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Economic Comparison of Traditional Small Box and Semi-Automatic Bin Handling Harvesting Technologies for Wild Blueberries from a Field Trial: A Stochastic Approach

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The type of handling system (i.e., traditional small box versus semi-automatic bin handling) distinguishes the two main types of existing commercial wild blueberry mechanical harvesters commonly used by farmers in Atlantic Canada and the northeastern United States. However, their impacts on costs and returns to farmers have not been evaluated. Partial budgeting (PB) methods were used to quantify and compare economic performance of the two technologies. Stochastic PB involved probabilistic sensitivity analysis, where multiple parameters were allowed to vary simultaneously, and the results evaluated. Net change in profit, estimated using a deterministic PB model based on two alternative measures of harvest rate (tonnes ha^{-1} and hours ha^{-1}) for 2017 data was CAD\$0.52 $tonne^{-1}$, and CAD\$674 ha^{-1}, and implies that switching from the small box handling system to the semi-automatic bin handling system is economically viable. Economic performance using stochastic PB analysis is consistent with the deterministic model results.

***Key words**:* Analysis, Automation, Mechanization, Monte Carlo Analysis, Profitability, Wild Blueberries

Profitability of wild blueberry (*Vaccinium augustifolium*) production in Atlantic Canada and the northeastern United States depends largely on the availability of labor-saving and cost-effective mechanical harvesters to reduce the overall cost of production (Esau et al., 2019; Gallardo and Sauer, 2018; Yiridoe, 2018). The producer price of wild blueberries has stagnated since 1991 and declined since 2014 for farmers in Atlantic Canada (Statistics Canada, 2017), and in the northeastern United States (U.S. Department of

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Agriculture (USDA), 2019; Yarborough, 2018). On the other hand, farm labor wages[1] and other wild blueberry production costs are projected to increase in the foreseeable future (Strik and Yarborough, 2005; Takeda et al., 2013; Hu et al., 2016; Rodgers, Morgan, and Harri, 2017).

The cost associated with harvesting wild blueberries accounts for a substantial percentage of total production costs (Esau et al., 2019; Gallardo and Zilberman, 2016; Yarborough, 2000), and current wild blueberry harvesting systems are labor-intensive (Yarborough and Hergeri, 2010). Manual harvesting of wild blueberries using hand-held metal rakes is labor intensive and not cost-efficient (Khan, 2019). Mechanical harvesters with small box handling systems are commonly used for wild blueberry harvesting and require a worker to operate the tractor-harvester and a second worker to handle the boxes. The availability of farm labor for harvesting field crops, berries, and fruits is a major challenge in Atlantic Canada and the northeastern United States (Farooque et al., 2014; Yarborough, 2000). Cost-effective mechanical harvesting technologies have the potential to improve labor productivity by about 60 times (Takeda et al., 2013), while at the same time reducing harvest costs by up to 85% (Gallardo et al., 2018; Zhang et al., 2016). On average, the harvesting cost using hand-held metal rakes is estimated at CAD\$1.20 kg^{-1}, compared with CAD\$0.33 kg^{-1} using mechanical harvesting (Swinkels, 2018).

The mechanical harvest handling systems studied are manufactured and customized specifically for wild blueberries (also sometimes referred to as lowbush blueberries). Machine harvest and handling systems for other blueberry species such as northern highbush blueberries (*Vaccinium corymbosum*), southern highbush blueberries (*V. darrowi* × *V. corymbosum*), and rabbiteye blueberries [*V. virgatum* (syn. *V. ashei*)] are different and not the focus of this study. The difference in mechanical harvesters used is primarily linked to important differences in the biology and agronomy of these blueberry species. For example, mature wild blueberry plants range in height from 5 to 25cm, (and, on average, are about 15cm high) (Chang et al., 2017; Kinsmann, 1993). On the other hand, the southern highbush blueberry plant height ranges from 91.4 to 152.4 cm, compared with the height of the northern highbush blueberry which ranges from 82.7 to 146.4 cm. In contrast, the rabbiteye blueberry plant height ranges from 182.9 to 243.8 cm (Takeda et al., 2008). The type of harvest handling system (i.e., traditional small box handling versus semi-automatic bin handling) distinguishes the two main types of existing commercial wild blueberry mechanical harvesters (Figure 1). Mechanical

[1] In 2019, the government of Nova Scotia, Canada, announced that minimum wage will increase by CAD\$0.55 a year for the next three years. Specifically, minimum wage rates would increase by CAD\$0.55 to CAD\$11.55 in 2019 and to CAD\$12.65 by 2021. Starting in April 2022, the minimum wage rate in the province will be inflation-adjusted annually, using the Consumer Price Index (Government of Nova Scotia, 2019).

harvesters with the small box and semi-automatic bin handling systems are commonly used in the wild blueberry growing regions of Atlantic Canada and the northeastern United States. Official statistics on wild blueberry industry harvester use are not available. However, personal communication with wild blueberry specialists indicate that about 45-50% of farmers in Quebec and Atlantic Canada currently use mechanical harvesters with a small box handling system, compared with about 5-10% of farmers who use manual hand-held metal rakes (Swinkels, 2018). Hand-held rakes are common among small-scale operators, and also used on areas of commercial farms with rocky and rough terrains where mechanical harvesters cannot be used.

(a) Mechanical Harvester Illustrating Semi-automatic Bin Handling System.

(b) Mechanical Harvester Illustrating Worker (at rear), and Small Box Handling System.

Figure 1. Mechanical Harvesting Systems with Alternative Box Handling Systems.

Wild blueberry farmers face various challenges, including high farm labor wages, shortage of labor during the summer season, and a short harvesting time window (3-4 weeks), which prompted producers to seek cost-efficient and labor-saving technologies for berry harvesting. However, their economic performance in terms of impacts on costs and returns to farmers has not been evaluated. This study investigated whether the semi-automatic bin handling harvesting system would improve profitability relative to the traditional small box handling system. A wild blueberry farmer may not automatically switch from the small box to a semi-automatic bin handling system without considering the economic viability of the new harvesting equipment. Other factors associated with the berry harvest handling system adoption decision include user-friendliness and socioeconomic factors (Gallardo and Zilberman, 2016), but these are beyond the scope of the current study.

The purpose of this study was to compare the economic performance of two wild blueberry mechanical harvesters which are distinguished by the harvest handling system (i.e., small box versus semi-automatic bin) based on data from on-farm trials. Deterministic partial budgeting methods were used to assess the economic viability of switching from small box handling to semi-automatic bin handling. The partial budgeting (PB) methods were used to quantify and compare net change in profits associated with the two wild blueberry mechanical harvesting systems. Second, to account for uncertainty in important parameters that influence economic performance, stochastic partial budget (SPB) analysis was conducted and net changes in profits were compared.

Literature Review of Related Studies

Economic Analysis of Mechanical Harvesting Systems for Specialty Crops

Various economic studies have examined the economic viability of adopting mechanical harvesters and harvest handling systems for specialty crops. One branch of such economic studies has investigated the effects of adopting particular mechanical harvesters and harvest handling systems on social welfare (e.g., Huang and Sexton, 1996). A second group of studies have examined production efficiency associated with integrating farm labor with mechanical harvesting. Examples include apple production in Washington and Pennsylvania (Baugher et al., 2009), and Bartlett pear (*Pyrus communis*) orchards in California (Elkins et al., 2011). Rodgers, Morgan, and Harri (2017), for example, evaluated the effect of producer risk preferences on adoption of machine harvesting for southern highbush blueberries. Rodgers, Morgan, and Harri (2017) concluded that labor uncertainty and risk were important determinants of adopting mechanical harvesting technologies. A third group of studies emphasize the effects of mechanical harvesting on farm returns. The analyses in this latter group of studies include partial budget analysis of relative profitability, and actual profitability of whole-farm production systems.

