Assessment of the economic viability of grass-fed beef production in the Northeastern U.S.

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Abstract The grass-fed beef segment of the beef industry has garnered increased interest among consumers and farmers in recent years. Given the availability of high-quality forage, pastureland and markets in New York and New England (NYNE), expansion of beef production in the region may contribute to a gradual shift toward grass-based finishing systems in the region. However, biological potential does not necessarily equal economic opportunity. The ability of this market to grow depends on the sector's capacity to lower the production costs and the willingness of consumers to pay premiums high enough to absorb the costs associated with the particular production program. This study aims at assessing the economic viability of grass-fed beef production in NYNE. We calculate the grass-fed beef costs that account for all phases through the grass-fed supply chain. Our findings suggest grass-fed beef can compete with conventional grain-fed beef in the region if the grass-fed beef operations can achieve economies of scale.

Keywords food production, agricultural commodities, food prices, food policy

Introduction

Grass-fed beef [1] in the U.S. has attracted the attention of more cattle producers and food companies (Cheung and McMahon 2017; Gillespie et al. 2016). Consumer interest in grass-fed beef because they believe it is healthier, has better taste and flavor, and is beneficial to environmental protection and climate change mitigation (Mccluskey et al., 2005). Corresponding to the growing preference, there is growing interest in producing more beef from cattle raised in exclusively pasture-based systems, rather than grain-finishing feedlot systems in the U.S. (Hayek and Garrett, 2018; van Vliet, Provenza and Kronberg 2021). Given the availability of high-quality forage, pastureland and markets in New York and New England (NYNE hereafter), expansion of beef production in the

[1] Grass-fed beef refers to beef from cattle whose lifetime diet consists of only grass and other forage, except for milk consumed prior to weaning; no grains are fed. Various terms are used to describe this type of beef, each with subtle differences (e.g., grass-fed, pasture-fed, forage-fed, grass-finished, and forage-finished). We use the term grass-fed beef throughout this paper.

region may contribute to a gradual shift toward grass-based finishing systems in the region. However, the economic viability of the grass-fed beef production expansion has far gone unanswered. The higher production cost as compared with conventional beef and the large price premium that grass-fed beef commands over conventional beef, may make grass-fed beef unaffordable for many consumers. To address this gap and offer pertinent information, we build an aspirational model to identify and quantify the economic inputs and outputs of a representative grass-fed beef cattle expansion scenario in NYNE and access the economic viability of such an expansion.

As recent survey data from the USDA/NRCS (2018) shows, only 43% of the land in pasture cover in the Northeast is actually grazed. This is well below most other regions of the U.S. In addition to having unused agricultural land, yield gaps for forage crops and grazing are large compared to the yield gaps observed for principal grain crops. In contrast, forages are about half of their economic yields (Thorn, Baker and Peter, 2020). Given this circumstance, a niche appears to exist for forage-based, ruminant production systems in the Northeast U.S. Given the inherent biological capacity of the region's natural resource base, we develop one possible scenario for expanding production without expanding regional agricultural land or displacing existing agricultural industries. The design of the beef cattle expansion scenario accounted for the forage needs of existing livestock production and the expansion of sectors related to the grass-finishing, namely, cow-calf operations and hay production. The scenarios assume that expansion of forage demand, to feed grass-finished cattle, catalyzes further increases in forage productivity (yield gap) and expansion of agricultural activity onto unused pasture land. For ease of interpretation, the expansion scenario is based on a historical benchmark, the number of beef calves produced in the Northeastern U.S. in 2017. The scenario assumes the region produces three times the number of calves currently available in the region for grass-finished meat. Calves for the grass-finished system come from existing cow-calf operations and from new cow-calf operations in a 1:2 ratio. The scenario represents 339,750 grass-fed beef cattle pasture-raised across 127 counties in NYNE in addition to existing beef cattle grown in the region.

The expansion scenario focuses on what is possible, not necessarily on what is economically viable. Biological potential does not necessarily equal economic opportunity. Expansion of the Northeast beef sector will continue to depend on the willingness of consumers to pay premiums high enough to absorb the current higher production and supply chain costs. Consequently, the ability of this market to grow depends on the sector's capacity to lower the production costs to broaden its consumer base and generate more consumer demand. Beef production growth in the region is undesirable if the prices of final beef products are higher than consumers' willingness to pay. To assess the economic viability of grass-fed beef production in NYNE, a life-cycle cost analysis of grass-fed beef finishing operations is necessary. The costs should account for all phases through the grass-finished beef supply chain, including phases of cow-calf, stocker, slaughter, processing, to retail marketing.

It remains an empirical question whether expanded beef in NYNE is a cost-competitive with meat brought in from elsewhere. Based on the above evaluations, we will assess whether grass-fed beef in NYNE can be produced at a lower cost, as this could be the key to allowing U.S. producers to compete with domestic conventional beef, grass-fed beef in other regions and grass-fed imports. Domestic conventional feedlots with efficient supply chains produce grain-fed beef at low cost. Grass-fed operations have costs of production that are substantially higher than those of conventional feedlots. Northeast grass-fed beef also faces competition from grass-fed beef in other regions with favorable production conditions. Considering consumer strong preference for local grass-fed beef, we should account for the high price premium for local beef paid by consumers in the Northeastern U.S. when conducting cost comparison and the economic viability analysis.

This study offers a comprehensive evaluation of the economic viability of grass-fed beef production in NYNE under the given production expansion scenario. Our results provide pertinent information on whether it is economically viable to expand the grass-fed beef production in the NYNE region. The findings of this study are useful in the context of developing a grass-fed beef production program in the Northeastern U.S. Such information is currently lacking and is useful to help inform decisions of various stakeholders interested in grass-fed beef production in the region.

2. Data

To develop the viability analysis, we first estimate the potential for expanding production without expanding regional agricultural land or displacing existing agricultural industries. Given the availability of pasture land and productivity, 127 counties in NYNE can expand grass-fed cattle production up to 337,950 head. Expanded beef cattle and existing cattle both use currently existing slaughter and processing capacity in the NYNE region. When investigating the production cost in the expansion scenario, we combine the existing beef cattle production in the year 2012 with the potential production under the expansion scenario. USDA/NASS reports county-level annual production statistics for beef cattle remained in local feedlots and slaughtered and processed locally in NYNE (Table 11 Cattle and Calves-Inventory and sales-Cattle on Feed Sold, USDA/NASS, 2012)[2]. In the seven states, such data is not reported for a subset of the counties for anonymity reasons. In these cases, we use the average production for those counties with data suppression. However, estimated production only accounts for a small proportion of annual domestic production (5 percent) so the estimation error from our imputation procedure should have limited influence on the model solution. Table 1 shows the cattle production we consider when examining the grass-fed beef production cost under the scenario.

