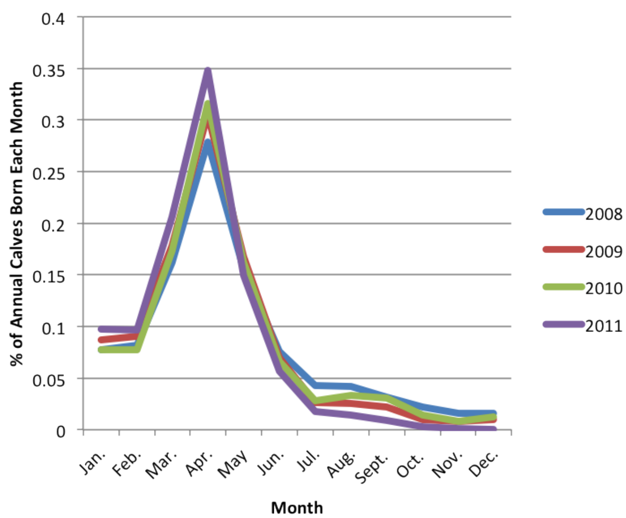

Figure 2.2: Monthly Frequency of Calving in Ontario (2008–2011).

halves of each year. To do so we use data from a voluntary survey reported by the Canadian Cattle Identification Agency (CCIA) (which lists the number of calves born each month) to generate in percentage terms the frequency of cows giving birth each month. As can be observed in figure **??**, the majority of calves are born in the first half of a given year – depending on the year, 80-95% of the calves were born in the first biannual period between 2008-2011 (CCIA). This had to be done because the inventory counts represent the number of cows on Ontario cow-calf operations at a given point in time, not the numbers of cows that have calved in the six months preceding that date. By calculating the proportion of births in the first and second half of the year we can obtain a measure of the percentage of the inventory that calved in each biannual period, and accordingly the number of cows that have given birth each biannual period. The inventory may change across periods due to both the culling of the herd, and due to the introduction of replacement heifers into the herd. In reference to the latter case, a heifer becomes a calf after she gives birth to her first calf; therefore, even if a heifer is pregnant, then according to CANSIM (table 003-0032) she would be recorded as a heifer, not a cow, until after she has given birth.

Since we needed to obtain estimates of the monthly number of beef calves born, we also had to calculate the proportion of calves born each month in a given biannual period from the CCIA survey data. We then multiplied the biannual inventory counts of beef cows on cow-calf operations by the proportion of beef cows calving for that biannual period and the proportion of calves born each month as reported in the CCIA survey for Ontario. This gave us the number of calves born each month. From this we needed to account for the death loss at this stage (assumed to be 2%) and the weaning rate (2% loss). As a calf is assumed to have completed the stage when it reaches a weight of 550 lbs. for bull calves and 500 lbs. for heifer calves, we took the number to calves born each month and advanced the number ahead by 7 months (the stage takes approximately 7-8 months from birth) to get an estimate of the number of calves supplied each month.[5] These monthly calf estimates were then aggregated by quarter, which are reported in column a of table 2.3.

As discussed earlier, given the amount of time required for a calf to gain enough weight to graduate to the backgrounding stage, and the prevalence of late winter/early spring births (see figure **??**) can easily explain the large number of feeder calves available in the fourth quarter of each year (table 2.3).

Note the flows in table 2.3 are not distinguished by gender. This is done as the gender ratio of calves born (ratio of heifers calves to bull calves) is a parameter to be varied in the model itself.[6]

Finally, column b of table 2.3 captures the quarterly number of calves demanded by the provincial backgrounding sector. By imposing an equilibrium condition, we calculated it as equivalent to the quarterly supply of calves, so that the market clears – e.g. $D_{Calves} \equiv S_{Calves}$.

2.3 The Backgrounding Sector

Table 2.4 demonstrates the quarterly supply, demand, exports and interprovincial imports of stockers in Ontario (2005–2012). The table is not disaggregated by gender as the model is designed so that the assumed sex ratio of calves and the proportion of interprovincial stocker imports can easily be varied in the model. It was felt that this allowed the model to be more flexible, especially with regards to the lack of available data and the corresponding necessary arbitrary assumptions regarding the composition of interprovincial cattle imports.

The monthly provincial supply of stockers[7] are a function of the monthly number of feeder calves demanded minus the assumed death loss (2%) affiliated with the backgrounding stage.[8] The monthly estimate is then shifted forward

[5]These weights are rough approximations and in reality the weight at which a cattle completes each stage, or the duration of time it takes an animal to do so will be highly contingent on several factors.

[6]In each model, the default ratio assumes that 50% of the calves born are heifers.

[7]We use the term stocker and feeder cattle interchangeably here, however, regardless of the terminology used they infer the same thing.

[8]Mortality estimates at each stage was obtained via discussion with Graeme Hedley.

Table 2.3: Quarterly Flows of Ontario Feeder Calves (2005 – 2012).

Year	Quarter	Supply of Calves (a)	Demand for Calves (b)
2012	4	76,568	76,568
2012	3	63,408	63,408
2012	2	2,851	2,851
2012	1	19,018	19,018
2011	4	150,501	150,501
2011	3	44,288	44,288
2011	2	11,958	11,958
2011	1	28,898	28,898
2010	4	146,956	146,956
2010	3	37,311	37,311
2010	2	9,364	9,364
2010	1	28,532	28,532
2009	4	152,658	152,658
2009	3	45,693	45,693
2009	2	17,421	17,421
2009	1	40,178	40,178
2008	4	149,748	149,748
2008	3	44,854	44,854
2008	2	20,657	20,657
2008	1	45,506	45,506
2007	4	151,295	151,295
2007	3	47,516	47,516
2007	2	18,590	18,590
2007	1	43,565	43,565
2006	4	159,072	159,072
2006	3	49,897	49,897
2006	2	21,029	21,029
2006	1	43,727	43,727
2005	4	166,676	166,676
2005	3	40,145	40,145
2005	2	29,120	29,120
2005	1	37,877	37,877

by 6 months to account for the time required for a feeder to gain the required weight to complete the backgrounding stage, and then aggregated into quarterly estimates.[9]

A challenge when attempting to infer the supply of stockers emerging from the backgrounding stage is accounting for heifer and bull retention.[10] Any assumption made regarding heifer retention will capture the effects of any expansion (or contraction) of the provincial beef cow herd, and in the short-run, influence the number of fed heifers available for slaughter. We assume that heifer retention occurs somewhere between the cow-calf and backgrounding stage. We present the percentage of heifers retained for herd replacement as an parameter which can be determined by the researcher for the model for each quarter. The default assumption is that a cow will be culled at approximately 10 years of age, which implies that a heifer retention ratio of 10% is necessary in order for the provincial herd to maintain a given level.[11] Also, we assume that 7% of bull calves are retained for the breeding stock.

As mentioned in the previous subsection, the provincial supply of stockers is highly cyclical due to the calving strategy and the time required for an animal to gain the necessary weight to complete the backgrounding stage. This stage takes roughly 6 months (22-28 weeks) to complete at which time steers are assumed to weigh on average 950 lbs. and feeder heifers weigh roughly 850 lbs..

To calculate the number of replacement and slaughter heifers and steers supplied at this stage, the supply of stockers must first be estimated. The number of replacement heifers is obtained by multiplying it by the estimated number of stockers by the assumed heifer retention ratio and the proportion of stockers attributable to heifers, which is a function of the assumed sex ratio and proportion of stocker heifers imported from other provinces. The supply of backgrounded heifers available for slaughter is done in a symmetric manner, except it is multiplied by one minus the heifer retention ratio. The provincial supply of stocker steers are then just the estimated as supply of stockers times the proportion of steers after deducting the number of bull calves retained for breeding stock. Section 6, *Identities*, provides a more complete description of the formulas used to determine the number of steers and heifers from the estimated behavioural equation at this stage (equations 4.4 to 4.7).

An additional source of supply is feeder animals entering the supply-chain from dairy operations, which for simplicity, we assume occurs at the backgrounding stage. The majority of bull calves from dairy operations are typically sold

[9]Six months is used here as it is an average of the 24 to 26 weeks as stated in the OMAF cost-of-production insurance program.

[10]We arbitrarily assume that heifer retention occurs at the backgrounding stage. However, in reality it is likely that a producer decides to retain a calf after it completes of the cow-calf sector.

[11]Graeme Hedley estimate.

Table 2.4: Quarterly Flows of Ontario Stocker Cattle (2005 – 2012).

Year	Quarter	Interprov. Feeder Imports (a)	Supply of Feeders (b)	Supply of Stockers from Dairy Op. (c)	Demand for Feeders (d)	Stocker Exports to US (e)
2012	4	7,348	2,794	13,652	22,523	1,271
2012	3	89,761	18,638	14,590	122,191	798
2012	2	21,792	147,491	9,297	178,350	229
2012	1	39,659	43,402	10,904	93,629	337
2011	4	34,376	11,719	10,166	55,764	497
2011	3	68,629	28,320	10,986	107,158	776
2011	2	26,377	144,017	9,295	179,304	384
2011	1	37,801	36,565	10,373	84,203	536
2010	4	23,506	9,177	9,905	41,897	691
2010	3	69,961	27,961	9,177	106,147	953
2010	2	29,687	149,605	5,662	183,653	1,301
2010	1	44,886	44,779	7,996	96,881	781
2009	4	44,102	17,072	11,315	70,029	2,460
2009	3	118,199	39,374	10,831	167,101	1,303
2009	2	35,757	146,753	5,094	185,173	2,431
2009	1	54,742	43,957	9,770	105,162	3,308
2008	4	45,150	20,244	3,067	65,395	3,067
2008	3	94,004	44,596	10,017	145,540	3,076
2008	2	31,617	148,269	5,406	183,192	2,099
2008	1	49,995	46,566	7,335	98,520	5,375
2007	4	46,550	18,218	10,663	70,617	4,814
2007	3	101,104	42,694	8,730	148,554	3,973
2007	2	35,691	155,891	4,264	191,517	4,328
2007	1	65,288	48,899	3,219	113,021	4,385
2006	4	59,703	20,608	7,535	83,423	4,422
2006	3	83,414	42,853	4,706	126,383	4,590
2006	2	45,944	163,343	3,601	210,167	2,721
2006	1	59,049	39,342	8,495	100,159	6,727
2005	4	63,799	28,538	5,004	89,693	7,648
2005	3	78,881	37,120	4,822	114,829	5,993
2005	2	53,993	109,373	845	164,211	0
2005	1	49,456	97,263	3,177	149,896	0

as bob calves[12] which are then raised to produce veal. However, there are some animals that enter the beef supply chain at various stages. We first approximate the number of dairy calves born each month (using CANFAX west data), subtracted for death loss, deducted the number of bob calves and larger calves (441-600 lbs. and 600+ lbs.) sold in the provincial veal market[13] and shift the residual number of calves forward a year to account for the time required to gain the necessary weight.

Next, while Canfax Cattle Services reports the export of feeder cattle to the U.S., it fails to identify the exports by weight, but rather defines them generically as 'feeders.' We assume that they are exported at either the end of the cow-calf stage or at some point during the backgrounding stage, thus, we estimate the structural equation for feeder exports at this stage. The percentage of stockers that are heifers (steers) is determined by multiplying the estimate (generated by structural equation) by an assumed proportion. Examination of data on live exports to the U.S. of live bovine cattle weighing between 200 and 320 kg (440 and 704 lbs.) (Statistics Canada), reveals that the majority of the live exports in the weight class are steers in recent years (80-100%), but this varies over the 1994-2010 period.

The authors note that the latter two stages of the supply-chain are often vertically integrated. Many cow-calf operations will (partially or completely) background their own animals and ship out their animals as yearlings, while this is a reality of the system we ignore this fact in order to make this model tractable. Thus, we treat the cow-calf sector as independent from the backgrounding stage, and implicitly assume that those farmers who background their own animals are buying from themselves.

2.4 The Finishing Sector

Table 2.5 and 2.6 represents the quarterly disposition of the Ontario finishing sector for the period 2005–2012. Canfax Cattle Services reports notable live exports of fed cattle to the United States. As can be observed, live exports of fed cattle fell to zero for the first and second quarters of 2005. This occurred because of the BSE crisis resulted in a border closure to live exports until the export of live cattle under 30 months was permitted again.

[12] A bob calf is a term used for a calf that is sold at anywhere from a few days after birth to 2-3 weeks old, usually weighing approximately 125 lbs or less.

[13] It is likely that calves are bought as bob calves (under 125 lbs.), put on feed and then sold again on the provincial veal market. Thus, it is likely that there is some double counting the number of animals intended for veal. In effect this would understate the provincial supply of feeder animals from dairy operations. However, in reality the number of animals from dairy operations entering into the beef industry at this point is a black box, as such this appears to be the best option available.

Table 2.5: Quarterly Flows of Ontario Fed Heifers (2005 – 2012).

Year	Quarter	Supply of Heifers (a)	Interprov. Imports of Heifers (b)	Demand for* Heifers (c)	Heifer** Exports (d)
2012	4	35,214	8,248	38,916	4,546
2012	3	35,536	4,265	37,859	1,942
2012	2	49,829	4,867	51,223	3,473
2012	1	48,009	3,002	46,895	4,116
2011	4	41,334	8,588	42,059	7,863
2011	3	44,423	3,667	42,976	5,114
2011	2	57,698	5,621	55,948	7,371
2011	1	58,802	2,990	54,085	7,707
2010	4	47,403	7,015	46,732	7,686
2010	3	48,728	3,167	47,721	4,174
2010	2	63,160	6,740	61,413	8,487
2010	1	54,091	3,657	48,056	9,692
2009	4	46,029	12,246	47,064	11,211
2009	3	43,826	6,569	44,986	5,409
2009	2	55,022	7,571	57,773	4,820
2009	1	55,736	4,342	53,101	6,977
2008	4	51,464	9,702	52,676	8,490
2008	3	49,235	4,993	48,320	5,908
2008	2	63,820	6,855	61,976	8,699
2008	1	63,810	3,538	53,853	13,495
2007	4	46,851	11,578	51,468	6,961
2007	3	40,977	7,470	47,490	957
2007	2	55,966	7,090	61,418	1,638
2007	1	58,688	5,323	58,685	5,326
2006	4	45,919	9,816	54,773	962
2006	3	46,142	7,805	53,659	288
2006	2	56,793	7,014	63,272	535
2006	1	51,373	6,621	55,152	2,842
2005	4	51,459	7,893	56,010	3,342
2005	3	46,439	4,150	49,694	895
2005	2	56,062	8,917	64,979	0
2005	1	50,875	4,222	55,097	0

*Source: Canfax Cattle Services.

**Source: Canfax Cattle Services.

Table 2.6: Quarterly Flows of Ontario Fed Steers (2005 – 2012).

Year	Quarter	Supply of Steers (a)	Interprov. Import of Steers (b)	Demand for* Steers (c)	Steer** Exports (d)
2012	4	97,173	9,107	102,983	3,297
2012	3	95,557	4,709	98,111	2,155
2012	2	77,766	6,563	81,955	2,374
2012	1	80,659	4,049	82,488	2,220
2011	4	93,884	9,724	97,769	5,839
2011	3	99,151	4,152	100,104	3,199
2011	2	84,503	7,612	88,281	3,834
2011	1	88,754	4,048	88,891	3,911
2010	4	106,747	8,299	108,563	6,483
2010	3	105,598	3,746	104,872	4,472
2010	2	102,444	8,271	103,862	6,853
2010	1	100,937	4,487	99,702	5,722
2009	4	107,661	15,596	114,282	8,975
2009	3	104,054	8,366	106,066	6,354
2009	2	88,197	9,614	94,431	3,380
2009	1	94,213	5,513	92,063	7,663
2008	4	108,189	11,240	102,097	17,332
2008	3	110,141	5,784	105,055	10,870
2008	2	98,753	7,750	98,096	8,407
2008	1	111,088	4,001	98,697	16,392
2007	4	101,953	14,760	97,641	19,072
2007	3	94,854	9,523	98,137	6,240
2007	2	97,414	8,136	100,539	5,011
2007	1	110,371	6,108	106,099	10,380
2006	4	103,369	11,377	108,899	5,847
2006	3	116,302	9,046	124,639	709
2006	2	101,735	8,330	108,057	2,008
2006	1	97,676	7,864	98,574	6,966
2005	4	122,680	8,097	119,365	11,412
2005	3	117,327	4,257	116,614	4,970
2005	2	103,942	11,053	114,995	0
2005	1	101,786	5,234	107,020	0

*Source: Canfax Cattle Services.