Harper, Takeda, and Peterson (1999) estimated net returns for eastern thornless blackberry production using improved mechanical harvesters coupled with novel shakers with alternative trellis designs. The authors reported that mechanical harvesting for fresh market packouts was profitable based on output as low as 13 to 31% of expected yield, compared with a breakeven yield of 44 to 49% using manual hand harvesting. It was concluded that lower harvest costs associated with the mechanical harvesters considered would also make them financially viable for processing blackberry producers. As with Harper, Takeda, and Peterson (1999), Gallardo and Zilberman (2016) compared net returns using manual versus machine harvesting in highbush blueberry production in Washington state for the fresh and processed berry markets. The results suggest that reducing the gap between fresh and processed blueberry prices, reducing yield quality losses (from fruit bruises), and increases in labor wages improve profitability and the likelihood of adoption of the mechanical harvester. Other studies that compared farm profitability using manual harvesting versus mechanical harvesters included sweet cherry production in Washington state (Seavert and Whiting, 2011), olives in California (Klonsky et al., 2012), and asparagus production in Washington state (Cembali et al., 2008). In general, technical engineering efficiencies associated with the mechanical harvesters reduced costs and improved profitability. For example, Seavert and Whiting (2011) reported that machine harvest cost was US$0.04 kg^{-1} (or 93% less) compared with traditional hand harvesting at US$0.55 kg^{-1}.

The present study contributes to the limited but growing set of economic studies which apply partial budgeting methods to evaluate the economic feasibility of switching from an existing mechanical harvesting system to an improved alternative. The applications to harvesters for specialty crops are limited, compared with grains and other field crops, and animal production systems. Praweenwongwuthi, Laohasiriwong, and Rambo (2010), for example, applied partial budgeting methods to compare the viability of manual versus combine harvesting of rice production in Thailand. The authors reported that net change in profit was 30.3% higher for the combine harvester compared with manual harvesting. Gallardo and Brady (2015) compared the cost of using ladders versus labor working conditions-enhancing platforms to harvest apples produced in Washington state. The study concluded that platforms would need to increase labor productivity by about 13% or more in order to motivate adoption.

In summary, the economic studies suggest considerable progress in developing and promoting adoption of mechanical harvesters and harvest handling technologies for various specialty crops. While some of the mechanical harvesters studied enhance labor working conditions, the majority are labor-saving mechanical harvesters and harvest handling systems. In addition, the literature suggests that mechanical harvesters may generate benefits to producers, especially over the long run. The limited rates of adoption may be due to barriers such as uncertainty associated with new machine harvesting technologies, upfront capital investment costs, and other challenges with switching to new innovations. Financial considerations and overall profitability vary by location and need to be investigated for specific farming conditions.

Parametric and Stochastic Partial Budget Analysis

Partial budgeting methods are commonly used to examine the effects of a small (proposed) change in a farm operation or enterprise; only those costs and benefits affected by the change are considered in the analysis (Flinn, Jayasuriya, and Maranan, 1991; Dalsted and Gutierrez, 1990). Thus, partial budget analysis allows for evaluating relative (as opposed to actual) profitability associated with the change. The reliability of the partial budgeting results may be limited due to uncertainty or variability associated with important input and parameter values used in the analysis (Dhoubhadel and Stockton, 2010). Parametric and stochastic partial budgeting methods are often used in sensitivity analysis to quantify the uncertainty around important estimates.

Parametric partial budget analysis is also sometimes referred to as sensitivity analysis (Flinn, Jayasuriya, and Maranan, 1991). Parametric partial budget analysis allows for evaluating the effects of changes or uncertainty in selected cost and benefit parameters on net change in profit (Alimi, 2000; Flinn, Jayasuriya, and Maranan, 1991; Dillon and Hardaker, 1980). Partial budgeting analysis can be parametrized by evaluating discrete values of a variable, such as low, average, and high levels of a particular variable (Kay, Edwards, and Duffy, 2016). Another technique commonly used in parametric partial budget analysis involves changing (i.e., increasing or decreasing) a parameter by a desired percentage level. The analysis evaluates how sensitive net change in profit is to the range of a given parameter. Such a sensitivity analysis generates outcomes on only a selected range of a given or desired variable or parameter. Applications of partial budgeting in economic analysis of agricultural management include Swinkels et al. (2005), Doupé and Lymbery (2002), Sharmasarkar et al. (2001), and O’Brien et al. (1998).

Stochastic Partial Budgeting

Stochastic partial budgeting addresses the uncertainty problem associated with deterministic partial budgeting by using a range of values to a variable between the highest and lowest, to create a probability density function (PDF). A combination of variables in the model and their probability distributions are used to determine the range and probability of final possible outcomes. The final outcome can be graphed as a cumulative distribution function (CDF). Stochastic methods can be applied to important variables in the analysis, such as output price, output level, interest rate, and labor wage.

In this study, stochastic partial budget (SPB) analysis involved multivariable probabilistic sensitivity analysis. Unlike one-way sensitivity analysis where one parameter is varied at a time and the results evaluated, the SPB analysis allows several key parameters to vary simultaneously, and the results evaluated. Key parameters used in the initial deterministic partial budget analysis were fitted to probability distributions to quantify the uncertainty around the estimates. Uncertainty surrounding all costs was modelled by fitting a log-normal distribution, which assumes parameters to be normally distributed in the log scale, using the method of moments approach to estimate the alpha and beta parameters required for the distribution. Uncertainty surrounding interest rate on investment was modelled by fitting a beta distribution, which is constrained to the interval [0, 1], again using the method of moments approach to estimate the alpha and beta parameters required for the beta distribution (Gray et al., 2011).

Data

Berry production and related harvest data were obtained from on-farm field trials conducted during 2017 and 2018 in Nova Scotia, Canada. For all the farms studied in both years, recommended wild blueberry agronomic and management practices were implemented over the past decade, including herbicides, fungicides, insecticides, induced pollination, and mechanical pruning. The harvest operations conducted allowed for comparing wild blueberry harvest efficiency of the mechanical harvesters with the alternative handling systems. Field data for 2017 were obtained from harvesting a single farm-field. Thus, the two harvesters were tested under similar experimental conditions or units. In contrast, data for 2018 were obtained from the two harvesters tested or operated on separate farms with different field conditions. Second, a frost event in 2018 adversely affected wild blueberry yield throughout the Maritimes. Consequently, economic comparisons were analyzed separately for the data in 2017 and 2018.

Primary data on harvest time and berry handling time were used to estimate harvest rate (measured in kg h^{-1} and h ha^{-1}) for the two harvesters. Harvestable yield per ha was estimated using the following relationship:

$$(1) \qquad \boldsymbol{Y_i} = \text{Ɣ} * \boldsymbol{\tau}$$

where Y_i is the harvestable yield using harvest handling technology, i=1 for harvester with small box handling (s), and i=2 for harvester with semi-automatic bin handling system (b). Ɣ denotes average yield harvested per hour, and $\boldsymbol{\tau}$ is the time (hours) required to complete harvesting one ha. Harvestable yield was classified as (Fonsah et al., 2007): i) optimistic (or high) yield; ii) average (or typical) yield; and iii) pessimistic (or low) yield, and summary statistics reported according to year (Table 1).

Financial and other economic data were obtained from various sources (Table 2). For example, the mechanical harvester price and harvest handling technology data were obtained from Doug Bragg Enterprises Ltd., a leading manufacturer of mechanical harvesters in Atlantic Canada. Time series data on wild blueberry prices (1981-2016) were obtained from Statistics Canada (2018) and Wild Blueberry Producers Association of Nova Scotia. Interest rate was based on Bank of Canada and commercial banking rates (Statistics Canada, 2018). Time series data on the wage rate (1982-2016) were obtained from the Government of Canada (2018). Harvester usage data (e.g., fuel consumption rate, harvester use) were obtained from local wild blueberry farmers and wild blueberry harvester manufacturers.

Empirical Methods

In this study, the small box handling system is the comparator or reference technology, while the semi-automatic bin handling system is the new alternative with which the comparison is made. First, manual harvesting using hand rakes involves 5-10% of mainly small-scale farmers and is not common among commercial producers (Khan, 2019). Partial budget evaluation of the semi-automatic bin handling technology relative to manual hand raking, a declining and less used wild blueberry harvesting method in Atlantic Canada and the northeastern United States, will likely generate results that make the new harvesting system highly artificially financially viable. In addition, given the limited use of this increasingly dated blueberry harvesting method, it was reasoned that partial budgeting analysis using hand raking as the comparator would not provide findings that are generalizable and relevant to most commercial wild blueberry farmers. On the other hand, as noted earlier, the small box handling system is the predominant mechanical harvest handling system (among at least 50%) of existing commercial farmers. Industry observation with the current incarnations of the mechanical harvesters indicate that commercial farmers with existing small box handling systems are among those contemplating the switch (Swinkels, 2018).