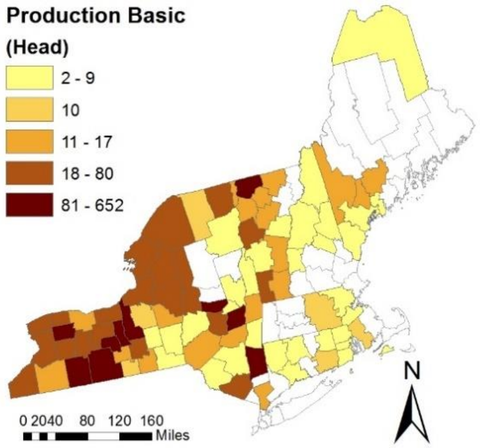
Table 1. Cattle Production in the Scenario (Unit: Head)

Program	Cattle (head)
Grass-finished expanded	339,750
Existing (2012)	40,633
Grass-finished[a]	2,844
Grain-finished	37,889
Total	380,383

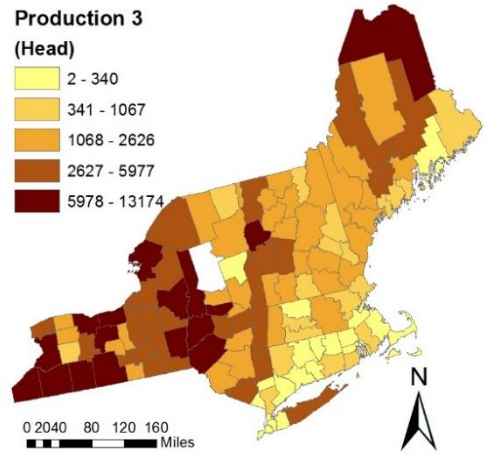
[a] The literature suggests that grass-fed cattle make up 7% of the beef cattle in 2012 in NYNE (Dillon, Rotz and Karsten, 2020; Bussard, 2016).

Figure 1 shows the distribution of beef cattle production, including both grain-fed in the year 2012 (basic production, Fig.1 (a)) and grass-finished beef cattle in the expansion scenario based on which we conduct the viability analysis (Fig.1 (b)).

[2] The NYNE contains over one and half million head of cattle (60% beef cattle, 40% dairy cattle) (USDA-NASS, 2012). The majority of beef cattle is sold across state lines beyond NYNE before feedlot operation because it is more costly to fatten cattle in feedlots in NYNE. Almost all dairy cattle in NYNE are mostly shipped to large scale plants in Pennsylvania (e.g., Cargill, JBS and Nicolas Meat Packing) for slaughter and processing.



(a). Basic production (year 2012)



(b). Expanded production scenario

Figure 1. Distribution of annual beef cattle production across counties

The annual production data are disaggregated into monthly data. To date, there were no publicly available estimates of monthly distributions of the grass-finished beef cattle population. The monthly distributions were estimated using slaughter statistics for all cattle from USDA/NASS (2013) (Fig. 2). Such an estimation of monthly distributions is consistent with the result of a survey conducted by Lozier, Rayburn and Shaw (2005). The survey indicates that the grass-finished beef producers slaughter in all twelve months of a year, with peaks in October and November, and lowest frequencies in February, March, and April.

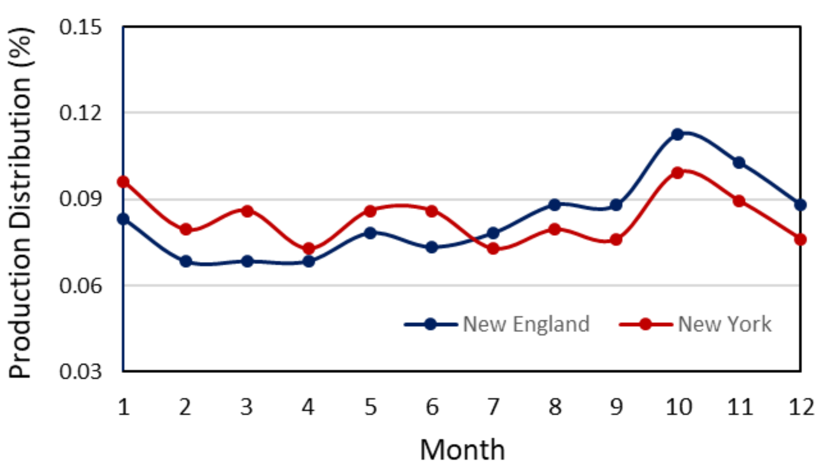


Figure 2. Monthly cattle production distribution in NYNE

This study assumes regionally produced beef just meets the demand of the niche consumer market for local beef in each county and the volume of grass-finished or grain-finished beef shipped to each county for consumption is proportional to the population of the county based on 2012 U.S. Census Bureau data (U.S. Census Bureau, 2013).

To examine existing slaughter and processing infrastructure, capacity and operating costs in the region, we conducted a survey via questionnaires and interviews during 2018 and 2019 of all NYNE's USDA inspected red meat packing plants (Waro et al., 2019). The survey includes questions on maximum the number of animals a plant can slaughter and process per day, the fee for slaughter and processing services, the costs for expanding plant capacity, the longest and average distance a farmer travels to a plant, and the appropriate maximum distance for a farmer to bring livestock to slaughter.

Data were collected assuming single-species days. That is, survey respondents were asked to quantify the volume of cattle that can be slaughtered or processed if plant capacity is used to exclusively harvest and process cattle. To account for the fact that multiple species may be harvested across months and occupy slaughter and processing capacity, we exclude the slaughter and processing capacity for other species from the capacity for beef cattle. For doing this, we convert each livestock into a single unit called "cattle equivalent". The average ratio of capacity for cattle to the capacity for each other type of livestock for each plant was calculated to estimate equivalence. As estimated by Lewis and Peters (2012), a factor of 3.77 and 5.22 hogs per head of cattle is used when covering slaughter and processing capacity from number of hogs to number of cattle while a factor of 4.18 and 5.17 lambs per head of cattle is used when converting slaughter and processing capacity from the number of lambs to the number of cattle. The number of hogs and lambs slaughtered and processed in 2012 (USDA/NASS, 2013) were then converted to cattle equivalents to approximate the capacity used by slaughtering and processing hogs and lambs. The capacity that can be utilized for cattle slaughter or processing is the left capacity after excluding the capacity for hog and lamb slaughter or processing.