**Source: Canfax Cattle Services.

As figure 2.1 demonstrates we assume that the majority of the inflows of beef cattle into the province is done at the backgrounding stage, however it is assumed that some fed heifers and fed steers are imported from other provinces. Calculation of the interprovincial imports of fed heifers (table 2.5, column b) and fed steers (table 2.6, column b) are discussed in the first subsection (2.1).

The provincial demand for fed cattle (column b, tables 2.5 and 2.6) is calculated as the sum quarterly sum of slaughtered heifers and steers at provincial and federally inspected plants in Ontario (Canfax Cattle Services). Finally, the supply of fed cattle is calculated assuming the equilibrium condition: $Supply_t = Demand_t + Exports_t - InterprovincialImports_t$ holds.

From table 2.5 and 2.6 one can see that contrary to the supply of and demand for feeder cattle and calves, the supply of and demand for fed cattle is far less cyclical. This is likely due to capacity constraints at slaughter plants that dictates the consistent demand for slaughter animals, and relatively stable demand for beef. Fed steers are assumed to complete this at a weight of 1450 lbs. and fed heifers at 1400 lbs.. While the duration of this period varies for heifers and steers, it is assumed it takes an average of 26 weeks (roughly 6 months) for an animal put on feed to complete this stage.

2.5 Non-fed Cattle

The supply of non-fed cattle is in part continent on whether the industry is expanding or contracting. While there will always be a supply of culled cows and bulls to some degree, due to herd replacement, during a period of contraction the number of culled animals should increase as farmers are culling more cows and during a period of expansion inventory could increase as either few cows are being culled in order expand their herd.

Figure 2.4 demonstrates July 1 inventory counts for beef cows in Ontario (CANSIM, table 30032). It shows that in 2012 the inventory of beef cows has decreased by over one hundred thousand head from the 2004 level. This would have led to the increase in the culling of older cows, and increased the supply of non-fed animals being slaughtered. Furthermore, due to the frequent replacement of the dairy herd, there is a stable supply of cattle from dairy operations. The supply of culled cows is, therefore, a function of herd dynamics on provincial beef operations and the number of culled cows from Ontario dairy operations (which is relatively consistent). This can be observed in figure 2.3, and the supply of culled cows is inversely related to the provincial beef cow inventory.

Figure 2.5 shows the provincial bull inventory between 2000 and 2012. While the relationship between herd expansion and contraction is more ambiguous due to the advent of artificial insemination and the need for fewer bulls, the inventory of provincial bulls does have an effect on the supply of bulls for slaughter. As the above figure indicates a reduction in the inventory of bulls will reduce the number of bulls available for slaughter. Tables 2.7 shows the supply, demand and export of culled bulls and cows.

The demand for non-fed cattle is calculated as the quarterly number of head of cows and bulls slaughtered at both provincially and federally inspected plants in Ontario (Canfax Cattle Services).

Monthly export of live non-fed cattle is reported by Canfax Cattle Services, which is then aggregated in quarterly estimates (tables 2.7, columns c and f). Since the BSE crisis resulted in the U.S.-Canada border closure, there are no exports to the United States from the third quarter of 2003 to the third quarter of 2007. The border opened to live cattle under 30 months in July of 2005, however, it remained closed to cattle over 30 months until November, 2007.

It is assumed that there are no interprovincial imports of culled cattle, as the supply of culled cows and bulls from the Ontario dairy industry supplements any vacant space in slaughter plants from deficient supply from provincial beef operations.

Finally, the supply of culled cows and bulls in a given period is determined here by an equilibrium condition which determines the supply of non-fed cattle as determined by the demand and exports of culled cows and bulls and the change in inventory (tables 2.7, column a and d).

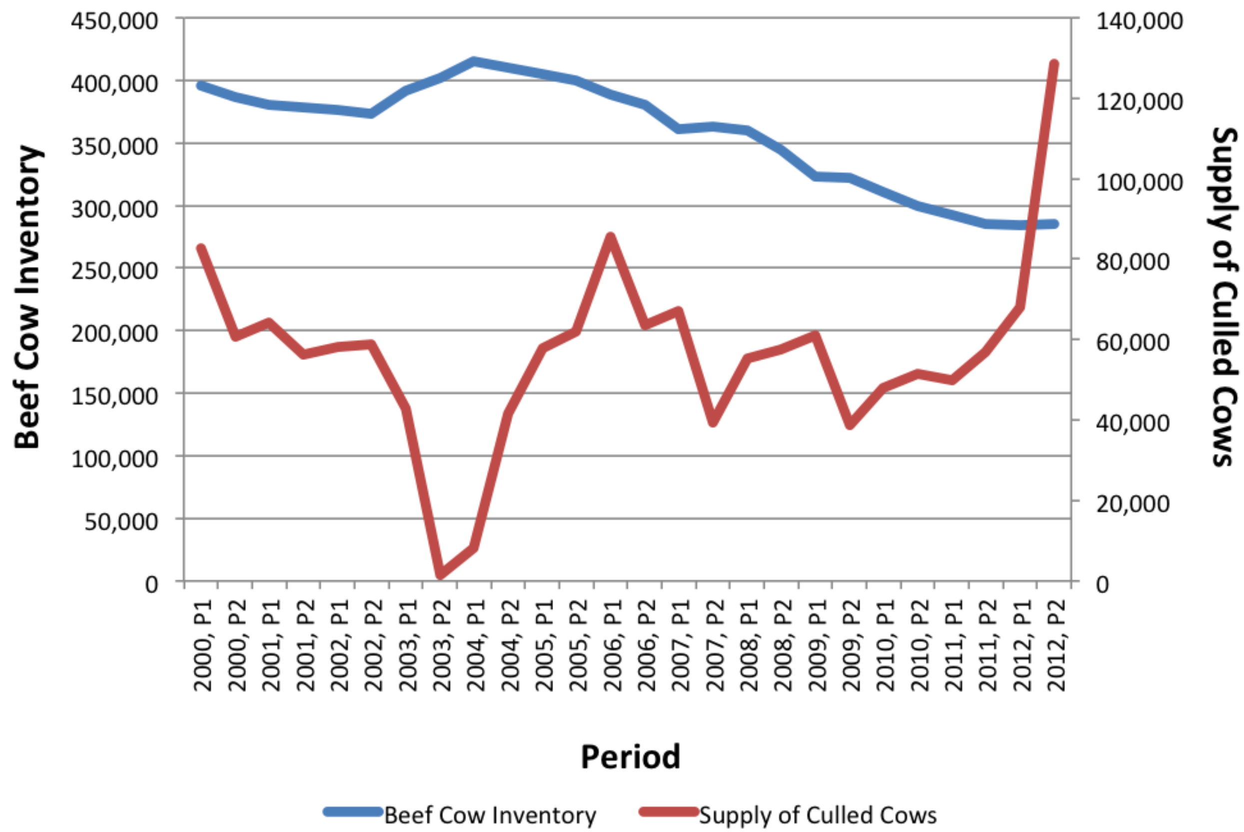

Figure 2.3: Relationship Between Beef Cow Inventory and the Supply of Culled Cows (2000-2012)

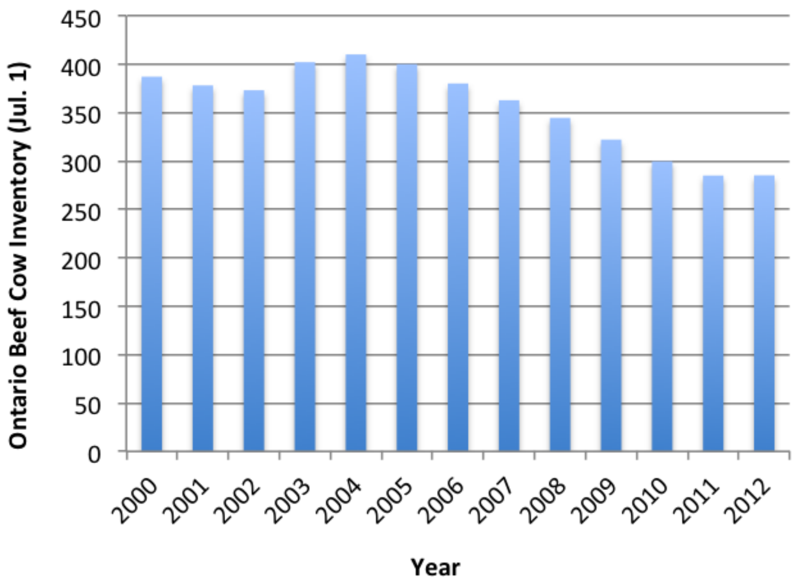

Figure 2.4: Provincial Beef Cow Inventory Count, Jul. 1 (2000-2012)

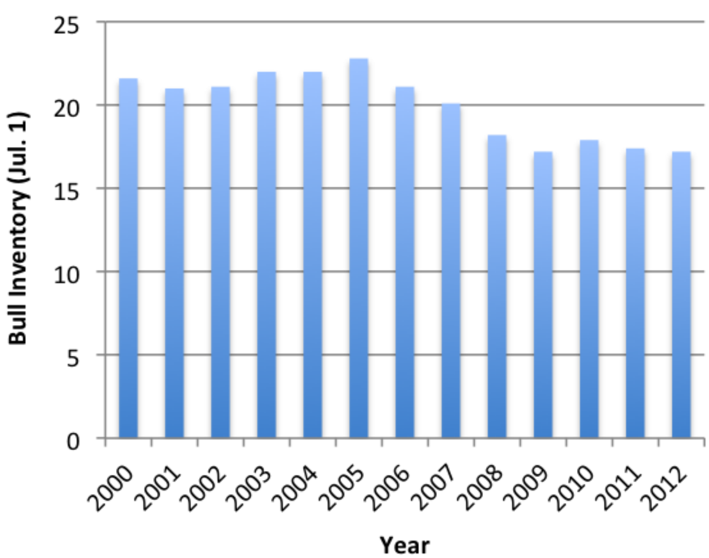

Figure 2.5: Provincial Bull Inventory Count, Jul. 1 (2000-2012)

Table 2.7: Quarterly Flows of Ontario Culled Cows (2007 – 2011.)

Year	Quarter	Supply of Culled Cows (a)	Demand for** Culled Cows (b)	Cow*** Exports (c)	Supply of Culled Bulls (d)	Demand for** Culled Bulls (e)	Bull*** Exports (f)
2012	4	73,875	29,077	27,748	2,988	3,174	414
2012	3	54,640	21,057	16,533	3,250	3,331	519
2012	2	33,255	22,821	10,584	4,953	3,922	281
2012	1	34,824	23,934	11,040	3,745	2,851	144
2011	4	32,360	21,282	7,678	2,705	3,186	169
2011	3	24,528	14,923	6,205	2,461	2,983	128
2011	2	20,606	11,624	7,982	4,826	3,794	232
2011	1	29,361	13,378	14,983	3,764	2,841	123
2010	4	30,183	8,817	16,166	3,226	3,009	117
2010	3	21,383	6,121	10,062	3,357	3,118	139
2010	2	20,786	6,827	13,559	4,327	4,450	327
2010	1	27,301	6,987	19,914	2,998	3,202	246
2009	4	25,040	6,990	17,600	5,102	3,888	364
2009	3	13,774	5,310	8,014	5,784	4,668	266
2009	2	27,640	6,578	10,262	5,418	5,314	304
2009	1	33,426	8,697	13,929	3,897	3,902	195
2008	4	31,456	8,956	14,150	3,541	3,285	406
2008	3	26,038	8,391	9,297	2,278	1,956	472
2008	2	25,321	9,718	16,653	4,135	2,449	636
2008	1	29,992	16,179	14,863	3,055	1,754	251
2007	4	22,088	18,746	3,342	769	2,357	62
2007	3	17,243	17,243	0	1,128	2,778	0
2007	2	30,229	20,479	0	5,883	3,583	0
2007	1	36,763	27,013	0	5,078	2,778	0

*Source: CANSIM, table 003-0032.

**Source: Canfax Cattle Services.

***Source: Canfax Cattle Services.

2.6 The Retail/Processing Sector

The retail/processing stage is considered here to be a single stage even though they are separate. Most of the data on slaughter capacity and/or the margins received by processors and retailers is considered proprietary and not made available to the public. For example, the wholesale price of beef which the retailers pay to processor is not available. As such the sectors are amalgamated due to a lack of available data.

There are several flows of beef into the processing sector (figure 2.1). The amount of beef supplied in Ontario at a given point in time is a function of imports from the United States, imports from other provinces (predominantly the west) and the supply from provincial slaughter plants.

The supply from provincial plants is contingent on slaughter capacity, the number of slaughter plants, as well as the supply of both fed and non-fed cattle. Holding the price received for beef by the processor as well as the price of slaughter animals constant, slaughter plants can only slaughter up to their capacity. Therefore, in the short-run the provincial sector faces capacity constraint with regards to the number of head the provincial plants can slaughter. The model imposed a constraint on the number of cattle that can be slaughtered, which can be varied in the model. The challenge when attempting to measure provincial slaughter capacity is estimating the capacity of provincially inspected slaughter plants; as many of them slaughter several types of livestock which make it difficult to pinpoint an exact capacity.[14] Varying the assumed slaughter capacity will therefore, increase or decrease the provincial supply. Inclusion of the constraint is further beneficial as it offers a venue for additional analysis.

Another implicit assumption in the model is that given a choice, and holding all else constant, that slaughter plants prefer to slaughter fed cattle, as they represent a higher-quality of beef cuts relative to non-fed cattle. It is important to make this assumption explicit as the slaughter capacity constraint is set up so that the residual vacant slaughter capacity is filled by non-fed cattle. This assumption had to be made as most plants will slaughter several types of fed and non-fed animals (e.g., Steers, Heifers, Cows, etc.), and can easily substitute between them. No information is readily available that reports how many steers, heifers, cows and/or bulls a plant slaughters in a given quarter. Therefore, the slaughter capacity is presented here as a provincial aggregate, and this assumption is made following **?**.

The supply of beef from Ontario slaughter plants is calculated as the number of head of cattle slaughtered in provincial and federally inspected plants times

[14]Source: Richard Horne, OCA

the average carcass weight, for the respective type of animal.[15] For example, the contribution of slaughter steers to the provincial supply of beef is the number of steers slaughtered in a quarter multiplied by the respective average warm carcass weight. This is the summed across the categories. The data used in the calculation of the supply is reported in table 2.8. The final column of the table represents the supply of beef (in carcass weight equivalent) in lbs..

The total quarterly provincial demand for beef is simply calculated as the annual national per capita disappearance of beef (in lbs.) with respect to carcass weight divided by four, times the quarterly estimated population for Ontario. Due to the lack of quarterly disappearance data, an annual per capita measure had to be used and was divided by four (column a of table 2.9). This implicitly assumes both that an individual's consumption of beef is constant over the year and that the average consumption of beef is constant across provinces (as we are using a national average). These are strong assumptions, as seasonality is likely a determinant of how much beef is consumed and due to differences in the demographics of Ontario's population, our consumption of beef likely differs from, say, Alberta. However, as no other viable alternative (to the knowledge of the authors) exists this assumption had to be made. The estimates are reported in table 2.9.[16]

Since we've aggregated the retail and processing sector, we also include the exports and imports of beef from the U.S. and the world (termed R.O.W.). All estimates are aggregated from monthly reported beef exports and imports by country of destination from Statistics Canada (arranged by the Red Meat Division, AAFC). These are reported in table 2.10 for the two aforementioned importing/exporting country groups.