Table 1. Summary of Wild Blueberry Yield Scenarios Used in Partial Budget Analysis.

Yield scenario	Sample Mean	Standard Deviation	Maximum	Minimum	Replications
(a) 2017 data (kg ha^{-1})					
Optimistic	7561	465	8290	7088	6
Average	6517	1443	8290	3450	12
Pessimistic	5473	1323	6694	3450	6
(a) 2018 data (kg ha^{-1})					
Optimistic	1944	106	2053	1813	6
Average	1790	197	2053	1412	12
Pessimistic	1637	136	1803	1411	6

Table 2. Financial and Harvest Cost Data[a] Associated with Switching from Small Box Handling to Semi-Automatic Bin Handling System.

	Unit	Small Box Handling System	Bin Handling System
(a) General information			
Purchase price	$	----	30000.00
Expected life of a harvester	yr	----	10.00
Harvester use	h yr^{-1}	280-320	280-320
Fuel consumption rate	L h^{-1}	4.00	4.00
Salvage value	$	----	7500.00
Interest rate	%	----	3.80
Fuel (diesel) price	$	1.20	1.20
(b) Annual fixed costs			
Depreciation	$	0.00	2409.38
Interest on investment	$	0.00	712.50
Housing and storage	$	0.00	450.00
(c) Annual variable cost			
Fuel cost	$	1440.00	1560.00
Lubrication cost	$	216.00	234.00
Repairs and maintenance	$	3486.00	4543.00
Labor cost (operator)	$	4500.00	4500.00
Labor cost (support worker)	$	3600.00	----
Annual rental rate of loader tractor	$	----	4000.00
Interest on operating expenses	$	565.43	633.54
Total cost per year	$	13807.43	19042.42

[a]Money reported in Canadian dollars (CAD$).

Wild blueberry farmers contemplating switching from the small box system to the semi-automatic bin handling system know it requires a minor modification to the harvester and an additional CAD$30,000 to upgrade to or purchase the semi-automatic bin handling system. As noted earlier, a mechanical harvester with the small box handling systems requires two workers; one tractor-harvester operator and a second worker at the rear of the harvester who manually loads and unloads the berry-filled and empty boxes (Figure 1). By comparison, a semi-automatic bin handling system requires only a tractor operator, who loads and unloads the empty and berry-filled boxes using a hydraulic mechanism. The tractor and most components of the single head and double head harvesters used with the small box handling system remain unchanged and are assumed to be used with the semi-automatic bin handling system. The upgrade involves a slight modification to the side berry conveyor to attach a debris hood system. Manual loading and unloading of boxes in the small box handling system is replaced with larger boxes in the bin handling system, which are loaded and unloaded by the tractor operator using a hydraulic mechanism.

Personal communication with farmers and harvester manufacturers indicates that wild blueberry mechanical harvesters are typically used for about 280-320 hours in a production year (Swinkels, 2018). Harvestable area using the small box and semi-automatic bin handling systems in a berry production year were estimated using the following equation:

(2) $$A_i = \frac{T_h}{HR}$$

where A_i represents the harvestable area (ha) using harvest handling technology, i=1 for a harvester with small box handling, and i=2 for the harvester with semi-automatic bin handling system. T_h represents total number of hours each mechanical harvester is assumed to operate during a full season (i.e., 300 hrs). HR denotes harvest rate (h ha^{-1}) for each of the two harvest handling systems. The harvest rates and harvestable area are summarized by year and harvest technology in Table 3.

A field harvest efficiency and performance study conducted as part of a larger research project indicates that the semi-automatic bin handling system is 22-29% more efficient than the small box handling system (Khan, 2019). The increased harvest efficiency translates into an extra 10 ha of harvested area in a berry production year and, ultimately, into additional revenue for the semi-automated bin handling system with a double head configuration. However, the additional revenue comes at additional investment and operating costs associated with upgrading to the semi-automatic bin handling technology.

In this partial budgeting analysis, only those costs that will increase or decrease and benefits that increased or decreased due to the change in the harvester handling system were evaluated; levels and costs of all unchanged production processes and inputs are not considered. The decision criterion in switching from the traditional small box handling system to the semi-automatic bin handling system is profitable (inferior) if positive effects are greater (lower) than negative effects.

Table 3. Harvest Rate and Harvestable Area of Alternative Box Handling Systems.

	------- Harvest Rate (h ha^{-1}) -----------		Harvestable Area Berry Production Year (ha)[a]	
	Small Box System	Bin Handling System	Small Box System	Bin Handling System
(a) Year 2017				
Pessimistic	7.05 (0.55)	5.82 (0.01)	42.55 (0.55)	51.54 (0.01)
Average	7.22 (0.24)	5.90 (0.11)	41.57 (0.24)	50.85 (0.11)
Optimistic	7.39 (0.05)	5.98 (0.12)	40.59 (0.05)	50.16 (0.12)
(b) Year 2018				
Pessimistic	6.75 (0.15)	5.30 (0.02)	44.44 (0.15)	56.60 (0.02)
Average	6.89 (0.19)	5.33 (0.04)	43.55 (0.19)	56.28 (0.04)
Optimistic	7.03 (0.07)	5.36 (0.06)	42.67 (0.07)	55.60 (0.06)

[a]Harvestable area was obtained by dividing the total number of hours in a production year (300 h) by harvest rate. Figures in parentheses represent standard deviations.

The main types of positive effects were estimated as reduced costs and additional revenue, while the main negative effects were the additional costs and reduced returns associated with the switch (Kay, Edwards, and Duffy, 2016). Positive effects of the switch involved reduced costs associated with eliminating the small box handling system and additional revenue associated with using the semi-automatic bin handling technology (i.e., added returns). Additional revenue from the semi-automatic bin handling system (AR_b) arises from increased harvesting time efficiency; 89% for the semi-automatic bin handling system compared with 73% for the small box system (Khan, 2019).

By comparison, negative effects of the change in harvesting technology arise from increases in the purchase and operating costs of the semi-automatic bin handling technology (additional cost) and a reduction in revenue from eliminating the use of the small box handling system (i.e., reduced revenue). Additional cost (AC_b) includes upgrading the harvester with the semi-automatic bin handling harvester, such as fixed cost FC_b (i.e., depreciation and interest on the associated added cost), and associated variable cost VC_b (e.g., additional fuel, lube, and repair and maintenance):

$$AC_b = FC_b + VC_b \quad (3)$$

Reduced revenue is associated with eliminating the small box handling system:

$$(4) \qquad RR_s = Y_s * P_f$$

where RR_s represents reduced revenue associated with using the small box handling technology, the index s denotes harvesting with the small box handling system. Y_s is the harvest/yield using the small box handling system, and P_f is the farm gate price of wild blueberries. Reduced revenue is associated with eliminating the use of the small box handling system for berry harvesting. Reduced costs arise from eliminating the small box handling technology and include cost savings from eliminating the small boxes, as well as labor cost savings from eliminating the small box loader/worker. Reduced costs *(RC_s)* are linked to eliminating variable and operating costs (such as fuel, lube, and repair and maintenance) for the small box handling system. The decision criterion, in terms of net change in profit (π_p), is represented as:

$$(5) \qquad \pi_P = (AR_b + RC_b) + (AC_b + RR_s) \begin{cases} > 0; \text{profitable to switch to bin handling sysytem} \\ < 0; \text{not profitable to switch to bin handling system} \end{cases}$$

Harvester cost data for the small box and semi-automatic bin handling systems are summarized in Table 2. Fixed costs (including depreciation, interest on investment, and housing and insurance) do not vary with production. Depreciation was calculated using the diminishing balance method, based on a 15% rate for powered machines and 10% for non-powered equipment (Yiridoe and Weersink, 1994). The depreciation rate was applied to the new or list price of the semi-automatic bin handling system upgrade. The interest rate on the CAD$30,000 investment upgrade was estimated by assuming that 70% of the depreciation value was equity and the remaining 30% was debt (Yiridoe et al., 1993). The interest rate on equity was assumed as 3.64% based on the average rate offered by commercial banks in 2017 on saving accounts (Statistics Canada, 2018). The interest rate on the debt portion was based on a prime rate of 3.7% (Bank of Canada, 2018), plus 0.5 for a debt charge of 4.2%. Thus, the interest rate on investment used was 3.80% [= (3.64*0.7) + (4.2*0.3)]. Insurance and housing or storage costs of equipment were assumed to be 1.5% of the purchase price of the harvester (Kay, Edwards, and Duffy, 2016; Yiridoe et al., 1993).