Monthly capacity is based on the daily kill and processing capacity from the survey mentioned above and an institutional constraint factor of 0.9. The institutional constraint was used to adjust monthly capacity due to daily procurement and scheduling problems (Wulff et al., 1990). A slaughter or a processor does not have the alternative (option) to inventory a supply of raw material to maintain a constant product process. Table 1 shows a summary of slaughter and processing capacity (monthly average), slaughter cost and processing cost of 56 surveyed plants.

Table 1. Survey Data Summary: Slaughter and Processing Capacity and Cost

	slaughter	processing
No. of plants	62	62
Capacity mean (heads/month)	374	115
maximum	1187	743
minimum	48	11
median	238	80
Std. Dev.	290	136
Handling cost mean ($/head)	75	468
maximum	130	705
minimum	30	198
median	75	423
Std. Dev.	20	310

Source: Survey conducted in 2018 and 2019.

A plant slaughters cattle and processes the resultant carcasses, given slaughter and processing capacity constraints. We use the term "slaughter" and "processing" to include all the steps involved in turning a live animal into a carcass or meat for sale. A typical slaughter operation includes such activities as stunning, skinning, eviscerating, and cleaning the animal to a carcass and cutting carcass into halves or quarters. The carcass accounts for about 62 percent of the weight of the grain-finished live animal (Goodsell and Stanton, 2011). The ratio is 55 percent for grass-finished cattle (Cheung and McMahon 2017). Processing operations focus on such activities as cutting half/quarter carcasses to sub-primal cuts; cutting sub-primal cuts into fixed-weight steaks, roasts, and other boneless and trimmed retail cuts; and packaging as desired by buyers and customers. In this study, value-added processing such as grinding, casing, smoking, cooking, drying, and otherwise transforming meat and trimmings from the cutting step into sausage, ham, bacon, jerky, and other products are not included in processing procedures in the focal plants. The processed meat products account for 72 percent of the weight of the carcass for grain-finished cattle and 70 percent for grass-finished cattle (Cheung and McMahon 2017; Goodsell and Stanton, 2011).

Meat food products must be shipped in an enclosed vehicle, such as refrigerated truck, in such a manner to assure delivery and wholesomeness of those products while maintaining product safety. The average refrigerated truck transportation cost statistics is reported by USDA's Agricultural Marketing Service (2019). When transporting animals, larger farms with larger shipping volumes can increase the capacity utilization of trucks. We charge each truck on a specific route equally, based on a cost of $4/loaded mile for a truck carrying up to 40 cattle, whether it is full or (nearly) empty.

To mirror the realistic beef cattle operation situation, we limit the average and maximum transportation distance for an animal's journey to a plant. Our survey suggests that the shipping distance that farmers deem appropriate is 1.5-2 drive hours, i.e. 67.5 miles if a normal truck speed of 45 miles per hour is used[3]. Our model defines 80 miles as the constraint of average transportation (assembly) distance between production locations and plant locations. The survey also suggests that farmers' maximum shipping distance is 5 drive hours. Accordingly, we define 225 miles as the maximum transportation (assembly) distance in the model.

The travel distance between farms and slaughter plants, between slaughter plants to processing plants, and between processing plants to consumers is identified using ArcGIS Online Network Analysis Services (2020 ArcGIS Online release). Normally, transporting animals or animal products uses trailers or trucks. We calculate the distance between origins and destinations through applying the truck routing algorithm in ArcGIS Online.

We have assumed that the land used to raise cattle is leased in our model. With given land in cropland pasture or permanent pasture and yield of hay crops, and hay requirements for grass-finished cattle, the land required to feed per cattle can be calculated. The production cost per cattle within the farm gate is positively related to this required acre of land. The pasture lease rates by county are from USDA/NASS Quick Stats (2022). With respect to cattle production costs, we collected data on the economics of beef finishing from a range of sources. In the U.S. beef industry,

[3] This represents the truck speed we used in our survey when investigating the animal shipping distance.

the most commonly used production systems are cow-calf, backgrounding, and finishing operations. Cattle ready for harvest from different production locations are consolidated at plants, slaughtered and processed there, and then distributed to consumers in different demand regions. To facilitate cost evaluation, we break down the costs by 1) cow-calf production cost; 2) operational costs; 3) overhead costs; 4) slaughter and processing costs; and 5) transportation costs. Operational costs include feed pasture costs and other operational costs. Feed/pasture costs include fertilizer and herbicide, hay and non-grain supplements for grass-fed operations and cost of grain-based rations for the feedlot model. This item also includes minerals, machinery and other feed-related costs. Other operational costs include health and veterinary, hired labor, marketing, checkoff, transportation and death loss. Overhead costs consist of items such as land lease rates, management (or owner's labor in some cases), maintenance (irrigation, machinery and fencing), utilities, fuel, property taxes and accounting costs. We focus on current operations so do not include the upfront capital expenditure associated with purchasing facilities or building initial infrastructure.

The model assumes the purchase of a feeder animal weighing 750-800 pounds at the start of the finishing phase. We use default purchase cost values from the literature, $1,088/grass-fed cattle and $1,084/grain-fed cattle (Cheung and McMahon, 2017).[4]

Plentiful evidence shows that the facilities have cost functions with economies of scale (Camargo, Miranda and Luna 2009; Dupont 2008; Ge et al. 2019). The operating costs per unit of output are decreasing as the scale of output increases (der Broek et al., 2006; Ollinger, MacDonald and Madison, 2005; Teratanavat, Salin and Hooker, 2005). Mosheim and Lovell (2009) investigate the trend of increasing farm size in the U.S. and concluded that scale economies represent the driving force toward consolidation and scaling up farm size. In this study, we incrementally introduce economies of scale when estimating the grass-fed beef production cost. For many producers, this provides sufficient additional revenue to be profitable, as they keep production cost low through economy of scale. To account for the effect of the scale of economies in cattle