Finally, we also account for surplus of beef through the use of the net interprovincial imports of beef, which we treat as a residual capturing any excess supply of beef in the market. It is not possible to estimate the flows of beef between provinces as the data is not publicized, therefore the inclusion of this category is largely an construct of convenience.

[15] Note that since these are actual slaughter numbers, it is implicitly assumed that the capacity constraint is non-binding.

[16] The results in table 2.9 are reported for expositional ease. The behavioural equation (3.37) for is estimated for a representative consumer, from which a per capita disappearance is estimated. This estimate is then multiplied by the provincial population for the period to get an estimate of the provincial consumption of beef.

Table 2.8: Quarterly Provincial Supply of Beef (2007–2012)

		Slaughtered Cattle*				Ont. Avg. Warm Carcass Weight **				
Year	Quarter	Steers	Heifers	Cows	Bulls	Steers	Heifers	Cow	Bull	Supply of Beef
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
2012	4	102,983	38,916	29,077	3,174	898	803	652	850	145,384,386
2012	3	98,111	37,859	21,057	3,331	898	803	652	850	135,064,969
2012	2	81,955	51,223	22,821	3,922	898	803	652	850	132,940,651
2012	1	82,488	46,895	23,934	2,851	898	803	652	850	129,759,227
2011	4	103,862	61,413	6,827	4,450	882	825	688	852	150,760,385
2011	3	99,702	48,056	6,987	3,202	882	825	688	852	135,118,524
2011	2	114,282	47,064	6,990	3,888	882	825	688	852	147,746,220
2011	1	106,066	44,986	5,310	4,668	882	825	688	852	138,294,078
2010	4	94,431	57,773	6,578	5,314	878	784	731	748	136,987,840
2010	3	92,063	53,101	8,697	3,902	878	784	731	748	131,738,701
2010	2	102,097	52,676	8,956	3,285	878	784	731	748	139,943,166
2010	1	105,055	48,320	8,391	1,956	878	784	731	748	137,718,079
2009	4	98,096	61,976	9,718	2,449	865	768	712	666	141,000,858
2009	3	98,697	53,853	16,179	1,754	865	768	712	666	139,419,621
2009	2	97,641	51,468	18,746	2,357	865	768	712	666	138,903,803
2009	1	98,137	47,490	17,243	2,778	865	768	712	666	135,487,989
2008	4	100,539	61,418	20,479	3,583	872	778	719	884	153,344,985
2008	3	106,099	58,685	27,013	2,778	872	778	719	884	160,053,357
2008	2	108,899	54,773	26,186	3,941	872	778	719	884	159,884,900
2008	1	124,639	53,659	24,385	3,059	872	778	719	884	170,668,881
2007	4	108,057	63,272	30,034	2,685	875	772	658	975	165,776,106
2007	3	98,574	55,152	32,388	1,930	875	772	658	975	152,022,648
2007	2	119,365	56,010	33,426	3,004	875	772	658	975	172,607,303
2007	1	116,614	49,694	24,617	2,571	875	772	658	975	159,105,729

*Source: Canfax Cattle Services (columns a - d).

**Source: Red Meat Division, AAFC (columns e - f).

Table 2.9: Quarterly Provincial Demand for Beef (2008–2011)

Year	Quarter	Per Capita Beef Disappearance (a)	Population (b)	Beef Disappearance (c)
2012	4	15.054	13,546,112	203,916,397
2012	3	15.054	13,505,900	203,311,066
2012	2	15.054	13,464,470	202,687,399
2012	1	15.054	13,438,807	202,301,081
2011	4	14.894	13,415,805	199,815,000
2011	3	14.894	13,366,294	199,077,583
2011	2	14.894	13,324,435	198,454,135
2011	1	14.894	13,295,154	198,018,024
2010	4	15.296	13,280,877	203,137,654
2010	3	15.296	13,223,789	202,264,465
2010	2	15.296	13,171,750	201,468,502
2010	1	15.296	13,137,499	200,944,616
2009	4	15.505	13,121,266	203,438,669
2009	3	15.505	13,068,845	202,625,907
2009	2	15.505	13,021,622	201,893,738
2009	1	15.505	12,991,623	201,428,619
2008	4	16.385	12,981,064	212,688,243
2008	3	16.385	12,932,480	211,892,219
2008	2	16.385	12,883,257	211,085,724
2008	1	16.385	12,851,184	210,560,224

*Source: CANSIM, table 002-0011.

**Source: CANSIM, table 051-0005.

Table 2.10: Provincial Beef Exports/Imports (2007–2012)

Year	Quarter	Exports to U.S. (a)	Exports to R.O.W. (b)	Imports from U.S. (c)	Imports from R.O.W. (d)
2012	4	27,366,409	6,581,802	98,825,558	18,146,436
2012	3	26,294,011	4,743,728	83,952,477	11,949,905
2012	2	28,034,151	3,683,548	81,758,189	14,406,260
2012	1	31,071,139	3,434,262	65,783,302	25,911,604
2011	4	31,168,821	4,783,885	79,941,605	12,611,152
2011	3	28,993,901	4,091,483	95,599,830	9,848,461
2011	2	32,807,889	4,387,007	82,559,728	17,632,492
2011	1	32,778,601	4,106,403	64,369,034	13,271,867
2010	4	34,935,630	6,254,681	74,631,603	7,249,884
2010	3	36,084,380	3,975,090	69,325,744	9,413,807
2010	2	41,346,098	4,915,436	57,717,009	15,845,685
2010	1	37,917,543	4,609,590	55,714,600	23,420,217
2009	4	36,486,311	6,404,248	58,583,499	6,917,898
2009	3	31,877,793	5,022,514	66,261,076	13,076,892
2009	2	26,104,951	4,577,448	66,224,501	19,059,370
2009	1	16,664,314	5,391,797	50,525,774	20,412,603
2008	4	19,105,566	7,003,909	57,686,402	6,560,195
2008	3	20,682,875	4,955,883	66,898,707	8,832,450
2008	2	22,123,697	5,760,682	67,966,166	5,828,687
2008	1	18,127,831	6,410,114	53,768,519	12,355,475
2007	4	16,177,599	3,805,397	66,793,648	7,173,745
2007	3	29,997,451	4,340,074	59,343,429	10,963,610
2007	2	40,991,196	5,522,374	54,156,351	10,622,038
2007	1	47,571,036	3,712,397	36,638,723	13,202,059

Source: All data in this table is compiled by the Red Meat Division, AAFC (originally from Statistics Canada).

Chapter 3

Structural Equations

This chapter discusses the specification for each of the structural equations which form the foundation of the model. Each structural equation involves the estimation of an important variable in the provincial supply-chain, and is specified in a manner that attempts to capture the decision-making of each agent (or agents) at a given stage in the supply chain. The chapter is divided up into several sections each outlining the structural equations used to estimate the quantities, prices, carcass weights or trade flows at each stage in the supply chain. This was done to allow the reader to quickly find and identify the equation of interest.

All of the structural equations discussed below include an intercept as well as quarterly dummies to account for the seasonal nature of the provincial beef sector represented as Q_i where i denotes the quarter.[1] Any variable with a "D" preceding numbers denotes a dummy variable.

A Box-Cox transformation test was preformed on each of the equations listed before to test for the appropriate functional form. A linear functional form was the null form, which was then tested against a log-linear functional form. Since the null functional form was rejected in the majority of cases, in favour of the log-linear functional form, we will only mention when the null was not rejected and the linear functional form was used instead.

The origin of each of the variables identified in the equations is cited in length in the appendices A and B. Appendix A cites all of the dependent or cattle related variables, while appendix B lists all of the price variables used.

[1] To avoid a dummy variable trap, the binary variable indicating the fourth quarter was dropped making it the base case represented by the coefficient on the intercept term.

3.1 Price Transmission Equations

3.1.1 Fed Cattle Price Transmission Equations

$$PFH_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 USFHP_t * CUX_t \quad (3.1)$$
$$+ \beta_6 Trend + \beta_7 PFH_{t-1} \quad (3.2)$$

$$PFS_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 USFSP_t * CUX_t \quad (3.3)$$
$$+ \beta_6 Trend + \beta_7 PFS_{t-1} \quad (3.4)$$

Equation 3.3 and **??** represent the price transmission equation for the provincial fed heifer and steer prices, respectively. They are assumed to be a function of the product of the U.S. fed cattle prices ($USFHP_t$ and $USFSP_t$) and the Canada-U.S. exchange rate (CUX_t). Since Canada is a small exporting country in the fed cattle market, we assume that we are price takers and correspondingly that our price is determined by what happens in the (much) larger U.S. market. Lagged dependent variables are included to correct for first-order autocorrelation (PFH_{t-1}), and a trend variable is included to account for a change in the trend underlying the relationship between the prices. A likelihood ratio test confirms that the latter two variable significantly improve the fit of both models. Durbin's H test, however, revealed that inclusion of a one period lag did not completely correct for autocorrelation.

The observations between the third quarter of 2003 and the second quarter of 2005 is dropped from the sample. During this period the BSE border closure, the absence of exports or live fed cattle may have inhibited the transmission of fluctuations in the U.S. price to the Ontario price. Eliminating the observations affiliated with the period prevents introducing any bias into the estimates, we do so following **?**.

3.1.2 Stocker Price Transmission Equations

$$PBH_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 PFH_t + \beta_6 D2003Q3 + \beta_7 PBH_{t-1} \quad (3.5)$$
$$PBS_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 PFS_t + \beta_6 D2003Q3 + \beta_7 PBS_{t-1} \quad (3.6)$$

The provincial price received for feeder heifers (steers) is assumed to a function the price of a fed heifer (steer) (PFH_t and PFS_t) (equations 3.5 and 3.6, respectively). This is because if the price of fed cattle decreases there will be a corresponding decrease in the derived demand for stockers, and vice versa. The dummy variable $D2003Q3$ is included in each equation to account for the onset of the BSE crisis, resulting in the closure of the U.S.- Canada border to cattle under 30 months. The effect of a border closure would have lead to the shock in fed cattle prices transmitting down to feeder markets.

Durbin-Watson tests revealed the presence of first-order serial correlation in both equations, which were then corrected for by the inclusion of lagged dependent variable. A Durbin's H test reveals that this did rid the models of autocorrelation.

3.1.3 Calf Price Transmission Equations

$$PHC_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 PSH_t + \beta_6 PHC_{t-1} \tag{3.7}$$

$$PSC_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 PSS_t + \beta_6 Trend + \beta_7 PSC_{t-1} \tag{3.8}$$

Equations 3.7 and 3.8 represent the price transmission equations for feeder calves in Ontario. The price of heifer and bull calves (PHC_t and PSC_t) in Ontario is a function of the price of feeders (PBH_t and PBS_t). A lagged dependent variable corrects for first-order autocorrelation.

3.1.4 Non-fed Cattle Price Transmission Equations

Owning to the reality that a substantial number of culled cows and bulls exported to the U.S. from Ontario (see table 2.7), it is assumed that we are also a price taker for non-fed cattle. Due to U.S.-Canada border closure, to all live cattle over 30 months were not allowed to be exported to the U.S. between the third quarter of 2003 and the fourth quarter of 2007. As such observations for this time period were eliminated from the sample being estimated. This was done to prevent introducing bias into the estimated relationship between non-fed cattle prices in the U.S. and Canada.

$$PCC_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 USCP_t * CUX_t + \beta_6 OCP_{t-1} \tag{3.9}$$

$$PCB_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 USBP_t * CUX_t + \beta_6 OBP_{t-1} \tag{3.10}$$

Equations 3.9 and **??** state that the price received for Ontario culled cows and bulls is a function of the product of the U.S. slaughter cow and bull price ($USCP_t$) and the Canada-U.S. exchange rate. For both structural equations, lagged dependent variable was used to correct for the presence of positive first-order autocorrelation.

3.1.5 Wholesale Beef Price Transmission Equation

As can be observed from table 2.10, the volume of imports of beef into Ontario (column c) is continually larger than the exports to the U.S (column a), indicating that we are a net importer of beef in Ontario. Furthermore, due to the presence of large packing plants located in the U.S., along with the absence of any tariffs on processed beef between Canada and the U.S. and the size of the U.S. population, it is assumed here that Ontario is a price-taker in the retail beef market.

$$OWBP_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 USWBP_t * CUX_t + \beta_6 Trend + \beta_7 OWBP_{t-1} \tag{3.11}$$

Equation 3.11 represents the price transmission equation for the Ontario wholesale beef price ($/lbs.). It assumes that Ontario is a price-taker and that the U.S. markets set the price. This is not an unreasonable assumption as the U.S. processing market is substantially larger than the provincial one. The provincial price ($/lbs.) is therefore a product of the U.S. wholesale beef price ($USWBP_t$) and the Canada-U.S. exchange rate ($CUEx_t$).

A trend variable ($Trend$) is included to account for an underlying trend in the dependent variable, while the lagged dependent variable is included as an explanatory variable to correct for first-order autocorrelation ($OWBP_{t-1}$).

3.1.6 Retail Beef Price Transmission Equation

$$ORBP_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 OWBP_t + \beta_6 Trend + \beta_7 ORBP_{t-1} \tag{3.12}$$

Equation 3.12 represents the price transmission equation for beef as a function of the Ontario wholesale beef price ($OWBP_t$), and a trend variable. The retail beef price is modelled here as a function of the provincial wholesale price, rather than as a function of the U.S. retail price, to account for the differences in the marketing of beef and concentration of grocery stores in Canada relative to the U.S.. In short, the retail price of beef is determined by the mark ups, on the wholesale beef price, charged by provincial retailers which in part is contingent on the degree of market power.

A Durbin-Watson test reveals that the model suffered from positive serial correlation. A Durbin H test revealed that inclusion of a lagged dependent variable as a covariate to corrected for it.

3.2 Cow-Calf Sector

3.2.1 Supply of Feeder Calves

$$\begin{aligned}\ln SFC_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PCalf_{t-4} + \beta_6 Trend \\ &+ \beta_7 D2012Q2 + +\beta_8 D2012Q4 + \beta_9 \ln INVC_{t-4} + \beta_{10} \ln SFC_{t-1}\end{aligned} \tag{3.13}$$

The above equation was used to estimate the number of feeder calves produced each quarter by Ontario cow-calf producers. It is function of the average price of feeder calves ($PCalf_{t-4}$) lagged 4 quarters, the inventory of beef cows in the previous year ($INVC_{t-4}$), a trend, and the number of calves supplied the previous quarter.

$PCalf_{t-4}$ represents the average quarterly rail grade price ($/100 lbs.) expected to be received by producers for feeder calves. The rail grade price is used here instead of the quarterly average cash price, as the former represents the price received for high quality calves in Ontario. It is lagged to capture the price that a cow-calf farmer would respond to when deciding how many cows/heifers to inseminate. A period of 4 quarters was chosen as it roughly captures the reality that farmers make their output decisions each year.

Next, the inventory or number of beef cows from the previous year (lagged four quarters) accounts for the capacity (short-run production) constraints faced by cow-calf producers when attempting to expand output. Even if the price of feeder calves increase ten fold in a short period, provincial producers have a limit on the amount of calves that can be supplied to market. Inclusion of the beef cow inventory lagged 4 quarters (a year) captures the short-run capacity constraint of provincial production.

A dummy variable for the second and fourth quarters of 2012 ($D2012Q2$ and $D2012Q4$) were included as it appears that it there was an unusual drop in the number of calves supplied to market. A likelihood ratio test indicates that its inclusion significantly improved the fit of the model.