Variable costs include fuel, lubrication, repairs and maintenance cost, and directly related to hours of use of the harvester. For both small box and semi-automatic bin handling systems, average diesel fuel consumption was estimated as 4 L hr^{-1}. The existing retail price of diesel fuel (i.e., CAD$1.20 L^{-1}) was applied in the calculations.

The total fuel cost was determined by multiplying fuel cost per hour by harvester operating hours. Lubrication cost was assumed to be 15% of total fuel cost (Kay, Edwards, and Duffy, 2016). Repair and maintenance costs were calculated using American Society of Agricultural and Biological Engineers (ASABE) standards (ASABE, 2015):

(6) $$C_{rm} = (RF_1)P[\frac{h}{1000}]^{RF_2}$$

where C_{rm} denotes accumulated repairs and maintenance costs (CAD$). RF_1 and RF_2 are repairs and maintenance factors, respectively, obtained from ASABE standards. Values for RF_1 and RF_2 were obtained from ASABE (2015) for each equipment considered in the study. P is the harvester purchase price and h is the accumulated use of harvester in hours.

The annual costs of ownership of a small box handling system and semi-automatic bin handling system were based on important assumptions. The harvester with a semi-automatic bin handling system was assumed to be new. The annual ownership cost of small box handling technology was CAD$13,807 and assumed to be financed with a loan at 3.80% interest rate, compared with CAD$19,042 for the semi-automatic bin handling technology (Table 2). In this study, mechanical harvesters were assumed to be operated for 300 hours in a berry production year and used to estimate the annual harvest cost. The wild blueberry price (CAD$0.55 kg^{-1}) was based on the 2017 farm gate price received by producers.

Stochastic Partial Budget Analysis

The stochastic partial budget (SPB) analysis required data on the mean and standard errors (SE) of the parameters. The mean values were from the deterministic part ("average") of the analysis. For example, for the hourly labor cost, an SE of CAD$2 was assumed. For the farm gate price received by producers, an SE of CAD$0.07 was assumed, which is the SE associated with historical prices (from 1981 to 2016). In addition, 1% SE for interest rates was assumed. For all other parameters, including additional yield per hectare per year (kg per year) and harvester use, the difference between the pessimistic and the optimistic values served as a proxy for the SE. A complete list of the means, the SEs, and the alpha and beta values associated with the key parameters that were allowed to vary in the SPB are summarized in Table 4a (for 2017 data) and Table 4b (2018 data).

Using a Monte Carlo simulation, 1,000 random samples were repeatedly drawn from the probability distributions associated with the budget items. These budget items include the additional costs for the bin handling system, reduced revenue for a harvest using the small box system, the reduced costs associated with using the small box handling system, and the additional revenue associated with a harvest using the bin handling system, and the results evaluated. In each case, the summary statistics are reported. The overall net change in profit (CAD$ ha^{-1}) from the 1,000 simulated cases are also reported together with the 95% confidence intervals (estimated using the percentile method), along with a cumulative distribution function. Furthermore, the total additional cost and reduced revenue and the total additional revenue and reduced costs associated with each run of the trial are summarized using a scatter plot.

Table 4a. Parameters Used in Stochastic Partial Budget Analysis for 2017 Data.

Parameter	Mean	Standard Error	Distribution	Alpha	Beta
Additional yield per hectare (kg per year)	1303.40	417.00	Log-Normal	7.17	0.38
Farm gate price received by producers (kg)	0.55	0.07	Log-Normal	0.60	0.13
Labor cost (operator)	15.00	2.00	Log-Normal	2.71	0.14
Rental rate of loader tractor	12.00	2.00	Log-Normal	2.48	0.17
Small box handling system					
General Information					
Purchase price	0.00	0.00	Log-Normal	0.00	0.00
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	300.00	40.00	Log-Normal	5.70	0.14
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Interest rate	0.04	0.01	Beta	17.41	390.36
Fuel (diesel cost)	1.20	0.50	Log-Normal	0.18	0.59
Harvest rate	7.22	0.17	Log-Normal	1.98	0.02
Annual variable costs (CAD$)					
Fuel cost	1440.00	2.00	Log-Normal	7.27	0.00
Lubrication cost	216.00	2.00	Log-Normal	5.38	0.01
Repairs and maintenance	3486.00	2.00	Log-Normal	8.16	0.00
Operator cost	4500.00	150.00	Log-Normal	8.41	0.03
Labor cost	3600.00	150.00	Log-Normal	8.19	0.04
Hourly variable costs (CAD$)					
Fuel cost	4.80	0.01	Log-Normal	1.57	0.00
Lubrication cost	0.72	0.01	Log-Normal	0.33	0.01
Repairs and maintenance	11.62	0.01	Log-Normal	2.45	0.00
Labor cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	12.00	0.50	Log-Normal	2.48	0.04
Interest on operating expenses	1.88	0.01	Log-Normal	0.63	0.00

Table 4a (continued). Parameters Used in Stochastic Partial Budget Analysis for 2017 Data.

Parameter	Mean	Standard Error	Distribution	Alpha	Beta
Bin handling system					
General Information					
Purchase price	30000.00	5.00	Log-Normal	10.31	0.00
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	320.00	5.00	Log-Normal	5.77	0.02
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Salvage value	7500.00	1.00	Log-Normal	8.92	0.00
Interest rate	0.04	0.01	Beta	35.58	797.64
Fuel (diesel cost)	1.20	0.01	Log-Normal	0.18	0.01
Harvest rate	5.90	0.08	Log-Normal	1.77	0.01
Annual fixed costs (CAD$)					
Depreciation	2409.38	29.00	Log-Normal	7.79	0.01
Interest on investment	712.50	29.00	Log-Normal	6.57	0.04
Housing and storage	450.00	1.01	Log-Normal	6.11	0.00
Hourly fixed costs (CAD$)					
Depreciation	8.03	1.00	Log-Normal	2.08	0.13
Interest cost on investment	2.38	1.00	Log-Normal	0.86	0.60
Taxes, Insurance and Housing	1.50	0.50	Log-Normal	0.41	0.40
Annual variable costs (CAD$)					
Fuel cost	1560.00	1.00	Log-Normal	7.35	0.00
Lubrication cost	234.00	1.00	Log-Normal	5.46	0.00
Repairs and maintenance	4543.00	1.00	Log-Normal	8.42	0.00
Labor cost (operator)	4500.00	1.00	Log-Normal	8.41	0.00
Annual rental rate of loader tractor	4000.00	1.00	Log-Normal	8.29	0.00
Interest on operating expenses	633.54	1.00	Log-Normal	6.45	0.00
Hourly variable costs (CAD$)					
Fuel cost	5.20	0.50	Log-Normal	1.65	0.10
Lubrication cost	0.78	0.01	Log-Normal	-0.25	0.01
Repairs and maintenance	15.14	0.50	Log-Normal	2.72	0.03
Labor cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	13.33	0.50	Log-Normal	2.59	0.04
Interest on operating expenses	2.11	0.01	Log-Normal	0.75	0.00

Table 4b. Parameters Used in Stochastic Partial Budget for 2018 Data.