[4] Cheung and McMahon (2017) constructed a 2016 financial overview for 11 actual grass-finishing operations in the U.S., which include examples from most of the major cattle-producing regions. Data in the overview have been modified slightly to respect the sensitive nature of information obtained from producers we interviewed. Mostly we rely on the data to develop our estimation. However, all data used in our model are further modified to fit the operational environment in counites of NYNE.

production, following Cheung and McMahon (2017), we classify farms into three production scale levels from small to large: 1) 40 head and below; 2) 41-4000 head; and 3) 4001-10000 or above each year. Corresponding to the upper bound and lower bound production of each scale level, there are upper bound and lower bound values regarding cost components 2 and 3 for the scale level. We assume that the cost has a negative linear relationship with production in the same production scale level except in the case of production above 10,000. In that case, we assume the cost remains constant, the same as the upper bound cost in scale level 3. These cost data from the literature are representative of the U.S. average in general. To reflect the operational environment, we justify the cost data by using county labor salary if the cost relates to farm labor and management. We also adjust the cost data by using the county consumer price index if the cost relates to the purchase of materials or services for production inputs (U.S. Bureau of Labor Statistics 2022).

The traditional beef industry, especially the production of slaughter-ready finished grain-fed cattle, is relatively small in this region compared to other regions in the US. In our estimation, the production costs for growing grain-fed beef are from a representative small grain-fed feedlot in Iowa state (Iowa State University 2016).

3. Model

Given the costs for beef finishing operations, including the feeder cattle purchase costs, operational costs and overhead costs, we calculate the costs per animal within the farm gate, i.e., cost components 1), 2) and 3). Costs after the farm gate are estimated by solving a facility allocation optimization problem. These costs include the slaughter, processing and transportation costs, i.e., cost components 4) and 5). In addition to providing slaughter and processing services, a plant in the beef supply chain acts as a transfer point at which output from several farms (origins) is consolidated and disaggregated to several streams of beef products that are forwarded to demand locations, that is, consumption sites such as retail stores, restaurants and institutional consumers. We identify the optimal way to allocate cattle among these slaughter and processing plants with an aim to minimize the total operating costs after the farm gate.

Given the cattle expansion scenario and existing slaughter and processing capacity in NYNE, there is a shortage of plant capacity to slaughter and process cattle. There is a need to expand regional slaughter and processing capacity if all cattle produced locally are slaughtered and processed locally in the region. It appears that supporting existing plants that have been created for conventional beef may be more efficient and effective than constructing a new, parallel supply chain (Cheung and McMahon, 2017). From this point forward, in this study, the plant capacity utilization and expansion only consider currently existing plants in the region. We assume the slaughter cost and processing cost per cattle remain unchanged no matter to what extent a plant expands its capacity.

Interest in solving resource allocation and utilization problems in agricultural supply chain systems using optimization approaches has been growing steadily in recent years (Brahimiz and Aouarnb, 2015; De Keizer et al.; 2017; De Pue et al., 2019; Ge, et al., 2018a, 2018b, 2019, 2022a, 2022b; Mogalea et al., 2018; Walters et al., 2017). Following this approach in the literature, the capacity optimization problem is mathematically formulated as a linear programming model. The model involves determining values for a set of decision variables to minimize the objective function subject to a set of constraints. The following notations are introduced for the objective function and relative constraints.

Sets:

F={1,2,3,…,f} denotes a set of production locations;

G={1,2,3,…,g} denotes a set of consumption nodes;

I={1,…,i} denotes the production month;

K={1,2} denotes cattle categories, 1-grass-finished or 2-grain-finished;

S={1, 2, 3,…,s} denotes a set of slaughtering/processing locations

Parameters and exogenous variables

a denotes slaughter capacity of plant;

b denotes processing capacity of plant;

c denotes demand of processed products;

d denotes the distance between origin and destination;

h denotes the cattle production;

l denotes the live cattle price ($ per pound);

n denotes the upper bound of truck capacity (number of animals);

q denotes the average live weight of cattle;

t_1 denotes animal transport cost ($/loaded mile);

t_2 denotes refrigerated truck rate for transporting processed products ($/ton mile);

u denotes unit slaughtering cost;

v denotes unit processing cost;

θ denotes the shrink rate of cattle body weight during transportation (percentage/drive hour);

δ_1^k denotes dressing percentage;

δ_2^k denotes carcass cutting yield[5];

MDT maximum transportation distance of cattle assembly;

ADT average transportation distance of cattle assembly;

Decision and endogenous variables:

$x_{f,s,k,i}$ denotes quantity of cattle k shipped from production location f to plant s for slaughtering in month i;

$y_{s,k,i}$ denotes quantity of cattle k processed at plant s in month i;

$z_{s,g,k,i}$ denotes quantity of processed cattle products shipped from slaughter/processing location s to demand location g in month i;;

Objective functions:

TC denotes system-wide total annual costs

The basic algorithms of the problem are summarized and presented by a linear objective function and a set of system constraints formulated as follows (Eq (1) - Eq. (10)).

$$TC = + \sum_{f \in F} \sum_{s \in S} \sum_{i \in I} \left\{ int\left(\sum_{k \in K} x_{f,s,k,i} / n\right) \cdot d_{f,s} \cdot t_1 \right\} \quad \text{Assembling costs} \tag{1}$$

[5] Dressing Percentage = Carcass Weight / Live Weight; Carcass Cutting Yield = Pounds of meat/ Carcass weight.

$$+\sum_{f\in F}\sum_{s\in S}\{x_{f,s,k,i}\cdot\theta\cdot t\cdot q\cdot l\}$$ Shrink losses[6]

$$+\sum_{f\in F}\sum_{s\in S}\sum_{k\in K}\sum_{i\in I}\left(x_{f,s,k,i}\cdot u_s\right)$$ Slaughtering costs

$$+\sum_{s\in S}\sum_{k\in K}\sum_{i\in I}\left(y_{s,k,i}\cdot q\cdot\delta_1^k\cdot v_s\right)$$ Processing costs

$$+\sum_{s\in S}\sum_{g\in G}\sum_{k\in K}\sum_{i\in I}\left(z_{s,g,k,i}^2\cdot q\cdot\delta_1^k\cdot d_{p,g}\right)$$ Distribution costs (unprocessed product)