Due to the presence of negative autocorrelation, the lagged dependent variable was included to correct for it. The coefficient on the variable is negative indicating that an increase in last quarter's supply of calves decreases the supply in this quarter. Intuitively, this makes sense; since a producer faces an annual capacity constraint (i.e., the number of cows they have) then if they market their calves in this quarter then that leaves fewer calves to be marketed in the following quarter.

3.2.2 Demand for Feeder Calves

$$\begin{aligned} \ln DFC_t = &\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PCalf_t + \beta_6 \ln PFeeder_t \\ &+ \beta_7 D2012Q2 + \beta_8 D2012Q4 + \beta_9 Trend + \beta_{10} \ln DFC_{t-1} \end{aligned} \tag{3.14}$$

Equation 3.15 represents the derived demand for feeder calves. It is a function of a trend variable, the lagged demand for calves, the average provincial calf price and the Ontario's average feeder cattle price. The rail grade price of feeder calves is included as it represents the cost of purchasing calves in the market ($PCalf_t$), while the average rail grade price of stocker cattle in period t ($PFeeder_t$) captures the expected return to backgrounding animals. The coefficient on the price of calves is expected to be negative, as an increase in price would increase the cost-of-production at the backgrounding stage. While the coefficient on the price of stockers is expected to be positive, as an increase in the price received for backgrounded animals makes backgrounding animals more profitable.[2]

A trend variable ($Trend$) is included to capture the effects of an underlying decline in the demand for calves over the sample period. Dummy variables $D2012Q2$ and $D2012Q4$ correct for unusually low quarters. A Durbin-Watson test revealed that negative serial correlation was present, which was correct for through the inclusion of a lagged dependent variable.

[2]Note: A variable proxying feed costs is not included in the specification as most animals in the province are fed on forage.

3.3 Backgrounding Sector

3.3.1 Supply of Stockers from Provincial Dairy Operations

$$\begin{aligned}\ln SDFC_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \ln\beta_5 SSBPR_{t-4} + \beta_6 D2005Q12 \\ &+ \beta_7 D2008Q4 + \beta_8 \ln SDFC_{t-1}\end{aligned} \tag{3.15}$$

Equation 3.16 estimates the supply of stockers coming from dairy operations. It is assumed that a dairy farmer's decision to raise a bull calf to be put on feed instead of selling it as a bob calf is contingent on the relative gains to doing so. Therefore, this trade off is captured through the inclusion of the ratio of the feeder steers to bob calf price ($SSBPR_t$) lagged four quarters to account for the point in time when the decision would have been made. The coefficient should be positive as an increase in the price of feeder steers relative to the price of bob calves, *ceteris paribus*; or if the price received for bob calves decreases relative to the price of stockers should increase the number of feeder steers supplied as stockers from dairy operations.

Two dummy variables are included to account for low values of the dependent variable in the first and second quarters of 2005, and the fourth quarter of 2008 – i.e. the coefficients are negative. A likelihood ratio test reveals that inclusion of the two dummy variables significantly improves the fit of the model.

Finally, a Durbin-Watson test revealed that the model suffered from first-degree autocorrelation. A lagged dependent variable was then included, which a Durbin H test revealed rid the model of autocorrelation.

3.3.2 Provincial Supply of Stockers

$$\begin{aligned}\ln SBC_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PFeeder_{t-2} \\ &+ \beta_6 \ln PCalf_{t-2} + \beta_7 D2012Q4 + \beta_8 \ln SBC_{t-1}\end{aligned} \tag{3.16}$$

Equation 3.17 represents the provincial supply function for stocker cattle, which is assumed to be a function of the quarterly average rail grade stocker price (the output price) and the price of feeder calves. Note that no variable proxying feed costs is included as the majority of stockers coming from backgrounding operations are fed forage, and are therefore land based operations. In order to capture the prices that backgrounders responded to, both of the average Ontario rail grade calf price and average rail grade stocker price are lagged two periods. In other words, the quantity of feeder cattle supplied at time t (SBC_t) is determined by a backgrounder's decision to purchase calves at time $t-2$; this parallels the equation for the demand for feeder calves. The production decision is made two periods earlier when the farmer purchases the inputs; this implicitly assumes that the producer takes the current average fed cattle price as representation of what they expect to get for their stockers.

A dummy variable ($D2012Q4$) to account for an unusually low supply in the final quarter of 2012. A likelihood ratio test confirms that its inclusion significantly improves the fit of the model.

Finally, a Durbin-Watson test generates a test statistic of 2.58, which falls into the uncertain region, indicating that the model could suffer from negative autocorrelation. Due to the test statistic falling within the uncertain region (between the upper and lower critical values), a likelihood ratio test was used to confirm that the inclusion of the lagged dependent variable as a covariate significantly improved the fit of the model.

3.3.3 Provincial Demand for Stockers

$$\begin{aligned} \ln DBC_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PFeeder_t \qquad (3.17) \\ &+ \beta_6 \ln PFed_t + \beta_7 \ln CornP_t + \beta_8 D2012Q4 \qquad (3.18) \\ &+ \beta_9 D2003Q3 \end{aligned}$$

The above equation constitutes the derived demand function for feeder cattle (stockers). It is assumed to be a function of the average feeder price ($PFeeder_t$), the average fed cattle price ($PFed_t$) and the provincial corn price ($CornP_t$) in period t.

The average price of feeder cattle ($PFeeder_t$) represents the cost of the input. Accordingly, it is expected that the coefficient on the latter variable will be negative, as an increase in the price of stockers increase the cost of production for feedlot owners. Furthermore, the provincial corn price ($CornP_t$) is included as corn is the main feed for cattle on a high-energy ration and therefore represents the cost of a complementary. It's coefficient should be negative as well – if the price of corn increases then this will increase the cost associated with weight gain of a stocker.

As equation 3.19 a derived demand the average feeder price ($PFed_t$) (\$/100 lbs.) accounts for the output price faced by feedlots when they are making a decision of whether to, or how many, stockers to purchase. The parameter estimate should be positive indicating that if the price received by feedlots for their finished animals increases, that they will in turn increase their conditional demand for feeders, holding all else constant, as it is not more profitable to fatten cattle.

A dummy variable is included to correct for the presence of an noteworthy decrease in the demand for feeders in the fourth quarter of 2012 ($D2012Q4$). This likely has little to do with the market forces in the above equation, but more to do with gradual reduction in the number of feeder animals available in Ontario due to gradual declines in the provincial output of calves.

3.3.4 Exports of Feeder Cattle (Stockers) to U.S.

$$\begin{aligned} EFC_t = &\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 UCFPS_t \\ &+ \beta_6 USDP_t + \beta_7 D02Q203Q1 + \beta_8 DBSE + \beta_9 EFC_{t-1} \end{aligned} \tag{3.19}$$

Equation 3.20 represents the function determining the number of stockers exported to the U.S.. As can be seen here, the export of stockers to the U.S. is contingent on two key factors: (i) the U.S.-Canada average feeder price spread ($UCFPS_t$), which captures any arbitrage opportunities; and (ii) the U.S. diesel price ($USDP_t$) which is used as an approximation for the transportation basis. For the latter variable, the coefficient is expected to be positive; as the difference between the average U.S. stocker price and the Ontario stocker price becomes larger – i.e. either when the U.S. price increases, holding the Ontario price constant, or when the Ontario price decreases holding the U.S. price constant – the arbitrage gains becomes evident as it is now relatively cheaper for U.S. feedlots to purchase Ontario stockers.

The use of U.S. diesel price acts as a crude (pun intended) measure of the transportation basis. Failure to account for the role of transportation cost would most likely result in biased estimates (omitted variable bias). While, as discussed above, the movement of cattle depends on the price spread, there are threshold effects. Intuitively, if the price spread is not larger than the cost of transporting the animals, then the transaction will not place as it is no longer profitable to do so. Without knowledge of the destination and origin of the exports it is difficult to calculate an alternative measure of trade costs. Thus, we must estimate equation 3.20 using the U.S. disease price as a proxy variable for the transportation basis. We expect the coefficient on this variable to be negative, as an increase in the price of fuel will increase the transportation basis, and accordingly reduce the profitability of importing stockers for U.S. feedlots.

As equation 3.20 represents the excess supply (export) function for stocker cattle, all prices are estimated in \$USD, as that is the currency that the importers in the U.S. would respond to when making their decisions.

Here, $D02Q203Q1$ controls for a period (2002, quarter 2 to 2003, quarter 1) in which there was a surge of feeder exports to the U.S.. Additionally, the variable $DBSE$ is dummy variable equal to one during the BSE border closure to animals under 30 months (May, 2003 – July, 2005).

A Durbin-Watson test revealed the presence of first-order autocorrelation. A Durbin's H test reveals that the inclusion of the lag of the dependent variable was included remedied the problem.

This equation is estimated in a linear functional form as the price spread can be negative – when the Canadian price (expressed in U.S. dollars) is higher then the average U.S. stocker price – and as such one cannot take the logarithm of a negative number.

3.4 Finishing Sector

3.4.1 Supply of Fed Heifers

$$\begin{aligned} \ln SFH_t = &\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PFH_{t-2} + \beta_6 \ln PSH_{t-2} \\ &+ \beta_7 \ln CornP_t + \beta_8 D9801 + \beta_9 D2003Q2Q4 + \beta_{10} D2008Q12 \end{aligned} \tag{3.20}$$

The above equation states that the supply of fed heifers is dependent on the fed heifer price (PFH_{t-2}), the feeder heifer price ($PFeederH_{t-2}$), and the provincial corn price ($CornP_{t-2}$) lagged two periods. This is intended to capture the decision-making process of a feed-lot operator as their decision to put cattle to put is contingent on these aforementioned factors approximately two quarters in advance of when the designated amount of weight has been gained. Thus, inclusion of these variables is intended to capture the farmer's expectation of what they will received for the animal as well as the cost which are incurred 2 quarters earlier.

The dummy variables $D9801$, $D2003Q2Q4$, and $D2008Q12$ were included to control for outliers in the dependent variable.

3.4.2 Demand for Fed Heifers

$$\begin{aligned} \ln DFH_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PFH_t + \beta_6 \ln PBBeef_t \\ & + \beta_7 D1999 + \beta_8 D2003Q2 + \beta_9 \ln DFH_{t-1} \end{aligned} \tag{3.21}$$

The demand for fed heifers by the Ontario processing sector is modelled as a function of the price of fed heifers (PFH_t) and the price of Canadian boxed beef ($PBBeef_t$). The price of fed heifers represents a main input cost for slaughter plants; therefore, an increase in the price of fed heifers, increases the cost of producing processed beef and should result in a decreased demand for fed heifers. Next, the price of Canadian boxed beef is included as the demand for slaughter cattle represents a derived demand originating from a demand for Canadian beef. Its coefficient is expected to be positive indicating that processor demand for fed heifers will increase, if the wholesale price of beef increases processors will seek to increase their supply which in turn generates increased demand for fed heifers.

The dummy variables $D1999$, and $D2003Q2$ are included to account for a period of low demand and the onset of the BSE crisis, respectively. Likelihood ratio tests reveal that their presence significantly improves the fit of the model.

A Durbin-Watson test (a test statistic of 1.23) revealed that the equation suffered from positive serial correlation. The lagged dependent variable was included as an explanatory variable to correct for autocorrelation – Durbin H's test revealed that the model no longer suffers from autocorrelation.

3.4.3 Exports of Fed Heifers to the U.S.

$$\begin{aligned} EFH_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 UCHPS_t + \beta_6 DBSE \\ & + \beta_7 D0506 + \beta_8 D2008Q1 + \beta_9 D2012Q3 + \beta_{10} EFH_{t-1} \end{aligned} \tag{3.22}$$

Equation 3.23 represents the export supply equation for fed heifers. As can be seen exports of fed heifers are a function of the U.S.-Canada fed heifer price spread ($UCHPS_t$) – the difference in price between the U.S. and Canadian fed heifers in U.S. dollars. Similar to the export equation for stocker cattle (equation 3.20), the coefficient on the price spread variable should be positive indicating that as the difference between the U.S. and Ontario fed heifer price gets larger then the arbitrage opportunity increases and more cattle will be exported to the U.S..

The dummy variable $DBSE$ is included to correct for the period when the U.S. border was closed to cattle under 30 months after the BSE outbreak between June 2003 to July 2005. $D0506$, $D2008Q1$, and $D2012Q3$ are dummy variables indicating periods of unexplained high or low levels of exports (for various reasons). A likelihood ratio test confirms that these variable significantly improved the fit of the model.

A lagged dependent variable was included to correct for autocorrelation. A Durbin H test reveals that it corrected the problem.

The above equation had to be estimated using a linear functional form because of the BSE border closure, there are several zeros in the dependent variable, and because of the price spread variable taking on negative values prevented us from using a log-linear functional form (again, as one cannot take the natural log of a zero).

3.4.4 Supply of Fed Steers

$$\begin{aligned} \ln SFS_t = &\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PFS_{t-1} + \beta_6 \ln PSS_{t-1} \\ &+ \beta_7 \ln CornP_{t-2} + \beta_8 D9899 + \beta_9 D2001Q1 + \beta_{10} D2011 \end{aligned} \tag{3.23}$$

The above equation states that the supply of fed steers is dependent on the fed steer price (PFS_{t-1}), the feeder steer price ($PFeederS_{t-1}$), and the provincial corn price ($CornP_{t-2}$) lagged two periods. This is intended to capture the decision-making process of a feed-lot operator as their decision to put cattle to put is contingent on these aforementioned factors approximately two quarters in advance of when the designated amount of weight has been gained. Thus, inclusion of these variables is intended to capture the farmer's expectation of what they will received for the animal as well as the cost which are incurred 2 quarters earlier.

Again, equation 3.24 was estimated in a log-log functional form. The dummy variables $D9899$, $D2001Q1$, and $D2011$ were included to account for outliers in the dependent variable. A likelihood ratio test reveals that their inclusion significantly increases the fit of the equation.

3.4.5 Demand for Fed Steers

$$\begin{aligned}\ln DFS_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PFS_t + \beta_6 \ln PBBeef_t \\ &+ \beta_7 D9900 + \beta_8 2001Q1 + \beta_9 D2006Q3 + \beta_{10} \ln DFS_{t-1}\end{aligned} \tag{3.24}$$

The derived demand for fed steers from the provincial processing sector is modelled as a function of the price of fed steers (PFS_t) in period t and the price of Canadian boxed beef ($PBBeef_t$). The estimated coefficient on the price of fed steers is assumed to be negative, as it is the main input for packing plants and an increase in price represents and increase in the cost of producing processed beef. Next, the price of Canadian boxed beef is included it represents the wholesale output price for Canadian beef. The coefficient should be positive as processing plants will slaughter more fed steers given an increase in the price of beef, holding all else constant.

The dummy variables $D2001Q1$ and $D9900$ are included in order to account for unseasonably low demand, and $D2006Q3$ is included to account for an unusually high demand. Likelihood ratio tests reveal that their presence significantly improves the fit of the model.

Finally, a lagged dependent variable is included to correct for first order serial correlation. A Durbin H test reveals that this rid the model of autocorrelation.

3.4.6 Exports of Fed Steers to the U.S.

$$\begin{aligned}EFS_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 UCSPS_t \\ &+ \beta_6 DBSE + \beta_7 D2000 + \beta_8 D2007 + \beta_9 D2008\end{aligned} \tag{3.25}$$

Equation 3.26 represents the exports of fed steers to the U.S as a function of the U.S.-Canada fed steer price spread ($UCSPS_t$). Parameter estimates for the latter variable should be positive indicating that as the difference between the U.S. and Ontario fed steer price becomes larger than it is more profitable for U.S. packing plants to imports more live steers from Ontario, as this would lower their cost of production.