Parameter	Mean	Standard Error	Distribution	Alpha	Beta
Additional yield per hectare (kg per year)	358.00	61.40	Log-Normal	5.88	0.18
Farm gate price received by producers (kg)	0.55	0.07	Log-Normal	0.60	0.13
Labor cost (operator)	15.00	2.00	Log-Normal	2.71	0.14
Rental rate of loader tractor	12.00	2.00	Log-Normal	2.48	0.17
Small box handling system					
General Information					
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	300.00	40.00	Log-Normal	5.70	0.14
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Interest rate	0.04	0.01	Beta	17.41	390.36
Fuel (diesel cost)	1.20	0.50	Log-Normal	0.18	0.59
Harvest rate	6.89	0.28	Log-Normal	1.93	0.04
Annual variable costs (CAD$)					
Fuel cost	1440.00	2.00	Log-Normal	7.27	0.00
Lubrication cost	216.00	2.00	Log-Normal	5.38	0.01
Repairs and maintenance	3486.00	2.00	Log-Normal	8.16	0.00
Operator cost	4500.00	150.00	Log-Normal	8.41	0.03
Labor cost	3600.00	150.00	Log-Normal	8.19	0.04
Hourly variable costs (CAD$)					
Fuel cost	4.80	0.50	Log-Normal	1.57	0.11
Lubrication cost	0.72	0.01	Log-Normal	0.33	0.01
Repairs and maintenance	11.62	0.01	Log-Normal	2.45	0.00
Labor cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	12.00	0.50	Log-Normal	2.48	0.04
Interest on operating expenses	1.88	0.01	Log-Normal	0.63	0.00

Table 4b (continued). Parameters Used in Stochastic Partial Budget and for 2018 Data.

Parameter	Mean	Standard Error	Distribution	Alpha	Beta
Bin handling system					
General Information					
Purchase price	30000.00	5.00	Log-Normal	10.31	0.00
Expected life of a harvester	10.00	1.00	Log-Normal	2.30	0.10
Harvester use	320.00	5.00	Log-Normal	5.77	0.02
Fuel consumption rate	4.00	1.00	Log-Normal	1.39	0.27
Salvage value	7500.00	1.00	Log-Normal	8.92	0.00
Interest rate	0.04	0.01	Beta	35.58	797.64
Fuel (diesel cost)	1.20	0.01	Log-Normal	0.18	0.01
Harvest rate	5.33	0.06	Log-Normal	1.67	0.01
Annual fixed costs (CAD$)					
Depreciation	2409.38	29.00	Log-Normal	7.79	0.01
Interest on investment	712.50	29.00	Log-Normal	6.57	0.04
Housing and storage	450.00	1.01	Log-Normal	6.11	0.00
Hourly fixed costs (CAD$)					
Depreciation	8.03	1.00	Log-Normal	2.08	0.13
Interest cost on investment	2.38	1.00	Log-Normal	0.86	0.60
Taxes, Insurance and Housing	1.50	0.50	Log-Normal	0.41	0.40
Annual variable costs (CAD$)					
Fuel cost	1560.00	1.00	Log-Normal	7.35	0.00
Lubrication cost	234.00	1.00	Log-Normal	5.46	0.00
Repairs and maintenance	4543.00	1.00	Log-Normal	8.42	0.00
Labor cost (operator)	4500.00	1.00	Log-Normal	8.41	0.00
Annual rental rate of loader tractor	4000.00	1.00	Log-Normal	8.29	0.00
Interest on operating expenses	633.54	1.00	Log-Normal	6.45	0.00
Hourly variable costs (CAD$)					
Fuel cost	5.20	0.01	Log-Normal	1.65	0.00
Lubrication cost	0.78	0.01	Log-Normal	0.25	0.01
Repairs and maintenance	15.14	0.01	Log-Normal	2.72	0.00
Labor cost (operator)	15.00	0.50	Log-Normal	2.71	0.03
Rental rate of loader tractor	13.33	0.01	Log-Normal	2.59	0.00
Interest on operating expenses	2.11	0.01	Log-Normal	0.75	0.00

Results and Discussion

Economic Viability of Bin Handling Technology

The net change in profit using point estimates of variables in the deterministic partial budgeting model are presented separately for 2017 data (Table 5) and 2018 data (Table 6). Net change in profit was CAD$675 ha^{-1} (or CAD$0.52 kg^{-1}) in 2017 and implies that switching from the small box handling system to the semi-automatic bin handling technology was financially viable (Table 5). The semi-automatic bin handling system has capacity to harvest the same area in less time (354 minutes per ha for the bin handling compared with 433 minutes per ha for the small box handling system), and allows for generating extra revenue from harvesting the extra area. The breakeven yield associated with switching from the small box handling system to semi-automatic bin handling technology was 77 kg ha^{-1}. Additional revenue from the additional area harvested using the semi-automatic bin handling technology was CAD$717, while reduced costs (RC_S) associated with eliminating use of the small box harvesting system was CAD$332. Total additional costs (AC_b) of CAD$374 include variable costs (fuel, lubrication, repairs and maintenance cost) and fixed costs (depreciation, interest rate, insurance and housing) of semi-automatic bin handling technology. The combined reduced revenue and total additional cost was CAD$374 (Table 5).

Table 5. Net Change in Profit (CAD$), 2017 Data.

(a) Additional Costs (Bin Handling System)	Amount (CAD$ ha^{-1})			(c) Reduced Costs (Small Box Handling System)	Amount (CAD$ ha^{-1})		
	Yield Scenarios				Yield Scenarios		
	Pessimistic	Average	Optimistic		Pessimistic	Average	Optimistic
Fixed costs				Fixed costs			
Depreciation	46.73	47.38	48.02	Depreciation	---	---	---
Interest on investment	13.85	14.04	14.23	Interest on investment	---	---	---
Insurance and Storage	8.73	8.85	8.97	Insurance and Storage	---	---	---
Variable costs				Variable costs			
Fuel cost	30.26	30.68	31.10	Fuel cost	33.84	34.66	35.47
Lubrication cost	4.54	4.60	4.66	Lubrication cost	5.08	5.20	5.32
Repairs and maintenance	88.11	89.33	90.54	Repairs and maintenance	81.92	83.90	85.87
Labor cost (operator)	87.30	88.50	89.70	Labor cost (operator)	105.75	108.30	110.85
Rental rate of loader tractor	77.58	78.65	79.71	Labor cost (support worker)	84.60	86.64	88.68
Interest on operating expenses	12.29	12.46	12.63	Interest on operating expenses	13.29	13.61	13.93
Total for (a)	369.40	374.48	379.56	Total for (c)	324.47	332.30	340.12
(b) Reduced revenue				(d) Additional revenue			
Revenue for harvest using small box system	0.00	0.00	0.00	Revenue for harvest using bin handling system	602.03	716.87	831.67
Total for (b)	0.00	0.00	0.00	Total for (d)	602.03	716.87	831.67
(e) Total additional cost and reduced revenue	369.40	374.48	379.56	(f) Total additional revenue and reduced costs	926.50	1049.17	1171.79
				Net change in profit (CAD$ ha^{-1}) (f-e)	557.10	674.69	792.23
				Net change in profit (CAD$ kg^{-1})	0.51	0.52	0.52

Table 6. Net Change in Profit (CAD$), 2018 Data.

(a) Additional Costs (Bin Handling System)	Amount (CAD$ ha^{-1})			(c) Reduced Costs (Small Box Handling System)	Amount (CAD$ ha^{-1})		
	Yield Scenarios				Yield Scenarios		
	Pessimistic	Average	Optimistic		Pessimistic	Average	Optimistic
Fixed costs				Fixed costs			
Depreciation	42.56	42.80	43.04	Depreciation	---	---	---
Interest cost on investment	12.61	12.69	12.76	Interest cost on investment	---	---	---
Insurance and Storage	7.95	8.00	8.04	Insurance and Storage	---	---	---
Variable costs				Variable costs			
Fuel cost	27.56	27.72	27.87	Fuel cost	32.40	33.07	33.74
Lubrication cost	4.13	4.16	4.18	Lubrication cost	4.86	4.96	5.06
Repairs and maintenance	80.24	80.70	81.15	Repairs and maintenance	78.44	80.06	81.69
Labor cost (operator)	79.50	79.95	80.40	Labor cost (operator)	101.25	103.35	105.45
Rental rate of loader tractor	70.65	71.05	71.45	Labor cost (support worker)	81.00	82.68	84.36
Interest on operating expenses	11.19	11.25	11.32	Interest on operating expenses	12.72	12.99	13.25
Total for (c)	383.41	385.58	387.75	Total for (c)	310.67	317.11	323.55
(d) Reduced revenue				(d) Additional revenue			
Revenue for harvest using small box system	0.00	0.00	0.00	Revenue for harvest using bin handling system	180.07	196.90	213.88
Total for (d)	0.00	0.00	0.00	Total for (d)	180.07	196.90	213.88
(e) Total additional cost and reduced revenue	336.40	338.30	340.21	(f) Total additional revenue and reduced costs	490.74	514.01	537.44
				Net change in profit (CAD$ ha^{-1}) (f-e)	154.34	175.71	197.23
				Net change in profit (CAD$ kg^{-1})	0.47	0.49	0.51

Net change in profit for the analysis using 2018 trial data was CAD$176 ha^{-1} (or CAD$0.49 kg^{-1}) and indicate that upgrading from small box handling to the semi-automatic bin handling system was financially viable. The more efficient semi-automatic bin handling system results in less time to cover one ha compared with a small box handling system. For example, on average, the semi-automatic bin handling system took 319.8 minutes to complete one ha compared with 413.4 minutes for the small box system. The breakeven yield associated with upgrading from small box to the semi-automatic bin handling system was 38 kg ha^{-1}. Additional revenue generated from the additional area harvested using the semi-automated bin handling technology was CAD$197, while reduced cost associated with eliminating the use of the small box system was CAD$317. The total additional cost using the semi-automatic bin handling system was CAD$338. The combined total additional cost and reduced revenue was also CAD$317.