The objective function is minimized subject to following constraints,

$$\sum_{s\in S}x_{f,s,k,i}=h_{f,k,i} \qquad \forall\, f,k,i \qquad (2)$$

$$\sum_{g\in G}z_{s,g,k,i}=y_{s,k,i} \qquad \forall\, s,k,i \qquad (3)$$

$$\sum_{f\in F}x_{f,s,k,i}=\sum_{g\in G}z_{s,g,k,i} \qquad \forall s,k,i \qquad (4)$$

$$\sum_{s\in S}z_{s,g,i}=c_{g,i} \qquad \forall g,i \qquad (5)$$

$$\sum_{f\in F}\sum_{k\in K}\ x_{f,s,k,i}\geqq a_{s,i} \qquad \forall\, s,i \qquad (6)$$

$$\sum_{k\in K}\ \sum_{g\in G}\ y_{s,g.k,i}\geqq b_{s,i} \qquad \forall s,i \qquad (7)$$

$$x_{f.s.k,i}(MDT-d_{f,s})\geq 0 \qquad \forall\, f,s,k,i \qquad (8)$$

$$\sum_{f\in F}\sum_{s\in S}\ \sum_{k\in K}\sum_{i\in I}\ (x_{f,s,k,i}\cdot d_{f,s})/\sum_{f\in F}\sum_{s\in S}\ \sum_{k\in K}\sum_{i\in I}\ x_{f,s,k,i}\leq ADT \qquad \forall\, s,i \qquad (9)$$

$$x_{f,s,k,i}\geq 0\ ,\ \ y_{s,g,k,i}\geq 0\ ,\ z_{s,g,k,i}\geq 0 \qquad \forall\, f,s,k,g,i \qquad (10)$$

Eq. (1) states the objective function that minimizes total cost. Eq. (2) ensures that the total quantity of cattle shipped from production location (county) *f* to slaughter plants is equal to the total quantity produced in location *f* in month *i*. Eq. (3) indicates a balance between the inbound flow and outbound flow of a plant. Eq (4) ensures that slaughtered animals at a plant are processed at the same plant. Eq. (5) states a market clearing condition, i.e., the total beef products equal to the total demand of consumers. Eq. (6) and Eq. (7) ensures that all the existing plant capacity should be utilized before any capacity expansion. The three constraints ensure the existing capacity of

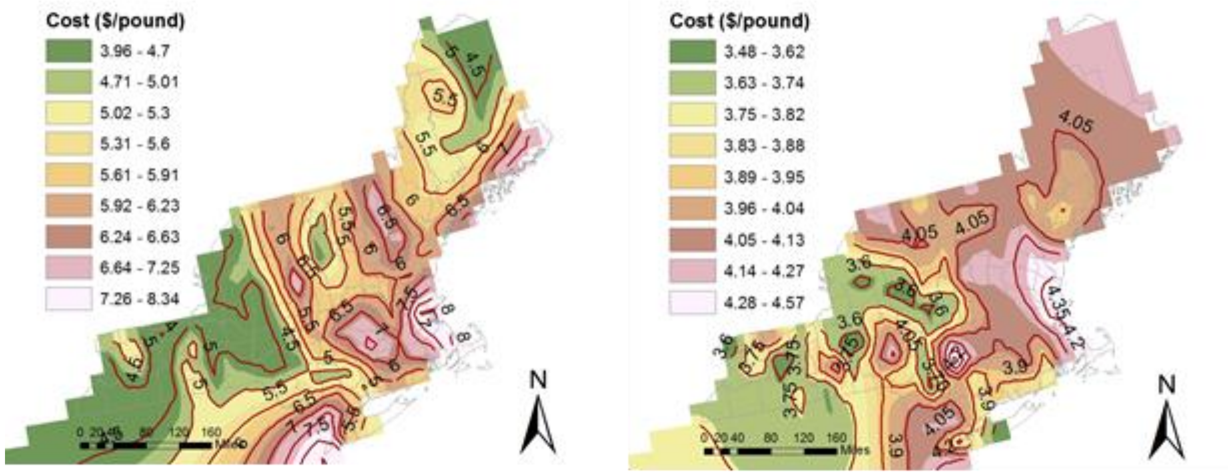
[6] Cattle body weight suffers shrink loss during transportation. Following the literature, we assume cattle begin to lose body weight immediately when they are moved. Shrink is generally greater during the first 4 hours, 1 percent of body weight per drive hour, and then 0.25 percent per drive hour from 5 to 8 or more drive hours (Coffey et al., 2001; Parish & Rhinehart, 2017). Using the live cattle price in the U.S. averaged from 2018 to 2020, $1.17/pound (USDA/NASS, 2021), we convert the shrink in weight throughout the transportation to value loss in dollars and include it in the objective function.

slaughter and processing is utilized as much as possible before considering any expansion of slaughter and processing capacity. Eq. (8) defines the maximum assembly transportation distance between production locations and plant locations. Eq. (9) ensures that the average assembly transportation distance is within a given range. Eq. (10) reflects the standard restrictions of non-negativity that ensure shipments only flow from farms to plants and from plants to consumers, and not vice versa.

The optimization problem includes four types of variables that can be chosen to minimize the total costs of the aforementioned activities. They are the number of live cattle shipped from farms to slaughter and processing facilities, amounts of final products processed at plants, and distribution of beef products to final demand locations. We identify optimal product flow patterns in the beef supply chain by allowing for the spatial distribution of infrastructure and spatial and temporal distribution of animal production. The optimization model assumes that individual producers are indifferent over the destination of their beef cattle and handlers are indifferent regarding which producers deliver cattle to their facilities and to where they ship their products. By solving the optimization problem stated above, we can estimate the cost per unit of product after the farm gate.

4. Result

Based on the cow-calf and backgrounder cost and the optimal beef cattle assembly and distribution calculations, we estimate the production cost per unit for both grass-fed and grain-fed beef products. Figure 3 shows the cost distribution across counties in NYNE. The costs account for all phases from farm to retailer including cost of feeder cattle, feed/pasture cost, other operational cost, overhead cost, assembly cost (shipping cattle from farm to plant), slaughter and processing cost, and distribution cost (shipping beef product from plant to retailer). The cost of grass-fed beef varies widely across counties, ranging from $3.96 to $8.34/pound with an average of $6.01/pound. The cost is comparatively low in New York, Northern Maine and central Vermont. Higher pasture land productivity and larger scale cattle production in these regions jointly contribute to the lower cost. The cost of grain-fed beef ranges from $3.48 to$4.57/pound with an average of $4.15/pound. The production cost of grass-fed is higher than that of grain-fed for each county, ranging from 3 percent to 92 percent with an average of 45 percent.