The dummy variable $DBSE$ corrects for the period in which the dependent variable is zero due to the closure of the U.S.-Canada border closure to animals under 30 months. The remaining dummy variables are used to account for years with unexplained high levels of exports to the U.S.. A likelihood ratio test confirms that their inclusion significantly improves the fit of the model.

3.5 Non-fed Sector

3.5.1 Provincial Demand for Slaughter Cows

$$\begin{aligned}\ln DCC_t =&\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PCC_t + \beta_6 \ln PFed_t \\ &+ \beta_7 D1999 + \beta_8 D2011 + \beta_9 D2012 + \beta_{10} \ln DCC_{t-1}\end{aligned} \tag{3.26}$$

The above equation represents the derrived demand for provincial slaughter plants for culled cows. It is assumed here that the demand for culled cows is contingent on the price of culled cows (PCC_t) and the average provincial price of fed cattle ($PFed_t$). As the price of culled cows represents the cost of the input, and this is a derived demand equation, the coefficient on price should be negative to indicate that, holding all else constant, an increase in price decreases the demand for the input as it would represent a higher cost of production. Next, the average price of fed cattle is included as non-fed cattle can be viewed as a substitute to fed cattle for processors. While fed cattle generally represent a source of higher quality beef, given substantial increase in the price of fed cattle that processors will increase the number of culled cows slaughtered in order to minimize their cost. As such the coefficient on the the average price of fed cattle should be positive, indicating that fed cattle are substitute inputs for processors.

There are several dummy variables were included to correct for periods of high or low demand, that likely occurred because of influences beyond the other explanatory variables alone. $D1999$ controls for a surge in the demand for culled cows in 1999; while $D2011$ and 2012 account for an substantial increase in the killing of culled cows, likely attributable to a significant declines in the beef cow inventory in Ontario.

A Durbin-Watson test revealed that first-order autocorrelation was present. This was corrected for through the inclusion of the lagged dependent variable as an explanatory variable. A Durbin H test indicates that it corrected for autocorrelation.

3.5.2 Export of Slaughter Cows to U.S.

$$\begin{aligned}ECC_t =&\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 UCCPS_t + \beta_6 USDP_t \\ &+ \beta_7 DBSE + \beta_8 D2003Q1 + \beta_9 D2007Q4 + \beta_{10} ECC_{t-1}\end{aligned} \tag{3.27}$$

The above equation represents the factors assumed to affect the volume of slaughter cows exported to the U.S. (shown in table 2.7). We assume that the size of exports is determined by the U.S.-Canada price spread ($UCCPS_t$) and the U.S. diesel price ($USDP_t$). Again, the parameter estimate on the price spread variable is expected to be positive; as the difference between the price received for culled cows in the U.S. versus Ontario increases it becomes more profitable for U.S. processors to import more culled cows to take advantage of the arbitrage opportunity.

Next, the U.S. diesel price is included to approximate the transportation costs associated with shipping animals cross border (most cattle are trucked, as such the majority of the cost will be diesel fuel). The coefficient on this variable should be negative indicating that an increase in the cost of shipping cattle will reduce the volume of cows imported because it is no longer profitable for some firms to do so.

As table 2.7 demonstrates there are a series of zeros representing the border closure during the BSE crisis, this was corrected for using a dummy variable ($DBSE$). A dummy variable was also included to account for a low trade volume in the fourth quarter of 2007, which likely stemmed from the adjustment and/or reestablishment of trade flows in the months following the reopening of the border to animals over 30 months in November, 2007. $D2003Q1$ was included to correct for an unusually high volume of exports during the first quarter of 2003 (before the BSE crisis).

The lagged dependent variable is included as an explanatory variable in equation **??** to account for the presence of autocorrelation. However, a Durbin h test revealed that this did not correct for it. Regardless, the variable continues to be included as it is statistically significant indicating that it is capturing some omitted effect from the previous period.

Equation **??** is estimated in a linear function form. This had to be done for reasons previous mention (for fed cattle exports to the U.S.). Specifically, the model could not be estimated in log-linear functional form due to the presence of zeros in the dependent variable, and the negative values of the price spread variable.

3.5.3 Beef Cow Inventory

$$\ln INVC_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \ln \beta_5 CCPR_t + \beta_6 Trend + \ln \beta_7 INVC_{t-1} \tag{3.28}$$

The inventory of beef cows was estimated as a function of the ratio of cow to calf prices, a trend variable and the lagged inventory of beef cows from the previous quarter. It is estimated in a double log functional form, as it fit the data better than a linear functional form.

In order to capture the decision making process of cow-calf producers of whether to expand or contract their breeding stock, we use a ratio of the cow to calf price in the current period ($CCRP_t$). The idea is that the decision of producers to increase the size of their herd is contingent on the relative profitability of keeping the cow versus culling it. If the cow price increases relative to the calf price, then there is incentive to cull the cow. In contrast, if the ratio decrease it implies that either the price of calves is increasing or that the price received for culled cows has decreased, suggesting that there is more value in holding on to the cow, as the gains to selling calves is relatively larger. The sign on the variable will be negative indicating that the beef cow inventory will decline if the relative price of culled cows increases, or that the inventory will increase if the value of calves increases relative to culled cows.

A trend variable ($Trend$) was included to capture the general contraction of the Ontario beef cow herd over the estimation period (1996-2011). As can be observed from figure **??**, there has been a decline in the beef cow inventory in recent years; thus, it is expected that there should be a negative coefficient on the variable.

The lagged dependent variable (INV_{t-1}) is included to correct for first-order autocorrelation as identified by a Durbin-Watson test statistic. The test statistic was less than 2 indication the presence of positive serial correlation. Durbin's h test for autocorrelation with a lagged dependent variable is less than the critical value indicating that inclusion of the lagged dependent variable corrected for serial correlated errors.

3.5.4 Provincial Demand for Slaughter Bulls

$$\begin{aligned}\ln DCB_t =&\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln PCB_t + \beta_6 \ln PBBeef_t \\ &+ \beta_7 D2006Q1 + \beta_8 D2009 + \beta_9 Trend + \beta_{10} \ln DCB_{t-1}\end{aligned} \tag{3.29}$$

The provincial demand for slaughter bulls is a function of the Ontario bull price (PCB_t) and the Canadian price of boxed beef ($PBBeef_t$). As equation 3.30 represents the input demand function for slaughter bulls, the coefficient on the provincial bull price is negative indicating that the price of bulls is inversely related to the quantity demanded. The coefficient on the wholesale price of Canadian beef is positive, as expected. Since the latter represents the output price received by slaughter plants, an increase in the wholesale price of beef with result in an increase the amount supplied by provincial processors, and in turn generate additional demand for slaughter cattle.

The dummy variables $D2006Q1$ and $D2009$ due to periods of high demand for slaughter bulls beyond what is attributable to the other covariates. Furthermore, a trend variable is included to account for the general increase in the number of bulls being culled over the sample period, which is likely due to the decline in the number of bulls on provincial operations (see figure 2.5).

A Durbin-Watson test for first-order autocorrelation reveal that it was present. It was corrected with the inclusion of the lagged dependent variable (DCB_{t-1}).

3.5.5 Export of Slaughter Bulls to U.S.

$$\begin{aligned} ECB_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 UCBPS_t + \beta_6 USDP_t \\ &+ \beta_7 DBSE + \beta_8 D2000 + \beta_9 D2008Q23 + \beta_{10} ECB_{t-1} \end{aligned} \tag{3.30}$$

The provincial export of slaughter bulls from to the U.S. is assumed to be a function of the slaughter bull price spread between the U.S. and Ontario ($UCBPS_t$), and the U.S. diesel price ($USDP_t$). The coefficient on the price spread variable is expected to be positive indicating that as the difference between the two region's prices become larger, that more bulls will be exported to the U.S.. Next, the parameter estimate for the U.S. diesel price, which proxies the transportation basis, is expected to be negative implying that if the price of fuel increases that fewer bulls will be exported as it is more costly to do so.

Again as in equation 3.30, a dummy variable is used to account for the U.S.-Canada border closure due to the BSE crisis ($DBSE$). While the dummy variables $D2000$ and $D2008Q23$ are used to control periods of unusually lower and higher exports, respectively, unexplained by fluctuations in other variables.

A lagged dependent variable (ECB_{t-1}) is included to account for autocorrelation in the model. A Durbin h test reveals that it corrected for the latter.

3.5.6 Bull Inventory

$$\begin{aligned} \ln INVB_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln BCPR_t \\ &+ \beta_6 Trend + \beta_7 \ln INVB_{t-1} \end{aligned} \tag{3.31}$$

Equation 3.32 states that provincial bull inventory is a function of the ratio of provincial bull price to the provincial rail grade calf price in period t ($BCPR_{t-1}$). The price ratio is included as represents the tradeoff between keeping the bull for reproductive purposes and profitability of selling the bull. The coefficient on this variable is, thus, expected to be negative as the price of bulls in the previous period makes it more profitable to cull them.

A trend variable ($Trend$) is included to account for the reduction in the bull inventory over the period (figure 2.5) (likely as a result of the advent of artificial insemination). As can be observed from figure 2.5, there is a general decline in the inventory over the sample period; therefore, the sign on this parameter should be negative.

The lagged dependent variable ($INVB_{t-1}$) is included to correct for positive first-order autocorrelation as identified by a Durbin-Watson test statistic. Durbin's h test for autocorrelation indicates that inclusion of the lagged dependent variable did correct for serial correlated errors.

3.6 Average Warm Carcass Weights

3.6.1 Heifer Warm Carcass Weight (in lbs.)

$$\begin{aligned}\ln HCW_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln HCPR_{t-2} + \beta_6 D2011 \\ &+ \beta_9 Trend + \beta_{10} \ln HCW_{t-1}\end{aligned} \tag{3.32}$$

3.6.2 Steer Warm Carcass Weight (in lbs.)

$$\ln SCW_t = \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln SCPR_{t-2} + \beta_6 Trend + \beta_7 \ln SCW_{t-1} \tag{3.33}$$

3.6.3 Cow Warm Carcass Weight (in lbs.)

$$\begin{aligned}\ln CCW_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln SCCPR_t + \beta_6 D2000 \\ &+ \beta_7 D2001 + \beta_8 D2007 + \beta_9 D2012 + \beta_{10} Trend + \beta_{11} \ln CCW_{t-1}\end{aligned} \tag{3.34}$$

3.6.4 Bull Warm Carcass Weight (in lbs.)

$$\begin{aligned}\ln BCW_t = &\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln SBCPR_{t-2} + \beta_6 D2009 \\ &+ \beta_9 Trend + \beta_{10} \ln BCW_{t-1}\end{aligned} \tag{3.35}$$

Equations **??** through 3.36 represent the factors which influence the weights of fed and non-fed cattle after they are slaughtered (i.e., the average warm carcass weights).

The cattle-corn price ratio, respective of each type of cattle (i.e. $HCPR_{t-2}$, $SCPR_{t-2}$, $SCCPR_t$, and $SBCPR_t$), are included as explanatory variables to account for the trade-off producers face when deciding when, and accordingly at what weight to market their animals. If the ratio increases it implies that either the corn price has decreased or that the price ($/100 lbs.) received for a slaughter animal has increased; and conversely, the opposite is true if the ratio decrease. In either case, the coefficient on the variable is expected to be positive indicating that an increase in the ratio incentivizes the producers to put more weight on the animal. For example, if the corn price decreases (holding constant the price received for a slaughter animal), then the ratio will increase and the weight of the cattle at slaughter will be higher than it otherwise would. The price ratio is lagged two period for heifers and steers to account for the decision-making process when a feed lot owner decides to make the initial investment in the animal. This approach may seem ambiguous for the non-fed cattle weight equations as typically they never get put on a high-ration diet; however, the corn price does serve to approximate the cost of feeding cows and bulls as it captures the opportunity costs of giving up cash cropping in favour of growing feed for cows and bulls.

Trend variables ($Trend$) were included to capture an underlying trends in the average warm carcass weights for fed and non-fed cattle. Over the sample period, fed cattle seem to exhibit an upward trend, while there appears to be a decline in the slaughter weight of the culled cows and bulls. In each of the above equations, dummy variables were included for years which deviated from the general trends in the dependent variable.

For all carcass weight equations, lagged dependent variables were included to correct for the presence of autocorrelation likely stemming from the annual nature of the data – the (AAFC) Red Meat Division only reports average warm carcass weights by type annually. For all of the above equations, Durbin h tests reveal that in all cases this corrected for first-order autocorrelation.

3.7 Retail & Processing Sector

3.7.1 Provincial Demand for Beef

$$\begin{aligned}\ln ODB_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln ORBP_t + \beta_6 \ln ORPP_t \\ &+ \beta_7 \ln ORCP_t + \beta_8 \ln ODI + \beta_9 Trend + \beta_{10} D2003\end{aligned} \tag{3.36}$$

Equation 3.37 represents the provincial Marshalian demand for beef. The per capita demand is modelled as a function of the price of beef ($ORBP_t$), the price of pork ($ORPP_t$), the price of chicken ($ORCP_t$), and per capita personal disposable income (ODI_t). A dummy variable is generated for 2003 ($D2003$) where beef consumption was notably higher then for any other year. A trend variable ($Trend$) was included to account for the declining per capita consumption of beef over the sample period.

3.7.2 Provincial Exports of Beef to the U.S.

$$\begin{aligned}\ln EBU_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 UORBPS_t + \beta_6 \ln PFed_t \\ &+ \beta_7 D2003Q2 + \beta_8 D2003Q3 + \beta_9 D07Q409Q1 \\ &+ \beta_{10} D2009Q2 + \beta_{11} Trend\end{aligned} \tag{3.37}$$

Ontario's exports of beef are modelled here as a function of the U.S.-Ontario retail beef price spread ($UORBPS_t$) and the average price of fed cattle in Ontario ($PFed_t$). The price spread accounts for any arbitrage between the U.S. and Ontario, while the inclusion of the average price of fed cattle represents the cost of production/opportunity cost associated with shipping beef instead of live animals.

The dummy variables $D2003Q2$ and $D2003Q3$ capture the effect of the introduction of the BSE crisis on beef exports to the United States. While the remaining dummy variables correct for other periods of unusually low export volume – i.e. $D07Q409Q1$ and $D2009Q2$.

The dependent variable (EBU_t) and the average price of fed cattle were transformed by taking their natural logarithm as a likelihood ratio test suggested that this fit the data better then a simple linear model.

3.7.3 Provincial Imports of Beef from the U.S.

$$\begin{aligned}\ln IBU_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 OURBPS_t \\ &+ \beta_6 ODP_t + \beta_7 D2004Q1 + \beta_8 D200405 + \beta_9 Trend + \beta_{10} \ln IBU_{t-1}\end{aligned} \tag{3.38}$$

The above equation assumes that imports of beef from the U.S. is a function of the Ontario-U.S. price spread ($OURBPS_t$), and the provincial average diesel price (ODP_t). As stated previously, the coefficient on the price spread variable is expected to be positive, indicating that the larger the differences between the Ontario and the U.S. price generates more of an arbitrage opportunity to import cheaper U.S. beef and sell it in the Ontario market.

A trend variable ($Trend$) is included to account for a general increase in the amount of beef imported from the U.S.. The dummy variables $D2004Q1$ and $D200405$ correct for periods of low beef imports likely attributable surplus beef in Ontario due to the BSE crisis.