The results also indicate that, under typical (or average) field conditions, net change in profit decreased by 75% from CAD$677 ha^{-1} in 2017 to CAD$176 ha^{-1} in 2018. In 2018, wild blueberry production was adversely affected by frost damage, resulting in a 70-80% decrease in wild blueberry yield across Nova Scotia. The variability in yield and increased harvest efficiency affected revenues to farmers.

In summary, upgrading from the small box handling to semi-automatic bin handling technology was financially viable, and consistent for both years. However, in general, production levels vary depending on input use, harvesting method, and weather, as well as economic and market factors (such as interest rates and labor wages). Sensitivity analysis was conducted to access the uncertainty associated with selected variables.

Sensitivity Analysis Results

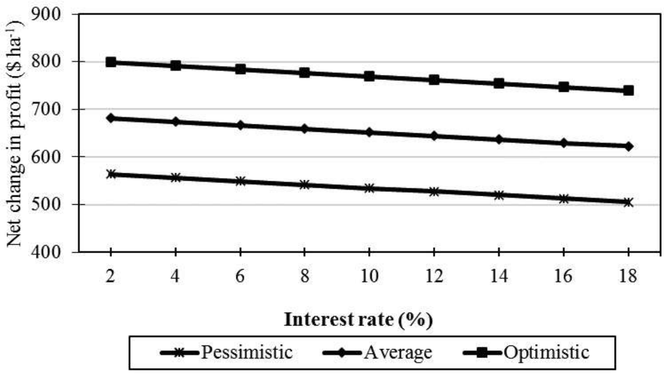
Wild blueberry production: Net changes in profits associated with the three yield scenarios are summarized in Tables 5 and 6. As expected, net change in profit was highest under the optimistic yield scenario and lowest for the pessimistic yield scenario, consistent for both years. For 2017, switching from the small box system to semi-automatic bin handling technology was financially viable for all three yield scenarios. On average, the net change in profit was highest under the optimistic yield condition (CAD$792 ha^{-1}) and lowest under pessimistic yield conditions (CAD$557.10 ha^{-1}).

Net change in profits increased as wild blueberry production increased, as expected. For example, net change in profits increased from CAD$674 to CAD$792 ha^{-1} when wild blueberry yield increased from typical yield conditions (1303 kg ha^{-1}) to optimistic yield conditions (1512 kg ha^{-1}). Similarly, net change in profits decreased by about 30% from CAD$792 to CAD$557 ha^{-1} when average berry yields decreased under a typical yield scenario (1095 kg ha^{-1}) compared with pessimistic yield conditions (1303 kg ha^{-1}). The findings imply that increasing output levels substantially increased net changes in profits for high production fields (optimistic scenario) compared with low production fields (pessimistic scenario) and typical field conditions.

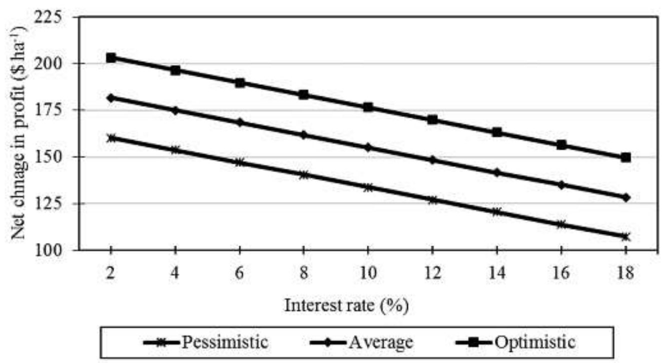
The net change in profits associated with switching from the small box to semi-automatic bin handling technology was lower in 2018 than 2017, due mainly to frost damage in 2018. Net changes in profits increased from CAD$177 to CAD$197 ha^{-1} (representing a 12% increase) when berry production increased under typical to optimistic field conditions. Switching from small box handling to a semi-automatic bin handling system was also financially viable when average berry yields decreased from typical to pessimistic yield conditions; the net change in profit decreased by 12% from CAD$176 to CAD$154 ha^{-1}.

On average, the net change in profit was higher for 2017 than 2018 due largely to frost damage. For example, the net change in profit was CAD$792.23 in 2017 and CAD$197.23 ha^{-1} in 2018 in optimistic field conditions, representing a 75% decline. On average, the net change in profit was also low in 2018 for typical yield conditions (a 74% decline) and pessimistic field conditions (72% lower) compared with 2017.

Interest rate: As expected, net change in profit decreased as the cost of borrowing increased (Figure 2). What is more insightful is that the rate of decline in relative profitability varied depending on the yield scenario and year considered. For example, under the optimistic yield scenario in 2017, when interest rates doubled from 4% to 8%, the net change in profit decreased by less than a proportionate rate of 1.9% from CAD$792 ha^{-1} to CAD$777 ha^{-1}. By comparison, under pessimistic yield conditions, a 100% increase in interest rates from 4% to 8%, resulted in a 2.5% reduction in the net change in profit from CAD$556 to CAD$542. This implies that the effect of an increase in the interest rate on a reduction in the net change in profit is higher for low production fields (pessimistic scenario) than for high production fields (optimistic scenario).



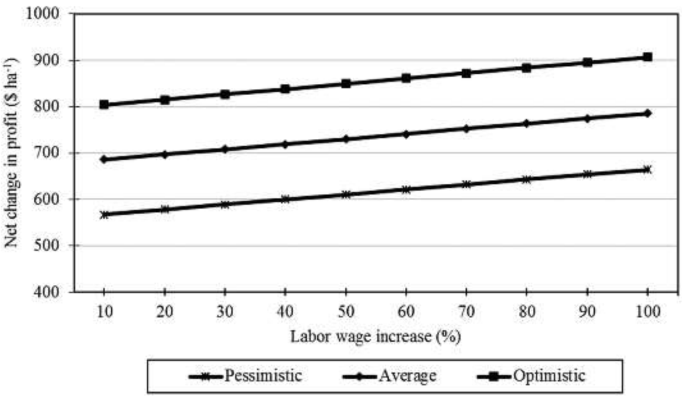
(a) Effect of Changes in Interest Rate on Net Change in Profit (CAD$ ha^{-1}), 2017 Data.



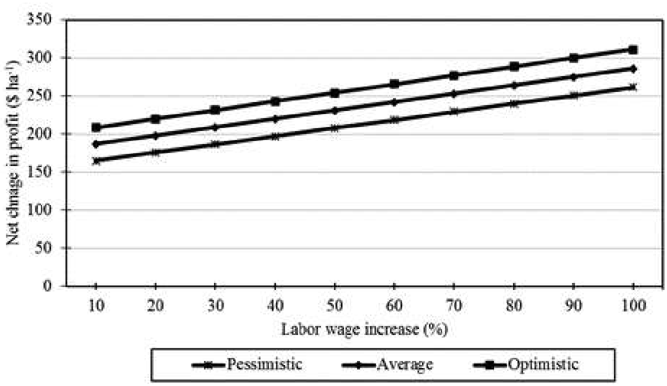
(b) Effect of Changes in Interest Rate on Net Change in Profit (CAD$ ha^{-1}), 2018 Data.