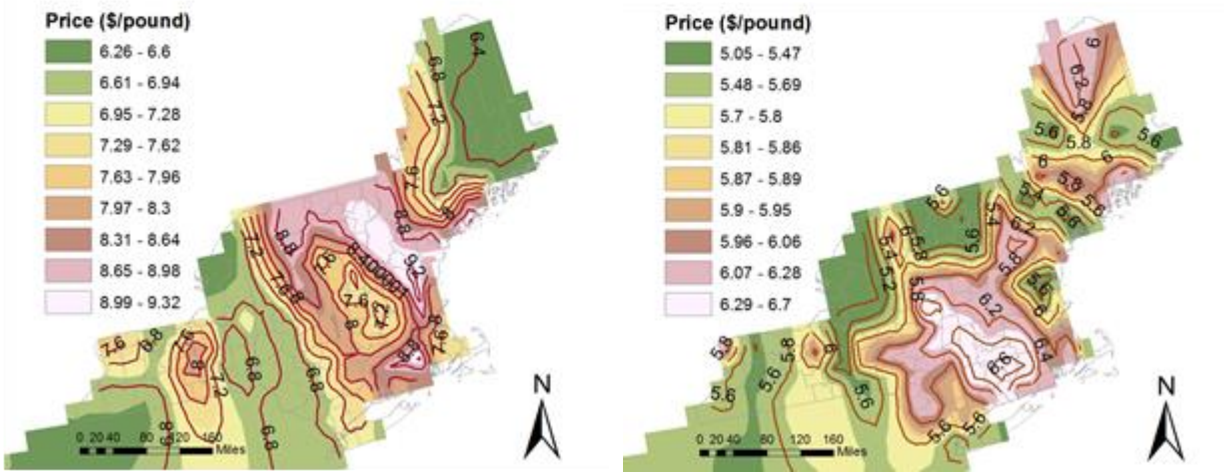


(a) Grass-fed beef (b) Grain-fed beef

Figure 3. Life cycle beef production cost

The model traces the movement of cattle and beef products from the origin to the destination. Every unit of product delivered to consumers has a cost value determined by the model. Given the estimation of beef production cost and the profit margins for producers and retailers, we estimate the price of final beef products at the retail level. U.S. data and statistics suggest the producer's profit margin is 9 percent and the retail margin is 42 percent (USDC/BEA, 2012). Figure 4 shows the distribution of grass-fed beef retail prices across the region along with the grain-fed retail prices. The grass-fed beef price ranges from \$6.26 to \$9.32/pound with an average of \$7.48/pound. The grain-fed beef retail prices range from \$5.05 to \$6.70/pound with an average of \$5.79/pound. These represent the lowest retail prices that can be realized through optimizing the beef supply chain in this case. The divergence of regional prices stems from the spatial variation in cattle production and consumption, capacity of plants, and slaughter and processing costs. For grass-fed beef, lower prices emerge in some areas of New York and Maine. Higher cattle production and lower production and handling costs in these areas contribute to the lower prices. Higher prices emerge in New Hampshire, Vermont and the New York metropolitan area. Lower cattle production but high production cost in these areas raises the supply cost.[7] Most consumed beef products in the region are shipped from other distant areas.

[7] The optimization model assumes local production serves local consumption first.

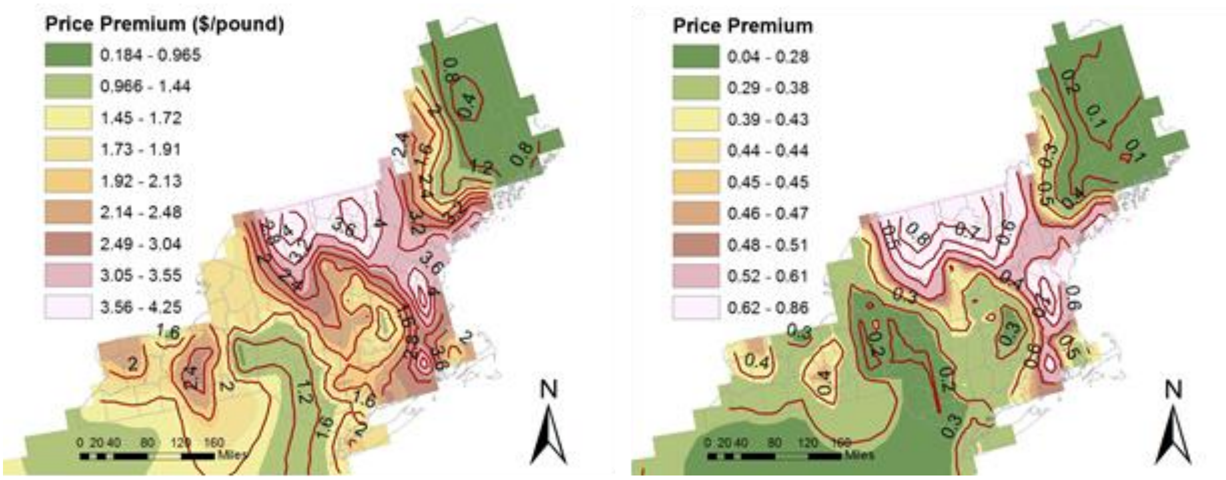


(a) Grass-fed beef (b) Grain-fed beef

Figure 4. Beef retail prices

Figure 5 shows the price premium for grass-fed beef across counties. The price premium shown here is the one to maintain a profitable grass-fed operation in NYNE. As shown in the figure, the price premium ranges from \$0.18 to \$4.25/pound (or 4 to 86 percent) with an average of \$1.69/pound (or 21 percent) for grass-fed beef, given the profit margins for producers and retailers. Such an average price premium value falls into a reasonable range. In the study of Umberger et al. (2002), 23% of the American consumers were willing to pay a premium of \$1.36 per pound for grass-fed beef against U.S. corn-fed beef. Tonsor and Shupp (2009) estimated U.S. consumer willingness to pay for "sustainably produced" beef is 23 percent.