A Durbin H-test revealed that inclusion of a lagged dependent variable rid the model of first-order serial correlation (IBU_{t-1}). Due to the presence of negative values for the price spread variable the model could not be estimated using a log-linear functional form. Thus, the dependent variable is transformed by taking the natural logarithm of the quantity of beef imports from the U.S.. This was done as

3.7.4 Provincial Exports of Beef to R.O.W.

$$\begin{aligned}\ln EBW_t =& \beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 \ln WBEP_t \\ &+ \beta_6 \ln PFed_t + \beta_7 D2003Q3 + \beta_8 D2003Q4 + \beta_9 \ln EBW_{t-1}\end{aligned} \tag{3.39}$$

Equation 3.40 represents the export demand from world markets excluding the United States, for Canadian beef. It is assumed to be determined according to the world export price (WEP_t), and the average price of fed cattle in Ontario ($PFed_t$). The world export price (WEP_t) is proxied by the quarterly unit value of all beef exports. It is an aggregate measure which does not account for any changes in the composition of beef exports in terms of quality. Therefore, the average price of fed cattle was included to account for any increase in volume attributable to decreases in the cost of production – outward shifts in the domestic supply curve – as the a decrease in the "export price" could be attributable to a relative increase in the export of low-value beef products, rather then a decrease in cost.

The parameter estimate on the export price variable is expected to be positive as provincial firms will find it profitable to increase the amount of beef they export given an increase in price. While the coefficient on the fed cattle price is expected to be negative. Since the provincial fed cattle price is a proxy for the cost of production, an increase in the price of the main input, holding all else constant, will reduce the amount of beef exported as firms not longer find it profitable to export.

The dummy variables $D2003Q3$ and $D2003Q4$ account for the exogenous shocks from the BSE crisis. A Durbin-Watson test revealed that first-order autocorrelation was present. This was corrected for through the inclusion of a lagged dependent variable – EBW_{t-1}.

3.7.5 Provincial Imports of Beef from R.O.W.

$$\begin{aligned} \ln IBW_t = &\beta_1 + \beta_2 Q_1 + \beta_3 Q_2 + \beta_4 Q_3 + \beta_5 WBIP_t \\ &+ \beta_6 D2002 + \beta_7 D2003Q4 + \beta_8 D0408 + \beta_9 2009Q4 + \beta_{10} \ln IBW_{t-1} \end{aligned} \tag{3.40}$$

Equation **??** is used to estimate the parameters influencing the volume of beef imports into Ontario from all other countries, excluding the United States. The volume of imports from the non-U.S. countries is assumed to be a function of the average price of beef imports (WIP_t). Unfortunately, since we are aggregating the quantity of imports across exporters, we do not have access to an actual estimate of the average price ($/lbs/) paid by importers in Canada (we are also implicitly assuming that there are no quality differences across or within trade flows). As such, we had to generate a unit value by dividing the value of beef imports by the quantity of imports in a quarter. We use this unit value as a proxy for the average price imported beef in a given period. The coefficient on the average price (unit value) is expected to be negative, as an increase in price reduce the quantity of imported beef demanded.[3]

The dummy variables $D2002$, $D2003Q4$ and $D2009Q4$ were included to account for periods of large imports. $D0408$ is a dummy variable equal to one if the observation falls between 2004-2008. This was included to account for a noteworthy drop in the volume of beef imports into Ontario, which is likely attributable to the saturation of the provincial beef market with Canadian beef, after the series of border closures to Canadian beef exports of the BSE crisis.

[3] An increase in the unit value could rise as the result of an increase in the quality of beef coming into Ontario – e.g. if the high-end cuts of beef are comprising more of the quantity of imports – as higher quality is typically receives a higher premium. This possibility could introduce some measurement error into the model, and accordingly bias the estimates. However, for simplicity and due to the absence of alternatives, we ignore this possibility here.

While we do not estimate in the typical log-linear functional form, we do transform the dependent variable by taking the natural logarithm of it. This is done in order to minimize the potential for heteroskedasticity. Finally, we include a lagged dependent variable to correct for the presence of first-order correlation.

Chapter 4

Identities & Equilibrium Conditions

This model makes use of partial equilibrium analysis and accordingly takes some of the explanatory variables as exogenous. We assume that we are price-takers (since we are a small exporting nation), which implies that the price of fed and non-fed cattle in Ontario is a function of the U.S. cattle prices. This means that in the model price variables will not automatically adjust to ensure that markets clear as they would under a general equilibrium analysis. This is problematic as economic theory dictates that if a surplus (shortage) occurs that prices would decrease (increase) so that the number of cattle demanded equalled the quantity supplied. Therefore, markets will not clear unless these conditions are imposed on the model. In short, the use of identities allows use to garner a closed-form solutions for the endogenous variables.

As such, use of these aforementioned conditions replaces structural equations for several variables of interest. For example, as the reader may notice, we essentially treat all interprovincial movements of cattle as a residual resulting from an identity.

Additionally since several of the structural (behavioural) equations do not distinguish between the proportion of steers and heifers, but rather estimate, say the number of provincial calves supplied, identities are used to determine the number of heifers and steers at each stage. This was done to allow the researcher to treat certain assumptions as parameters, rather than given, the latter of which would require correction of the assumptions in the data and then re-estimation of the parameters.

4.1 Cow-Calf

Identities 4.1 and 4.2 calculate the number of heifer and steer calves supplied to the provincial calf market in period t. Equation 3.14 (section 3) estimates the supply of calves, but fails to distinguish between the proportion of calves which are heifers and those that are steers. This is an important as accounting for heifer retention and differences in the number of heifers and steers slaughtered provincially warrant the distinction. As can be observed in 4.1 and 4.2 to vary this assumption as estimated gender ratios (number of heifer to steer calves) may vary. Furthermore, the overall number of heifer and steer calves demanded is also determined by the assumed gender composition of interprovincial imports of feeder calves from Western Canada. The latter two identities are used to obtain the number of heifer and steer calves demanded provincially – the second term represents the weighted average of the assumed sex ratio and the proportion of imported calves of a gender, weighted by the number of calves born provincially and the number of interprovincial imports, respectively. Use of identities 4.1 and 4.2 permit the quantity of heifer (steer) calves to be adaptive to the assumptions of the researcher.

Identity 4.3 stems from the assumption that there are no feeder calf exports to the U.S. or out of Ontario. Thus, the number of heifer calves demanded by backgrounders is always identical to the number of feeder calves imported from Western Canada and the amount produced by provincial cow-calf farmers.[1] Furthermore, since we infer the quarterly number of calves born, using CANSIM biannual counts and provincial monthly calving rates from the Canadian Cattle Identification Agency (CCIA), we estimate this along with the demand for calves using a behavioural equation discussed in the next section. Since data or information on the interprovincial movement of cattle is limited, and any available was aggregated, and failed to distinguish between the movement of dairy and beef cattle (as well as the stage of the cattle), we assume that this identity holds and treat the interprovincial imports of calves as a residual.

[1] We acknowledge that often feed lots do not only purchase or import feeder cattle from backgrounding operations, but also acquire feeder calves directly. However, we implicitly assume that those feed lots are effectively acting as backgrounders.

Cow-Calf Sector Identities

$$\text{Demand for Heifer Calves}_t \equiv \text{Demand for Calves}_t \times \frac{(\%\text{Heifer Calves} \times \text{Supply of Calves}_t + \%\text{Heifer Calf Imports} \times \text{Calf Imports}_t)}{(\text{Supply of Calves}_t + \text{Calf Imports})_t} \tag{4.1}$$

$$\text{Demand for Steer Calves}_t \equiv \text{Demand for Calves}_t \times \frac{(\%\text{Steer Calves} \times \text{Supply of Calves}_t + \%\text{Steer Calf Imports} \times \text{Calf Imports}_t)}{(\text{Supply of Calves}_t + \text{Imports of Calves})_t} \tag{4.2}$$

$$\text{Interprovincial Imports of Calves}_t \equiv \text{Demand for Calves}_t - \text{Supply of Calves}_t \tag{4.3}$$

4.2 Backgrounding Sector

Identity 4.6 represents the number of stockers attributable to feeder steers. As can be observed the number of feeder steers is assume to be a function of the assume sex ratio and interprovincial imports two quarters earlier. This is done as it is assumed that it take approximately 6 months, on average, for an animal to gain the necessary size to be sold to feed lots. In other words, the number of feeder steers supplied is assumed to be determined by the weight average of the proportion of feeder calves attributable to steer calves and the proportion of interprovincial calf imports attributable to steers lagged two quarters, times the estimated provincial supply of feeder cattle.

Identities 4.4 and 4.5 imply a similar relationship for feeder and replacement heifers, with one exception, for these identities we need to account for the fact that the supply of feeder heifers is contingent on the rate at which heifers are being retained for breeding purposes. However, Identity 4.4 is multiplied by one minus the assumed heifer retention rate (which is variable in the model), while identity 4.5 is simply multiplied by the weight attributable to heifer calves two quarters earlier and the assumed heifer retention rate.

Identities 4.7 and 4.8 simply imply that the number of feeder heifers and steers is determined by the estimated number of stockers exported to the United States time the assumed proportion they each represent. The latter proportion can easily be varied in the model. A restriction is also imposed so that they must sum up to one.

Finally, as stated by identity 4.9 and 4.10 the market must clear for both feeder heifers and steers. This implies that the interprovincial imports of stockers is represented by the residual demand – the remaining market demand plus exports less provincial supply from beef operations and provincial supply from dairy operations.

Backgrounding Sector Identities

$$\text{Supply of Feeder Heifers}_t \equiv \text{Supply of Feeders}_t \times \frac{(\%\text{Heifer Calves} \times \text{Supply of Calves}_{t-2} + \%\text{Heifer Calf Imports} \times \text{Calf Imports}_{t-2})}{(\text{Supply of Calves}_{t-2} + \text{Calf Imports}_{t-2})} \times (1 - \text{Retention Rate}) \tag{4.4}$$

$$\text{Replacement Heifers}_t \equiv \text{Supply of Feeders}_t \times \frac{(\%\text{Heifer Calves} \times \text{Supply of Calves}_{t-2} + \%\text{Heifer Calf Imports} \times \text{Calf Imports}_{t-2})}{(\text{Supply of Calves}_{t-2} + \text{Calf Imports}_{t-2})} \times \text{Retention Rate} \tag{4.5}$$

$$\text{Supply of Feeder Steers}_t \equiv \text{Supply of Feeders}_t \times \frac{(\%\text{Steer Calves} \times \text{Prov. Supply of Calves}_{t-2} + \%\text{Steer Calf Imports} \times \text{Calf Imports}_{t-2})}{(\text{Prov. Supply of Calves}_{t-2} + \text{Calf Imports}_{t-2})} \times (1 - \text{Retention Ra} \tag{4.6}$$

$$\text{Feeder Heifer Exports to U.S.}_t \equiv \%\ \text{Feeder Heifer Exports} \times \text{Exports of Stockers to U.S.}_t \tag{4.7}$$

$$\text{Feeder Steer Exports to U.S.}_t \equiv \%\ \text{Feeder Steer Exports} \times \text{Exports of Stockers to U.S.}_t \tag{4.8}$$

$$\text{Interprov. Imports of F. Heifers}_t \equiv \text{Demand for F. Heifers}_t + \text{Exports of F. Heifers}_t - \text{Supply of F. Heifers}_t - \text{Supply of Dairy F. Heifers}_t \tag{4.9}$$

$$\text{Interprov. Imports of F. Steers}_t \equiv \text{Demand for F. Steers}_t + \text{Exports of F. Steers}_t - \text{Supply of F. Steers}_t - \text{Supply of Dairy F. Steers}_t \tag{4.10}$$

4.3 Finishing Sector

For fed cattle there are only two identifies, each representing the interprovincial imports of fed cattle as the residual demand after the deduction of the provincial supply of fed cattle. Thus, identities 4.11 and 4.12 allow the market to clear as the behavioural equations estimate the demand for, supply of and exports to the United States of fed cattle.[2]

[2]As shown in table 2.5, the data used in estimation does not account for any interprovincial movement of cattle into (or out of) the province thus, any value is a residual and is only loosely attributable to the interprovincial imports of fed cattle. While this may seem contradictory, in practice there is likely a small volume of interprovincial movement in fed cattle so the researchers do not feel that this is a big intuitive jump.

Finishing Sector Identities

$$\text{Interprov. Imports of Heifers}_t \equiv \text{Demand for Heifers}_t + \text{Heifer Exports to U.S.}_t - \text{Supply of Heifers}_t \tag{4.11}$$

$$\text{Interprov. Imports of Steers}_t \equiv \text{Demand for Steers}_t + \text{Steer Exports to U.S.}_t - \text{Supply of Steers}_t \tag{4.12}$$

4.4 Non-Fed Sector

The demand, export, interprovincial imports and inventory equations are estimated using behavioural equations discussed in the preceding question. In order for the identity to hold we treat the supply of culled cows as a residual. This allow the model to account for changes in the breeding stock/inventory due to expansion or contraction of the industry. If supply of culled cows was not a function of the change in the estimated inventory then it would not reflect how expansion/contraction of the provincial industry affects the supply of culls. Identity 4.13 link the supply and interprovincial imports of culled cows to the demand for culled cows, exports to the U.S., and the change in the inventory – $\Delta Inventory$ (see identity 4.14).[3]

Next, identity 4.15 links the supply of culled bulls and the interprovincial imports of bulls to the demand for slaughter bulls in that period, the exports to the U.S. and a change in the provincial stock of bulls (denoted as Δinventory).[4] This identity is necessary because if the stock of bulls in Ontario was not included in the model then the market would not clear. For example, since in recent years the number of bulls has been declining likely due to the use of artificial insemination; if the change in the inventory was not accounted for then there would be a disjoint between the exports and the number of provincially slaughtered bulls (demand), and the number of bulls supplied to the market and the interprovincial imports of bulls.

[3] The change in the inventory of beef cows is represented by $\Delta\text{Inventory} = \text{Inventory}_t - \text{Inventory}_{t-1}$, or the difference between the inventory in the previous period and the current period.

[4] The change in the stock of bulls is represented by $\Delta\text{Inventory} = \text{Inventory}_t - \text{Inventory}_{t-1}$ (identity 4.16), or the difference between the inventory in the previous period and the current period.

Non-Fed Sector Identities

$$\text{Supply of Culled Cows}_t \equiv \text{Demand for Cows}_t + \text{Exports to U.S.}_t + \Delta\text{Cow Inventory} \tag{4.13}$$

$$\Delta\text{Cow Inventory} \equiv \text{Cow Inventory}_t - \text{Cow Inventory}_{t-1} \tag{4.14}$$

$$\text{Supply of Culled Bulls}_t \equiv \text{Demand for Bulls}_t + \text{Exports to U.S.}_t + \Delta\text{Bull Inventory} \tag{4.15}$$

$$\Delta\text{Bull Inventory} \equiv \text{Bull Inventory}_t - \text{Bull Inventory}_{t-1} \tag{4.16}$$

4.5 Retail/Processing Sector

The first identity (4.17) determines the supply of beef in a given quarter. The supply of beef is assumed a summation of the number of fed and non-fed cattle multiplied by their respective carcass weight, which are determined by structural equations in the model. Thus, the supply of beef is not estimated but assumed to be a direct function of the estimated number of cattle slaughtered in the province and the average warm carcass weights.

The total demand (disappearance of) for beef (in lbs.) in Ontario is assumed to be determined by the estimated per capita demand of beef times the quarterly provincial population (identity 4.19).

Again, the net interprovincial imports of beef are treated here solely as the residual provincial demand plus exports to all countries left over after the deduction of the provincial supply of beef, beef imports from the United States, and beef imports from the R.O.W.. While this number is not founded in any observable data, as the amount of beef imported from other provinces is not reported we just assume the difference is attributable to interprovincial movement of beef into Ontario (or out of if net imports become negative).