Figure 2. Sensitivity Analysis of the Effects of Changes in Interest Rate on Net Change in Profit.

The trend of the effect of changes in the interest rate on net changes in profit results for 2018 were generally similar to the findings for 2017. However, the actual differences were influenced by the generally lower berry yields in 2018. The rate of decline in the net change in profits was higher for 2018 due to the frost damage compared with 2017. For example, when the interest rate increased by 50%, the net change in profit decreased by 1.01% (from CAD$792 to CAD$784 ha^{-1}) under the optimistic yield scenario during 2017 (Figure 2a) compared with 3.65% decline (from CAD$197 to CAD$190 ha^{-1}) in 2018 (Figure 2b). Similarly, under the pessimistic yield scenario, when the interest rate increased by 50%, the net change in profit decreased by 1.25% in 2017 compared with a 4.54% decline in 2018.



(a) Effect of Changes in Labor Wage Rate on Net Change in Profit (CAD$ ha^{-1}) for 2017 Data.



(b) Effect of Changes in Labor Wage Rate on Net Change in Profit (CAD$ ha^{-1}) for 2018 Data.

Figure 3. Sensitivity Analysis of the Effects of Wage Rate on Net Change in Profit.

Labor wage: An increase in wage rates disproportionately increased the cost of harvesting for the small box handling system relative to the semi-automatic bin handling system because the former required an extra farm worker to load/unload the berry boxes. For example, when labor wages increased by 50% (for both tractor operator and support worker), the net change in profit increased by 7.19% under the optimistic yield scenario compared with a 9.69% increase under the pessimistic yield scenario (Figure 3a). The nominal effect of changes in the labor wage rate was higher for 2018 compared to 2017 (Figure 3). For example, when labor wages increased by 20% in 2017, the net change in profit associated with the switch increased by 4.41% from CAD$792 to CAD$827 ha^{-1} (Figure 3a), compared with 11.67% (from CAD$197 to CAD$220 ha^{-1}) in 2018 under the optimistic yield scenario (Figure 3b).

Stochastic Partial Budget Results

Results of the stochastic partial budget analysis for 2017 and 2018 are reported in Table 7. The results indicate that the average net change in profit in 2017 for the 1,000 simulated cases was CAD$729.96 (95% CI: 314.78 to 1458.54), with a minimum of CAD$235.77 and a maximum of CAD$2,285.25 compared with CAD$674.67 reported in the deterministic analysis. In addition, in all 1,000 cases, the total additional revenue and reduced costs were greater than the total additional costs and reduced revenue (see Figure 4a for the joint distribution of both variables). Figure 4b is the probability distribution function for the net change in profits (based on 2017 data). From Figure 4b (which was based on the 1,000 simulated cases), if a net change in profit of CAD$236 is selected, for example, the percentage of the simulated cases with a net change in profit less than or equal to that value is 4.6% (or 95.4% of the 1,000 simulated cases had more than CAD$236 in the net change in profit). If CAD$800 were to be selected, the probability becomes 60%, alternatively 40% of the simulated cases made more than CAD$800 in profit).

Similarly, for 2018, Table 7 shows a summary of the results. Table 7 results indicate that the average net change in profit in 2018 for the 1,000 simulated cases was CAD$180.11 (95% CI: 117.62 to 261.32), with a minimum of CAD$80.01 and a maximum of CAD$327.46, compared with CAD$175.69 reported in the deterministic analysis. In addition, in all 1,000 cases, the total additional revenue and reduced costs are greater than the total additional costs and reduced revenue (see Figure 5a). Figure 5b shows the probability distribution function for the net change in profit based on 2018 data. The results suggest that if a net change in profit of CAD$96 were to be selected, for example, 1.1% of the simulated cases have a net change in profit less than or equal to that value. Put differently, 98.9% of the 1,000 simulated cases had more than CAD$96 in the net change in profit. On the other hand, if CAD$211 were selected, the probability becomes 80% (or 20% of the simulated cases make more than CAD$211 in a net change in profit). In summary, the results indicate that there is no change in the main conclusions when the results from the deterministic model discussed earlier are compared with the results of the stochastic partial budgeting model.

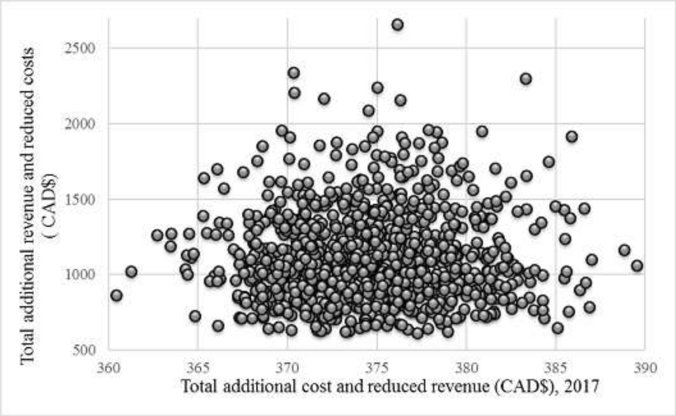


Figure 4a. Joint Distribution of Additional Revenue and Reduced Costs, and Total Additional Cost and Reduced Revenue for 2017 Data Based on the Simulated Sample.

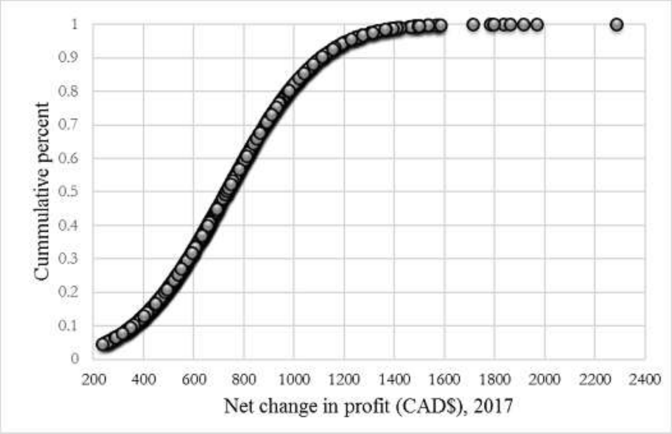


Figure 4b. Cumulative Distribution Function for Net Change in Profit, 2017 Data.

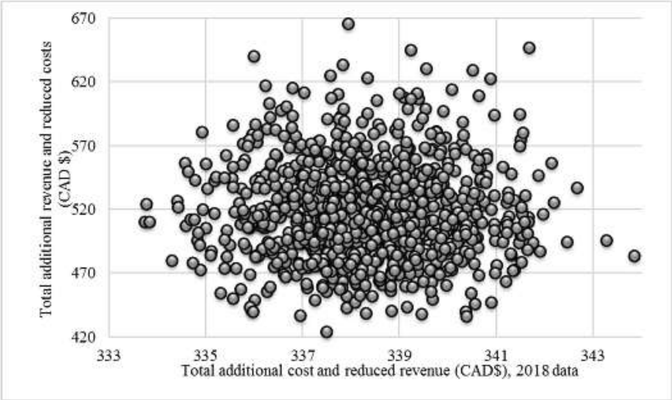


Figure 5a. Joint Distribution of Additional Revenue and Reduced Costs, and Total Additional Cost and Reduced Revenue for 2018 Data Based on the Simulated Sample.

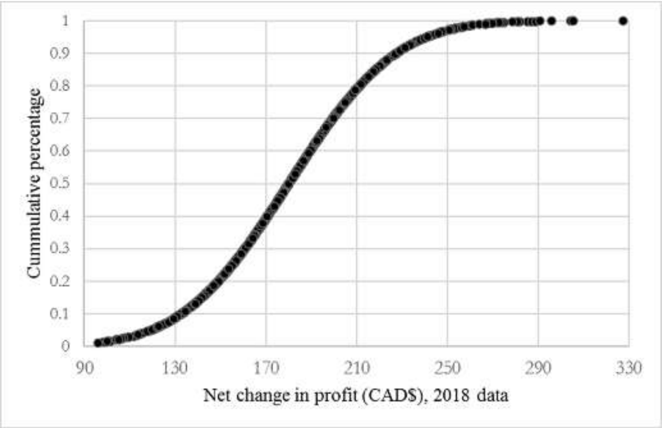


Figure 5b. Cumulative Distribution Function for Net Change in Profit, 2018 Data.