However, the price premium differs across counties. The resulting range of price premium is the one that is needed to offset on-farm and after the farm gate costs and make the production of grass-fed beef to be an economically viable alternative to grain-fed beef for producers in the region. Whether the price premium is reasonable relies on whether consumers deem it acceptable. A large price premium will render grass-fed beef uncompetitive to grain-fed beef. Given the beef supply costs and consumer willingness to pay, different pricing strategies for retailing grass-fed beef should be used in different retail sectors to maintain competitiveness and profitability. To this end, a thorough assessment of consumer attitudes toward and willingness to pay for grass-fed beef is needed to more fully understand the market potential and subsequently mitigate the market risk faced by potential producers. Further discussions on this issue go beyond the scope of this paper. This seems to be a promising area for further research.



(a) $ per pound (b) Ratio

Figure 5. Price premium for grass-fed beef

5. **Discussions**

The interest in growing the beef cattle industry in NYNE is driven by the proximity to markets and the possibility of using “local” or “regional” as differentiation attributes. It remains an empirical question whether beef produced in NYNE is cost-competitive relative to beef brought in from elsewhere, especially those higher-volume areas (e.g., Midwest) that enjoy higher efficiency in growing beef cattle. The grass-fed beef producers also face competition on two fronts: domestic feedlots with efficient supply chains, and Southern Hemisphere countries producing large quantities of grass-fed beef for export. The ability of this market to grow depends on the sector’s capacity to lower production costs in order to broaden its consumer base to generate more consumer demand. If the price of the final beef product is more than the consumer’s willingness to pay, or say the consumers are not willing to pay the premiums typically associated with such local offerings, it will be infeasible to offer them for sale (Froehlich et al., 2009).

Availability of land is not a constraint for grass-fed beef expansion in NYNE. There is enough extra grassland in the region to finish more than a half million grass-fed cattle in the region. Clearly, one approach for grass-fed production in the Northeastern U.S. to compete with the feedlot system is to establish large-scale grass-finishing operations. The best-practice grazing management and greater scale bring down the production cost. Because of the magnitude of the operation, processing and distribution costs should be reduced, allowing cost savings to cascade through the supply chain and lower consumer prices. This may enable a wide margin reduction in the price premium at the retail level while remaining profitable for grass-fed beef producers. Despite the fact that abroad grass-fed production costs are still lower, future growth in grass-fed beef consumption should not be entirely met by imports due to the important ecological and social benefits that well-managed grass-fed operations provide to the U.S.

Consumer preferences and willingness to pay for grass-fed beef will likely differ across regions of NYNE due to heterogeneous attitudes toward and knowledge of beef production in general. Additional research will be necessary to qualify those differences and to assess implications for producers in the region of interest. This kind of information is lacking but is essential to determine the economic viability of grass-fed beef in a region.

Consumer interest has grown as a result of recent information showing the regenerative benefits of grass-fed grazing. Grass-fed grazing has been found to increase soil quality, stimulate the establishment of healthy grasses, and sequester carbon in the ground to help mitigate climate change. To this end, a comprehensive assessment of the economic viability should also account for the benefit of carbon sequestration from grass-fed beef production systems. If the positive externality of carbon sequestration from pastureland is considered, the conclusion about the economic viability of grass-fed beef production could be different. In this case, the viability assessment will partially rely on the evaluation of potential net carbon sequestration from grass-fed beef production systems. This is a promising topic that deserves further investigation.

6. Conclusions

In this study, we collected data on the economics of beef finishing from a range of sources. By solving an optimization model, we estimate the potential costs occurring after the farm gate. Based on those, we assess the life-cycle cost of beef and compare the operational and financial performance of grass-fed and grain-fed systems. Given land availability and productivity in NYNE, grass-fed beef production can realize a certain level of economies of scale, which greatly lower the operational and overhead costs of grass-fed cattle production. This scale of operation also enjoys lower assembly and distribution costs, allowing the cost saving to flow along the supply chain. and the transportation costs. The findings of this study are useful in the context of developing a grass-fed beef production program in the Northeastern U.S.

In general, given an appropriate level of price premium for grass-fed beef, e.g., 50 percent to 80 percent, most grass-fed beef in NYNE can compete strongly with conventional feedlots in the region. In the U.S., there is clearly considerable demand for grass-fed beef, with a large number of consumers preferring the flavor of grass-fed beef over grain-fed beef. Cattle producers could use grass-fed beef as a marketing alternative by targeting these consumers in certain niche markets. Then grass-fed beef may begin to supplant traditional feedlot beef in a significant way at this stage, moving from a niche to the mainstream.

References

Brahimia, N, and T. Aouamb. 2015. Multi-item production routing problem with backordering: a MILP approach. *International Journal of Production Research* 54 (4): 1076-1093.

Camargo, R.S., G. Miranda, and H.P.L. Luna. 2009. Benders decomposition for hub location problems with economies of scale. *Transportation Science* 43 (1): 86–97.

Cheung, R., and P. McMahon. 2017. “Back to Grass: The Market Potential for U.S. Grassfed Beef. Work repot. Stone Barns Center for Food & Agriculture.” https://www.stonebarnscenter.org/wp-content/uploads/2017/10/Grassfed_Full_v2.pdf

Coffey, K. P., Coblentz, W. K., Humphry, J. B., and Brazle, F. K. 2001. Basic principles and economics of transportation shrink in beef cattle. *The Professional Animal Scientist* 17(4): 247–255.

der Broek, P. Schutz, L. Stougie, and A. Tomasgard. 2006. Location of slaughterhouses under economies of scale. *European Journal of Operational Research* 175 (2): 740-750.

De Pue, D., A. Bral, and J. Buysse. 2019. Abatement of ammonia emission from livestock housing fine-tuned according to impact on protected habitats. *Agricultural Systems* 176: 1026.

De Keizer, M., R. Akkerman, M. Grunow, J.M. Bloemhof, R. Haijema, and J.G.A.J. van der Vorst. 2017. Logistics network design for perishable products with heterogeneous quality decay. *European Journal of Operational Research* 262 (2): 535-549.

Dupont, L. 2008. Branch and bound algorithm for a facility location problem with concave site dependent costs. *International Journal of Production Economics* 112 (1): 245-254.

Ge, H., P. Canning, S. Goetz, and A. Perez. 2018a. Effects of scale economies and production seasonality on optimal hub locations: The case of regional fresh produce aggregation. *Agricultural Economics* 49(2): 157–169.