Retail/Processing Sector Identities

$$\text{Prov. Supply of Beef}_t \equiv \text{Demand for Cows}_t \times \text{Cow Carcass Weight}_t + \text{Demand for Bulls}_t \times \text{Bull Carcass Weight}_t + \text{Demand for Heifers}_t \times \text{Heifer Carcass Weig} \tag{4.17}$$

$$\text{Prov. Demand for Beef}_t \equiv \text{Per Capita Demand for Beef} \times \text{Population of Ontario}_t \tag{4.18}$$

$$\text{Net Interprov. Imports of Beef}_t \equiv \text{Prov. Demand for Beef}_t + \text{Beef Exports to U.S.}_t + \text{Beef Exports to R.O.W.}_t - \text{Prov. Supply of Beef}_t - textBeefImportsfr \tag{4.19}$$

Chapter 5

Application of the Model

This section lists the sheets in the SSM that summarize the output of the model in their various ways. The first section discusses the *Output Summary* sheet where the estimated prices and quantities are listed. The second section describes which relative measures of comparison are used to contrast the two outcomes and how they were calculated in *Changes Summary* sheet. The final section of this chapter, briefly describes the welfare measures and how they are calculated in the model.

5.1 Output Summary

The top of each market spread sheet lists the various prices or quantities estimated for both the baseline and counterfactual scenarios. In short, this sheet was created to unite all of the endogenized variables in one place where the research can look at their values before and after the imposition of an exogenous shock.

The next section discusses how relative measures of comparison were generated from these values.

5.2 Changes Summary

The changes summary has two components. Each component offers an different way of contrasting the given values for the baseline and counterfactual scenario. The percent change gives a relative measure of how much shock has changed the endogenized prices and quantities in the model. It uses the baseline estimates as the benchmark, or a representation of how things would be if the shock or change were not to occur. Assuming the baseline estimate is used to normalize the relative measure, the percentage change in quantity is calculated as:

$$\%\text{Change in Quantity} = \frac{\Delta Q}{Q_B} \times 100 = \frac{Q_C - Q_B}{Q_B} \times 100 \tag{5.1}$$

where:

Q_B is the quantity estimated in the baseline scenario.

Q_C is the quantity estimated in the counterfactual scenario.

and the percentage change in a price is calculated as:

$$\%\text{Change in Price} = \frac{\Delta P}{P_B} \times 100 = \frac{P_C - P_B}{P_B} \times 100 \tag{5.2}$$

where:

P_B is the price estimated in the baseline scenario.

P_C is the price estimated in the counterfactual scenario.

Each of the percentage changes are listed for each of the time period identified by the model (i.e., 2009, quarter 1 to 2011, quarter 4).

The second component to this sheet, lists the percentage change in the welfare measures (discussed in the next section). This allows the research a conveinent way of viewing how/whether a policy has transferred/taken welfare from consumers, producers and the market. The percentage change for each of aforementioned welfare measure was calculated in an analogous way as discussed above, and therefore its discussion will be excluded here.

5.3 Welfare Measures

There are four key welfare measures used in this model to describe the welfare of consumers, producers and in total for each market representing a stage of production in the Ontario beef supply-chain. These are consumer surplus (CS), producer surplus (PS), total surplus (TS) and dead weight loss (DWL).

These are calculated for both the baseline and counterfactual simulations in each provincial market for beef in the spread sheet labelled *Welfare Calculations*.

CS is a welfare measure commonly used in economics to describe the well-being of a consumer in a market. It is calculated as the area under the demand curve and the actual amount paid for the good (the market price), up to the quantity purchased in the market. Since the model assumes linear supply and demand curves, we can obtains the CS in the market by calculating the area of a triangle:

$$CS = \frac{1}{2} \times Q_D \times (P_{intercept} - P_D) \tag{5.3}$$

It is a monetary measure of additional welfare beyond what the consumer has paid that they gain from consuming the good. In short, the larger the surplus, the better off consumers are in the market.

Since we are estimating supply and demand functions, not inverse supply and demand functions, in order to calculate CS we need to know $P_{intercept}$ – the point where the demand curve intersects the vertical axis. To calculate this point we simply took the standard equation for an inverse demand curve, with α representing $P_{intercept}$:

$$P = \alpha - \frac{\partial P}{\partial Q_D} Q_D \tag{5.4}$$

and rearrange it for the intercept term:

$$\alpha = P - \frac{\partial P}{\partial Q_D} Q_D \tag{5.5}$$

where:

$$\frac{\partial P}{\partial Q_D} = \frac{1}{\frac{Q_D}{P}} \tag{5.6}$$

$$\alpha = P - \frac{1}{\frac{Q_D}{P}} Q_D \tag{5.7}$$

which is just the inverse of the parameter on the coefficient of interest in each behavioural equation. Since we wanted to be able to preform some sensitivity analysis on the elasticity estimates, in order to obtain $P_{intercept}$ we rearranged the formula for the own-price elasticity of demand (η) to get the slope associated with a given elasticity – i.e.:

$$\eta = \frac{Q_D}{P} \times \frac{P}{Q_D} \tag{5.8}$$

$$\frac{\partial Q_D}{\partial P} = \eta \times \frac{Q_D}{P} \tag{5.9}$$

After calculating this slope coefficient ($\frac{\partial Q_D}{\partial P}$), we substitute this into equation

5.7, and simplify to get:

$$\alpha = P_D - \frac{1}{\frac{\eta Q_D}{P_D}} Q_D \tag{5.10}$$

$$= P_D - \frac{P_D}{\eta Q_D} Q_D \tag{5.11}$$

$$= P_D + \frac{P_D}{\eta} \tag{5.12}$$

$$= P_D(1 + \frac{1}{\eta}) \tag{5.13}$$

$$= P_D(\frac{\eta + 1}{\eta}) \tag{5.14}$$

Since α represents $P_{intercept}$, we can substitute equation 5.14 into equation 5.3, which gives us the formula used to calculate consumer surplus for the model.

$$CS = \frac{1}{2} \times Q_D \times (\alpha - P_D) \tag{5.15}$$

$$= \frac{1}{2} \times Q_D \times (P_D(\frac{\eta + 1}{\eta}) - P_D) \tag{5.16}$$

$$= \frac{1}{2} \times Q_D \times (\frac{P_D}{\eta}) \tag{5.17}$$

Producer surplus (PS) is analogous to CS in that it provides us a monetary measure of how well off producers are. It is the area above the supply curve, which represents the marginal cost of production, but below the price received by producers, up to the quantity supplied to the market by producers. If the supply curve is linear then we can, again, use the formula for the area of a triangle to calculate PS:

$$PS = \frac{1}{2} \times Q_S \times (P_S - P_{intercept}) \tag{5.18}$$

where $P_{intercept}$ represents the point at which the inverse supply curve intersects the vertical (price) axis. Using similar steps to how we derived the formula for CS, we were able to obtain an equation to calculate the PS:

Note that determining the PS involves the use of a piecewise function. This is because for several of the derived inverse supply functions we note that the curve intersects the vertical (price) axis below zero. Since it is not plausible that producers (of any good) would supply the market at a negative price – i.e., that they would pay some consumer to "purchase" their good – than if the intercept is below zero, than this area must be subtracted from the initial estimate of producer surplus. Thus, the inclusion of the second term, if the intercept is below zero, accounts for this implausibility.

Dead weight loss (DWL) represents the lost welfare in the market that has been introduced into the market due to any intervention. Again with linear supply and demand equations, it is easy to compute the dead weight loss as it is simply the sum of two triangles:

$$DWL = \frac{1}{2}\Delta P_C \Delta Q_D + \frac{1}{2}\Delta P_S \Delta Q_S \tag{5.19}$$

Conventionally in a market characterized by autarky DWL can be represented by a single triangle, however our model assumes that Canada is a price-taker, which implies that regardless of the amount of beef we produce we will not influence the market price, unless there is a border closure. Therefore, the quantity demanded (Q_D) by consumers does not necessarily equal the quantity supplied (Q_S) by Ontario farmers. Therefore, in order to capture the dead weight loss, the dead weight loss to consumers and producers must be computed separately and then summed.

Total surplus (TS) is simply the sum of CS and PS minus any dead weight loss – i.e.:

$$TS = CS + PS - DWL \tag{5.20}$$

TS provides an overall measure of welfare in the market.

Chapter 6

Conclusion & Limitations

This manual was intended to provide guidance to interested parties on the structure, mechanics and processes underlying the estimation of this model. While it is fully acknowledge that there may be a few restrictive assumptions made, it is felt that the only manner in which to remedy these shortcomings would be to develop a far more complex model which endogenously determines price so that the markets are forced to clear. This would increase the complexity substantially, in addition to increase the cost of developing and/or using the model as software would have to be purchased. However, the authors feel that the marginal cost of doing so would substantially exceed the marginal benefit. Thus, readers of this manuscript are advised to cautious when describing result from this model as an exact science, rather than an calibrated approximation.

As long as the underlying assumptions are valid and based on observation, rather than opportunistic selection, doing so can eliminate biased results and assist in the development of polices founded on stable economic analysis. In short, this model seeks to generate a structural representation of how the beef sector operates, and use basic economics to generate estimates of the changes in prices, quantities and welfare arising from plausible alternative realities.

It is important to note that this model has a predictive element to it, in the sense that it 'predicts' what would occur if alternative circumstances were to arise. Completing this counterfactual exercise and then comparing it to what actually occurred (or to be more specific a calibrate representation of what occurred) is beneficial as it offers a reliable venue through which approximate changes in magnitudes of variables of interest can be compared. It, however, is not a predictive tool in the sense that it can forecast what the outcome will be in following years. Forecasting requires strong assumptions, and forecast estimates remain susceptible to any unforeseen shocks or structural changes which would render the output as irrelevant. Taking the approach of estimating the what occurred (the baseline scenario) and contrasting it with what would have occurred (the counterfactual scenerio), allows us to ignore the potential of structural changes or random shocks beyond what we intentionally imposed on the model. Thus, it should be kept in mind that this model is designed to answer "what if?" questions which could arise in the policy arena.

This model is what economists refer to as a partial equilibrium analysis, which means that it only focuses on what happens to the Ontario beef sector and view all other shocks or changes to the economy as exogenous (external). While this immensely simplifies the analysis with minimal loss to the explanatory power of the model, it does require that any change/shock to a variable which is not endogenized by the model be estimated or assumed. For example, if we were to assess the effect of an increase in the ethanol subsidy, then it would require taking one of two approaches. [1] A literature review could be used to obtain reasonable estimates of how much the corn price would increase, and these price estimates could be included in the model, providing an estimate of by how much the quantity demanded and/or supplied changes as various levels of the supply chain. Conversely, another alternative is to create an appendage to the model. In its current state, the SSM act as a nucleus. It does not have the capacity to answer all questions that could possibly arise in a policy setting. It is likely that an extension of the model will have to be created in order to estimate the impact of a proposed policy or potential shock. In some circumstance, or rather for some questions, this is the only choice. The reason being is that often pertinent policy driven issues, which the model is designed to inform, will be contemporary in nature, and literature on the topic may not be readily available yet. Therefore, the only solution will be estimate the size of the shock so that it can be imposed on the model.

Regardless of potential shortcomings, this model is intended to be a tool to assist policymakers in their analysis and/or inform them of the consequences of certain realizations.

[1] An increase in corn prices would increase the feed costs for the finishing sector in Ontario and therefore put downward pressure on the price of feeder cattle, as they are complementary inputs for feedlots. In the long-run, if the ethanol policy was not temporary would likely result in a reduction of the feedlot size because of increased costs associated with feeding the animals **?**.

Appendix A

Dependent Variables

The list below describes the origin/sources of the variables used to estimate the equations outlined in chapter 4 (Structural Equations).

BCW_t Annual average bull warm carcass weight (in lbs.). **Source: AAFC, Red Meat Division.**

CCW_t Annual average cow warm carcass weight (in lbs.). **Source: AAFC, Red Meat Division.**

DBC_t Quarterly demand for backgrounded/feeder cattle. Calculated as the sum of the provincial supply of stockers, interprovincial imports of stockers, and stockers from dairy operations less the live export of feeder animals to the U.S.. **Source: Authour's Calculation.**

DCB_t Quarterly provincial demand for slaughter (culled) bulls (number of head). Aggregated from monthly slaughter counts from both federally and provincially inspected plants in Ontario. **Source: Canfax Cattle Services.**

DCC_t Quarterly provincial demand for slaughter (culled) cows (number of head). Aggregated from monthly slaughter counts from both federally and provincially inspected plants in Ontario. **Source: Canfax Cattle Services.**

DFC_t Quarterly provincial demand for calves. It is calculated as the sum of the number of calves produced by the Ontario cow-calf sector and the interprovincial imports of feeder calves at time t (see table 2.3). **Source: Authour's Calculation.**

DFH_t Quarterly provincial demand for fed heifers. Aggregated from monthly slaughter counts from both federally and provincially inspected plants in Ontario. **Source: Canfax Cattle Services.**

DFS_t Quarterly provincial demand for fed steers. Aggregated from monthly slaughter counts from both federally and provincially inspected plants in Ontario. **Source: Canfax Cattle Services.**

EBU_t Quarterly exports of beef to the United States (in lbs.). Quarterly amount of beef exported to the U.S. was originally reported in kilograms, thus it was multiplied by 2.2 in order to get the equivalent measurement in pounds. **Source: Statistics Canada – prepared by AAFC, Red Meat Division**

EBW_t Quarterly exports of beef to the world, excluding the United States (in lbs.). Calculated as the sum of all beef exports minus those destine for the U.S.. It was originally reported in kilograms, thus it was multiplied by 2.2 in order to get the equivalent measurement in pounds. **Source: Statistics Canada – prepared by AAFC, Red Meat Division**

ECB_t Quarterly provincial exports of slaughter (culled) bulls to the U.S. (number of head). **Source: Canfax Cattle Services.**

ECC_t Quarterly provincial exports of slaughter (culled) cows to the U.S. (number of head). **Source: Canfax Cattle Services.**

EFC_t Quarterly provincial exports of feeder cattle (stockers) to the U.S.. **Source: Canfax Cattle Services.**

EFH_t Quarterly live exports of fed heifers to the U.S.. **Source: Canfax Cattle Services.**

EFS_t Quarterly live exports of fed steers to the U.S.. **Source: Canfax Cattle Services.**

HCW_t Annual average heifer warm carcass weight (in lbs.). **Source: AAFC, Red Meat Division.**

IBU_t Quarterly imports of beef from the United States (in lbs.). Beef imported from the United States was originally reported in kilograms, thus it was multiplied by 2.2 in order to get the equivalent measurement in pounds. **Source: Statistics Canada – prepared by AAFC, Red Meat Division**

IBW_t Quarterly imports of beef from the world, excluding the United States (in lbs.). Calculated as the sum of all beef imports minus those originating from the United States. It was originally reported in kilograms, thus it was multiplied by 2.2 in order to get the equivalent measurement in pounds. **Source: Statistics Canada – prepared by AAFC, Red Meat Division**

$INVB_t$ The biannual inventory of bulls in Ontario (Jan. 1 and Jul.1). **Source: CANSIM, Table 003-0032.**

$INVC_t$ The biannual inventory of beef cows in Ontario (Jan. 1 and Jul.1). **Source: CANSIM, Table 003-0032.**

ODB_t Ontario per capita demand for beef (in lbs.). It is reported as the annual national amount of beef (in terms of carcass weight) available per person (in kgs.). A quarterly estimate is obtained by dividing the annual number by 4, and multiplying it by 2.2 in get a measure in pounds (lbs.). **Source: CANSIM, Table 002-0011**

SBC_t Quarterly supply of backgrounded/feeder cattle (head per quarter). It is calculated as the number of provincial feeder calves demanded advanced 6 months to account for the 24 to 28 weeks to takes for a cattle to gain the necessary weight. An assumed mortality rate of 2% is then deducted from the count to account for death loss at the backgrounding stage. **Source: Authour's Calculation.**

SFC_t The quarterly number of feeder calves produced by provincial cow-calf producers. The number of calves born each month was inferred using the Canadian Cattle Identification Agency's (CCIA) calving survey, which cites the months when farms in each province typically calf. CANSIM reports the biannual number calves born each period (table 003-0083) which was then multiplied by the proportion of beef cows in the province calving in that biannual period to get the number of beef calves born in the biannual period. This was then multiplied by the proportion of calves born in each month (CCIA survey), and an assumed mortality rate of 2% deducted, to provide us with the monthly number of calves born each year. The number of calves was then advanced 7 months to account for the approximated time required to animal to achieve the weight. This was then aggregated to quarterly data. **Source: Authour's Calculation.**

SFH_t The quarterly provincial supply of fed heifers. The quarterly supply of fed heifers is calculated as the sum of the demand for fed heifers (Canfax Cattle Services) and the export of fed heifers to the U.S. (Canfax Cattle Services) minus the interprovincial imports of fed heifers (Source: Authour's calculation). **Source: Authour's calculation.**

SFS_t The quarterly provincial supply of fed steers. The quarterly supply of fed steers is calculated as the sum of the demand for fed steers (Canfax Cattle Services) and the export of fed steers to the U.S. (Canfax Cattle Services) minus the interprovincial imports of fed heifers (Source: Authour's calculation). **Source: Authour's calculation.**

SCW_t Annual average steer warm carcass weight (in lbs.). **Source: AAFC, Red Meat Division.**

Appendix B

Price Variables

$BCPR_t$ The Ontario bull-calf price ratio. It is calculated as the ratio of the provincial bull price (Source: Canfax Cattle Services) divided by the average provincial calf price (Source: Canfax Cattle Services) in period t. **Source: Authour's calculation.**

$CCPR_t$ The Ontario cow-calf price ratio. It is calculated as the ratio of the provincial cow price (Source: Canfax Cattle Services) divided by the average provincial calf price (Source: Canfax Cattle Services) in period t. **Source: Authour's Calculation.**

CBR_t The Ontario corn-Alberta barley price ratio. The ratio of the Ontario corn price (dollars per bushel) (Source: Daily Commodity Reports, University of Guelph, Ridgetown Campus) and the Alberta barley price (dollars per bushel) (Source: Alberta Grain Commission). **Source: Authour's Calculation**

$CornP_t$ Ontario's real quarterly average corn price (per bushel). It is calculated as the quarterly average corn price deflated by the provincial farm product price index for grains (FPPI - grains) obtained from CANSIM, table 002-0021 (base year = 2005, quarter 3). **Source: Daily Commodity Reports (University of Guelph, Ridgetown Campus) with permission from John Jordon.**

CUX_t The quarterly average U.S.-Canada exchange rate. **Source: CANSIM, table 176-0064**

$HCPR_t$ The heifer-corn price ratio. It is the deflated Ontario price for fed heifers (Source: Canfax Cattle Services) divided by the real provincial average corn price (Source: Daily Commodity Reports (University of Guelph, Ridgetown Campus)). **Source: Authour's calculation.**

ODI_t Ontario quarterly per capita disposable income. The annual measure of total provincial personal disposable income (Source: CANSIM, Table .) was deflated using a Canadian GDP implicit price deflator (base year = 2005) (Source: Organization for Economic Co-operation and Development) and then divided by quarterly provincial population estimates (Source: CANSIM, Table 051-005.). **Source: Authour's Calculation**

ODP_t Ontario diesel price ($/litre). The provincial average diesel price deflated using the Canadian implicit price deflator (Source: Organisation for Economic Co-operation and Development). **Source: Ontario Ministry of Energy and Infrastructure (Statistics Canada).**

$ORBP_t$ The average provincial retail beef price ($/lbs.). It is calculated as the price of beef as calculated in **?** in the third quarter of 2005 times the consumer price index for beef (Source: CANSIM, Table 326-0020). Prices were obtained with permission from the author. **Source: ?**

$ORCP_t$ The average provincial retail chicken price ($/lbs.). It is calculated as the price of chicken as calculated in **?** in the third quarter of 2005 times the consumer price index for beef (Source: CANSIM, Table 326-0020). Prices were obtained with permission from the author. **Source: ?**

$ORPP_t$ The average provincial retail pork price ($/lbs.). It is calculated as the price of pork as calculated in **?** in the third quarter of 2005 times the consumer price index for beef (Source: CANSIM, Table 326-0020). Prices were obtained with permission from the author. **Source: ?**

$OURBPS_t$ Ontario-U.S. retail beef price spread ($/lbs.). Calculated as the difference between the Canadian retail beef price (Source: **?**)and the deflated quarterly average U.S. retail beef price (Source: United States Department of Agriculture – Economic Research Service.) multiplied by the Canada-U.S. exchange rate. **Source: Authour's calculation.**

$PBBeef_t$ Quarterly Canadian AA boxed beef prices ($100/lbs.). The AA boxed beef price (Source: Canfax Cattle Services.) was deflated using obtained provincial beef price index from Cansim, table 326-0020 (base period=2003, Q3). **Source: Canfax Cattle Services.**

$PCalf_t$ The average price of Ontario feeder calves ($/100 lbs.). It was assumed that at the end of this stage that heifer and bull calves fall within the weight range of 500-600 lbs.. The price was deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

PCB_t The quarterly price of slaughter bulls ($/100 lbs.). It is aggregated from weekly provincial average slaughter bull prices and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

PCC_t The quarterly price of slaughter cows ($/100 lbs.). It is aggregated from weekly provincial average slaughter cow prices and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

$PFed_t$ The quarterly average price of fed heifers and steers ($/100 lbs.). Calculated as the arthimetic (simple) average of the provincial fed heifer and fed steer price deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

$PFeeder_t$ The quarterly average provincial feeder (stocker) cattle price ($/100 lbs.). It is the simple (arithmetic) average of 800+ lbs. backgrounded heifers and 900+ lbs.[1] backgrounded steers in Ontario at time t deflated using Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

PFH_t The quarterly price of fed heifers ($/100 lbs.). It is aggregated from weekly provincial average fed heifer prices and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

PFS_t The quarterly price of fed steers ($/100 lbs.). It is aggregated from weekly provincial average fed steer prices and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

PHC_t Quarterly average heifer calf price ($/100 lbs.). It is aggregated from weekly provincial average price for heifer calves between 500-600 lbs. and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

PSC_t Quarterly average steer calf price ($/100 lbs.). It is aggregated from weekly provincial average price for steer calves between 500-600 lbs. and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

[1] Here the weight ranges for backgrounded heifers and steers are reported as 800+ and 900+ lbs.

PSH_t Quarterly average feeder (stocker) heifer price ($/100 lbs.). It is aggregated from weekly provincial average price for 850 lbs. heifers (Canfax defines the weight range for heifers as "800+") and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

PSS_t Quarterly average feeder (stocker) steer price ($/100 lbs.). It is aggregated from weekly provincial average price for 950 lbs. steers (Canfax defines the weight range for steers as "900+") and deflated using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) obtained from CANSIM, Table 002-0021. **Source: Canfax Cattle Services.**

$SBCPR_t$ The quarterly slaughter bull-corn price ratio. It is the deflated Ontario price for slaughter bulls (Source: Canfax Cattle Services) divided by the real provincial average corn price (Source: Daily Commodity Reports (University of Guelph, Ridgetown Campus)). **Source: Authour's calculation.**

$SCCPR_t$ The quarterly slaughter cow-corn price ratio. It is the deflated Ontario price for slaughter cows (Source: Canfax Cattle Services) divided by the real provincial average corn price (Source: Daily Commodity Reports (University of Guelph, Ridgetown Campus)). **Source: Authour's calculation.**

$SCPR_t$ The steer-corn price ratio. It is the deflated Ontario price for fed steers (Source: Canfax Cattle Services) divided by the real provincial average corn price (Source: Daily Commodity Reports (University of Guelph, Ridgetown Campus)). **Source: Authour's calculation.**

$UCBPS_t$ U.S.-Canada quarterly average slaughter (culled) bull price spread ($USD/100 lbs.). Calculated as the difference between the deflated Lancaster, PA regional average bull price aggregated from monthly sales data (Source: United States Department of Agriculture – Agricultural Marketing Service) and the deflated Ontario slaughter bull market price (Source: Canfax Cattle Services) multiplied by the U.S.-Canada exchange rate (Source: CANSIM, table 176-0064). **Source: Authour's Calculation**

$UCCPS_t$ U.S.-Canada quarterly average slaughter (culled) cow price spread ($USD/100 lbs.). It is calculated as the difference between the deflated Oklahoma National Stockyards price for slaughter cows (Source: Livestock Marketing Information Center (LMIC)) and the deflated Ontario slaughter cow market price (Source: Canfax Cattle Services) multiplied by the U.S.-Canada exchange rate (Source: CANSIM, table 176-0064). **Source: Authour's Calculation.**

$UCFPS_t$ U.S. - Canada quarterly average feeder price spread ($USD/100 lbs.). Calculated as the difference between the deflated Oklahoma National

Stockyards price for feeder animals (Source: Livestock Marketing Information Center (LMIC)) and the deflated provincial average feeder price (Source: Canfax Cattle services) multiplied by the U.S.-Canada exchange rate (CANSIM, table 176-0064). All U.S. prices were deflated using the U.S. livestock index (Source: United States Bureau of Labour Statisics), while Canadian data was deflated using using the Farm Product Price Index for total livestock and animal products (base period=2005, quarter 3) (Source: CANSIM, Table 002-0021) **Source: Authour's Calculation**

$UCHPS_t$ U.S.-Canada quarterly average fed heifer price spread ($USD/100 lbs.). It is calculated as the difference between the deflated U.S. Fed Cattle five market average price for fed heifers (Livestock Marketing Information Center (LMIC)) and the deflated Ontario fed heifer market price (Canfax Cattle Services) multiplied by the U.S.-Canada exchange rate (CANSIM, table 176-0064). **Source: Authour's Calculation.**

$UCSPS_t$ U.S.-Canada quarterly average fed steer price spread ($USD/100 lbs.). It is calculated as the difference between the deflated U.S. Fed Cattle five market average price for fed steers (Livestock Marketing Information Center (LMIC)) and the deflated Ontario fed steer market price (Canfax Cattle Services) multiplied by the U.S.-Canada exchange rate (CANSIM, table 176-0064). **Source: Authour's Calculation.**

$UORBPS_t$ U.S.-Ontario retail beef price spread ($USD/lbs.). Calculated as the difference between the deflated quarterly average U.S. retail beef price (Source: United States Department of Agriculture – Economic Research Service.) and the Canadian retail beef price (Source: **?**) multiplied by the U.S. Canada exchange rate. **Source: Authour's calculation.**

$USDP_t$ Quarterly average U.S. diesel price ($USD/gallons). It is the quarterly U.S. No.2 diesel retail price ($/ gallon) deflated using the U.S. city average diesel price index (base year=2005, quarter 3) (Source: Bureau of Labour Statistic, Series ID: APU000074717). **Source: U.S. Energy Information Administration (www.eia.gov).**

$USBP_t$ U.S. quarterly average bull price ($USD/100 lbs.). The Lancaster, PA regional average bull price aggregated from monthly sales data and deflated using the U.S. livestock slaughter index (base year= 2005) (Source: U.S. Bureau of Labour Statistics, series id: WPU013). **Source: United States Department of Agriculture – Agricultural Marketing Service**

$USCP_t$ U.S. quarterly average cow price ($USD/100 lbs.). The Oklahoma National Stockyards price for slaughter cows deflated using the U.S. livestock slaughter index (base year= 2005) (Source: U.S. Bureau of Labour Statistics, series id: WPU013). **Source: Livestock Marketing Information Center (LMIC)**

$USFHP_t$ U.S. quarterly average price of fed heifers ($USD/100 lbs.). It is U.S. Fed Cattle five market average price for fed heifers deflated using the U.S. livestock slaughter index (base year= 2005) (Source: U.S. Bureau of Labour Statistics, series id: WPU013). **Source: Livestock Marketing Information Center (LMIC)**

$USFSP_t$ U.S. quarterly average price of fed steers ($USD/100 lbs.). It is U.S. Fed Cattle five market average price for fed steers deflated using the U.S. livestock slaughter index (base year= 2005) (Source: U.S. Bureau of Labour Statistics, series id: WPU013). **Source: Livestock Marketing Information Center (LMIC)**

$USRBP_t$ Quarterly average U.S. retail beef price ($USD/lbs.). The quarterly average retail value of beef ($USD/lbs.) deflated using the U.S. implicit price deflator (Source: United States Bureau of Labour Statisics). **Source: United States Department of Agriculture – Economic Research Service.**

$WBEP_t$ Quarterly average world beef export price ($/lbs.). Calculated as the ratio of the value of Canadian exports to the world, excluding the United States, deflated using a Canadian implicit GDP deflator (base year = 2005) (Source: Organization for Economic Co-operation and Development) and the quantity of beef exports to the world, excluding the United States. **Source: Statistics Canada – prepared by AAFC, Red Meat Division**

$WBIP_t$ Quarterly average world beef import price ($/lbs.). Calculated as the ratio of the value of Canadian imports from the world, excluding the United States, deflated using a Canadian implicit GDP deflator (base year = 2005) (Source: Organization for Economic Co-operation and Development) and the quantity of beef imports from the world, excluding the United States. **Source: Statistics Canada – prepared by AAFC, Red Meat Division**

Table B.1: Summary Statistics – Prices

Variable	Unit	Mean	Standard Deviation	Observations
$BCPR_t$		0.527	0.16	68
$CCPR_t$		0.458	0.114	64
$CornP_t$	\$/bushel	3.11	0.324	82
CUX_t	\$CDN/\$USD	1.246	0.208	48
$HCPR_t$		27.653	3.794	47
ODI_t	\$	25218.28	1067.289	48
ODP_t	\$/litre	1.187	0.196	88
$ORBP_t$	\$/lbs.	4.32	0.8	88
$ORCP_t$	\$/lbs.	2.18	0.42	88
$ORPP_t$	\$/lbs.	3.60	0.26	88
$OURBPS_t$	\$/lbs.	-0.200	1.127	48
$PBBeef_t$	\$100/lbs.	167.30	27.11	52
$PCalf_t$	\$/100 lbs.	111.26	17.244	68
PCB_t	\$/100 lbs.	59.40	19.357	68
PCC_t	\$/100 lbs.	55.61	14.47	64
$PFed_t$	\$/100 lbs.	93.54	9.46	88
$PFeeder_t$	\$/100 lbs.	96.57	11.34	64
PFH_t	\$/100 lbs.	93.64	11.798	64
PFS_t	\$/100 lbs.	99.50	10.972	64
PHC_t	\$/100 lbs.	105.41	17.138	68
PSC_t	\$/100 lbs.	119.72	16.645	92
PSH_t	\$/100 lbs.	92.54	9.48	88
PSS_t	\$/100 lbs.	94.53	9.46	88
$SBCPR_t$		16.87	6.292	47
$SCCPR_t$		14.72	4.399	47
$SCPR_t$		28.174	3.839	47
$UCBPS_t$	\$USD/100 lbs.	14.107	16.458	48
$UCCPS_t$	\$USD/100 lbs.	10.987	11.93	48
$UCFPS_t$	\$USD/100 lbs.	16.998	11.575	55
$UCHPS_t$	\$USD/100 lbs.	14.414	10.110	55
$UCSPS_t$	\$USD/100 lbs.	12.962	10.158	55
$UORBPS_t$	\$USD/lbs.	0.025	0.907	47
$USDP_t$	\$USD/gallons	2.308	0.716	48
$USBP_t$	\$USD/100 lbs.	58.96	4.895	48
$USCP_t$	\$USD/100 lbs.	49.653	4.100	80
$USFHP_t$	\$USD/100 lbs.	84.409	4.722	88
$USFSP_t$	\$USD/100 lbs.	84.615	3.924	88
$USRBP_t$	\$USD/lbs.	3.907	0.248	48
$WBEP_t$	\$/lbs.	1.653	0.452	50
$WBIP_t$	\$/lbs.	1.695	0.567	50

All prices are quoted in Canadian dollars unless otherwise stated.