Ge, H., P. Canning, S. Goetz, and A. Perez. 2018b. Optimal locations of fresh produce aggregation facilities in the United States with scale economies. *International Journal of Production Economics* 197: 143–157.

Ge, H., P. Canning, S. Goetz, and A. Perez. 2019. Embedding economies of scale concepts in the model of optimal locations of fresh produce aggregation hubs. *Agricultural and Resource Economics Review* 48 (3): 365-387.

Ge, H., M. Gómez, and C. Peters. 2022a. Modeling and optimizing the beef supply chain in the Northeastern U.S. *Agricultural Economics*. Published online. DOI: 10.1111/agec.12708.

Ge, H., S. Stephan, B. Cleary, J. Yi, and M. Gómez. 2022b. Facility Locations in the fresh produce supply chain: An integration of optimization and empirical methods. Accepted by *International Journal of Production Economics*.

Gillespie, J., Sitienei, I., Bhandari, B., and Scaglia, G. (2016). Grass-fed beef: How is it marketed by US producers? *International Food and Agribusiness Management Review* 19(2): 171–188.

Goodsell, M., and Stanton, T. 2011. “A resource guide to: Direct marketing livestock & poultry.” Cornell Small Farms Program, Cornell University. https://ecommons.cornell.edu/handle/1813/40257

Hayek, M.N., and R.D. Garrett. 2018. Nationwide shift to grass-fed beef requires larger cattle population. *Environmental Research Letters* 13 (8): 1-8.

Iowa State University. 2016. “Livestock Enterprise Budget for Iowa-2016.” Iowa State University. Extension and Outreach. https://www.ansc.purdue.edu/SP/TBC/assets/b1-21-iowa-budgets-edited.pdf

Mccluskey, J. T.I. Wahl, Q. Li, and P.R. Wandschneider. 2005. U.S. grass-fed beef: marketing health benefits. *Journal of Food Distribution Research* 36 (3): 1-8.

Mogalea, D.G., M. Kumar, S.K. Kumar, and M.K. Tiwaria. 2018. Grain silo location-allocation problem with dwell time for optimization of food grain supply chain network Transportation *Research Part E: Logistics and Transportation Review* 111: 40-69.

Mohammed, A., and Q. Wang. 2017. The fuzzy multi-objective distribution planner for a green meat supply chain. *International Journal of Production Economics* 184: 47–58.

Lewis, C. B., and Peters, C. J. 2012. A capacity assessment of New England's large animal slaughter facilities as relative to meat production for the regional food system. Renewable *Agriculture and Food Systems* 27 (3): 192– 199.

Lozier, J., E.B. Rayburn, J. Shaw. 2005. Growing and selling pasture-finished beef: Results of a nationwide survey. *Journal of Sustainable Agriculture* 25 (2): 93-112.

Ollinger, M, J.M. MacDonald, and M. Madison. 2005. Technological change and economies of scale in U.S. poultry processing. *American Journal of Agricultural Economics* 87 (1): 116–129.

Parish, J. A., & Rhinehart, J. D. 2017. “Understanding and Managing Cattle Shrink. Mississippi State University – Extension.” https://extension.msstate.edu/publications/understanding-and-managing-cattle-shrink.

Teratanavat, R., V. Salin, and N. Hooker. 2005. Recall event timing: Measures of managerial performance in U.S. meat and poultry plants. *Agribusiness* 21 (3): 351-373.

Thorn, A.M., M.J. Baker, C.J. Peters. 2021. Estimating biological capacity for grass-finished ruminant meat production in New England and New York. *Agricultural Systems* 189: 102958. https://doi.org/10.1016/j.agsy.2020.102958.

Tonsor, G.T., and R. Shupp. Valuations of 'sustainably produced' labels on beef, tomato, and apple products. *Agricultural and Resource Economics Review* 38 (3): 371–383.

Umberger, W. J., D.M. Feuz, C.R. Calkins, and K. Killinger-Mann. 2002. U.S. consumer preference and willingness-to-pay for domestic corn-fed beef versus international grass-fed beef measured through an experimental auction. *Agribusiness* 18 (4): 491–504. https://doi.org/10.1002/agr.10034

U.S. Bureau of Labor Statistics. 2022. Occupational employment and wage statistics. https://www.bls.gov/oes/current/oes_nat.htm

U.S. Census Bureau. 2012. Population estimates - American FactFinder - Census Bureau. https://factfinder.census.gov/bkmk/table/1.0/en/PEP/2012/PEPAGESEX.

U.S. Department of Commerce (USDC), Bureau of Economic Analysis (BEA). 2012. Input-Output Account Data. https://www.bea.gov/industry/input-output-accounts-data

U.S. Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS). 2018. National resources inventory pastureland resource assessment. Available at: https://www.nrcs.usda.gov/Internet/ FSE_DOCUMENTS /nrcseprd1403461.pdf

USDA, National Agricultural Statistics Service (NASS). Quick Stats. Accessed in April 2021, available at: https://www.nass.usda.gov/Quick_Stats/index.php

USDA, NASS. 2021. Prices received: Cattle prices received by month, US. https://www.nass.usda.gov/Charts_and_Maps/Agricultural_Prices/priceca.php

USDA, NASS. 2013. Livestock slaughter 2012 summary. https://usda.library.cornell.edu/concern/publications/r207tp32d

USDA, NASS. 2012 Census volume 1, chapter 2: county level. Table 11, cattle and calves - inventory and sales: 2012 and 2007. Available at: https://www.nass.usda.gov/Publications/AgCensus/2012 /Full_Report /Volume_1,_ Chapter_2_County_Level/

van Vliet, S., F.D. Provenza, and S.L. Kronberg. 2021. Health-promoting phytonutrients are higher in grass-fed meat and milk. *Frontiers in Sustainable Food Systems*. doi: 10.3389/fsufs.2020.555426

Walters, C. G., C.R. Shumway, and D.R. Huggins. 2017. Impacts of terrain attributes on economics and the environment: costs of reducing potential nitrogen pollution in wheat production. *Agricultural Economics* 48 (2): 143–152.

Waro, M., Gómez, M., Kalaitzandonakes, M., Peters, C., Baker, M., & Conard, M. 2019. "The state of New York & New England's USDA red meat harvest plants." Cornell University. https://gomez.dyson.cornell.edu/meat.pdf