Table 7. Results of Stochastic Partial Budget Analysis.

Budget Item	Deterministic Results	Stochastic Results				
	Mean	Mean	2.5th Percentile	97.5th Percentile	Minimum	Maximum
2017						
a) Additional costs (Bin handling system)	374.50	374.50	366.42	383.57	359.75	389.51
b) Revenue for harvest using small box system	0.00	0.00	0.00	0.00	0.00	0.00
c) Reduced costs (Small box handling system)	332.30	332.37	316.88	348.56	307.88	359.06
d) Additional revenue for harvesting using bin handling system	716.87	772.09	355.55	1495.92	290.80	2336.29
e) Total additional cost and reduced revenue (a+b)	374.50	374.50	366.42	1598.76	359.75	389.51
f) (Total additional revenue and reduced costs (c+d)	1049.17	1104.46	692.90	1832.50	613.04	2661.38
Net change in profit (f-e), (CAD$ per ha)	674.67	729.96	314.78	1458.54	235.77	2285.25
2018						
a) Additional costs (Bin handling system)	338.32	338.31	335.18	341.48	333.74	343.85
b) Revenue for harvest using small box system	0.00	0.00	0.00	0.00	0.00	0.00
c) Reduced costs (Small box handling system)	317.11	317.81	305.29	330.75	300.09	340.65
d) Additional revenue for harvesting using bin handling system	196.90	200.62	137.77	282.79	106.87	351.80
e) Total additional cost and reduced revenue (a+b)	338.32	338.31	335.18	341.48	333.74	343.85
f) Total additional revenue and reduced costs (c+d)	514.01	518.43	455.32	599.20	419.60	665.40
Net change in profit (f-e), (CAD$ per ha)	175.69	180.11	117.62	261.32	80.01	327.46

Implications and Conclusions

The economic performance of wild blueberry mechanical harvesters with a small box handling system and a semi-automated bin handling system were evaluated and compared. Production and harvest data for the analysis were obtained from on-farm studies conducted in 2017 and 2018, while economic data were obtained from several sources, including Statistic Canada and Nova Scotia Department of Agriculture statistical reports. Deterministic partial budget analysis was based on average values of key parameters and their net change in profit compared. In addition, parametric and stochastic partial budgeting methods were conducted to account for uncertainty associated with important parameters that influence economic performance. Monte Carlo simulations were repeatedly drawn from probability distributions associated with the budget computations.

The net change in profit was CAD$674 ha^{-1} using 2017 data and CAD$175.71 ha^{-1} using 2018 data and implies that switching from the traditional small box handling system to semi-automated bin handling technology is financially viable. The economic feasibility improved further with an increase in wild blueberry yields, and the labor wage rate. An increase in labor costs disproportionately negatively affected harvest costs for the small box handling system relative to the semi-automatic bin handling technology. As expected, higher interest costs resulted in lower net changes in profit for the semi-automatic bin handling technology. General conclusions from the stochastic partial budget analysis were consistent with results from the deterministic partial budget model.

The findings provide insights for wild blueberry farmers contemplating choices over cost-effective and labor-saving harvesting technology. The results provide evidence that yield levels and prices (of berries and labor) are important factors which influence financial viability of switching from the small box to the semi-automatic bin handling system. Prices (of berries and labor) and interest rates on harvester investments are beyond the control of producers. Thus, to increase more widespread adoption of the semi-automatic bin handling system, farmers should emphasize farm management practices with potential to increase yields. Wild blueberry farmers can mitigate labor uncertainty and risks by adopting the more labor-saving semi-automatic bin handling system.

This study forms part of a first effort under a larger research project to investigate the economics of adopting mechanical harvesters for wild blueberries. Further research, including evaluating whole farm net returns from wild blueberry production using the two harvest handling systems, will complement the findings from the present study. Farm profitability analysis accounting for long-term effects of the machinery investment will provide additional insights on the benefits to farmers. The limited farmer adoption of the more efficient semi-automatic bin handling system may be due to various factors. First, financial barriers such as the trade-off between labor savings and the initial (CAD$30,000) investment in the semi-automatic bin handling technology limit adoption of the system. In addition, given the relative newness of the semi-automatic bin handling system, there is uncertainty about operating costs and other costs associated with adapting work routines and farm management practices to the new technology.

Important limitations of the study need to be considered in interpreting the findings and broader policy and farm management implications. First, as noted earlier, this study focused on relative (as opposed to actual) profitability of the two harvest handling systems. Farm management changes that result in significant and long-term effects, although important, are beyond the scope of this study. In addition, the analysis assumed that the switch in harvest handling systems involved outright purchase of the semi-automatic bin handling component. Although this assumption is consistent with the predominant practice among existing commercial growers in the study area, others (especially small-scale operators) may use custom harvesting services, thereby avoiding risks associated with ownership. Furthermore, location-specific management and financial data used in the analysis limit extrapolation of the findings to all wild blueberry growing regions around the globe.

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Sample Selection Bias in Hedonic Pricing Models of Thoroughbred Broodmares

Matthew Muntifering and John N. Ng'ombe

An issue with ordinary least squares estimations in hedonic pricing model literature is that they do not account for sample selection bias. In broodmare auctions, the purchase decision and whether a price is realized or zero is endogenous. This paper contributes to the hedonic broodmare price analysis literature by implementing the Heckman sample selection regression to estimate a hedonic pricing model using data from the January 2020 Keenland Sale. Many published papers do not accommodate this selection process and may have biased coefficients. This paper further contributes methodologically to the thoroughbred broodmare literature by being the first to deliver a useful empirical application of a Bayesian Heckman selection model. The broodmare prospect, age, square of age, domestic status, and the day of the session are significant for broodmare pricing. These may be implemented within a profit-maximizing purchasing and breeding strategy.

***Key words**:* Bayesian Methods, Hedonic Models, Sample Selection Bias, Thoroughbred Broodmares

American Pharoah (2015) and Justify (2018) claimed the Triple Crown of Thoroughbred Racing after a draught since Affirmed (1978) took the title. Thirteen racers have won the prestigious award in history, with some earning more than $10 million in today's dollars.

The American Horse Council Foundation (AHCF) estimates 7.2 million horses are in the United States consuming 32 million acres of owned land and another 49 million acres of leased land. Further, AHCF estimates that the direct effect of the horse industry on the domestic economy is $50 billion. The direct employment total reaches near one million jobs earning roughly $38 million in various accounts. The ripple effects from this industry are estimated to be $122 billion and 1.7 million jobs. The high stakes associated with thoroughbred horseracing makes understanding the determinants of prices economically important for both buyers and sellers. According to Chizum and Wimmer (1997) and Wimmer and Chizum (2006), asymmetric information and adverse selection prevail in Thoroughbred markets. These issues may make the empirical findings of this paper useful for increasing market efficiency.

Vickner (2018) points out that, among all the hedonic price models applied to Thoroughbreds, majority study yearlings. Only Neibergs (2001), Maynard and Stoeppel

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(2007), and Dority et al. (2016) focus on broodmares. Chezum and Wimmer (1997), Vickner and Koch (2001), Robbins and Kennedy (2001), Wimmer and Chezum (2006), Parson and Smith (2008), Plant and Stowe (2013), and Marion and Stowe (2016) all focus predominately on yearlings. Stowe and Ajello (2010) perform ordinary least squares (OLS) in their hedonic pricing model of stud fee determinants, while Stowe (2013) extends this model to include fixed effects. Taylor et al. (2006) uses the Heckman model within the horse literature on data about Quarter horses. This paper contributes to the relatively scarce literature on broodmare pricing by applying a Bayesian Heckman selection model to account for sample selection bias. Failure to consider the endogenous selection process biases parameter estimates and would misinform prospective buyers, sellers, bloodline agents, policymakers, and fellow scientists.

Vickner (2018) suggests that a Bayesian Heckman selection model would be an interesting future contribution to Thoroughbred literature. Heckman et al. (2013) provide the details for extending the classical selection model to a Bayesian framework. Ng'ombe and Boyer (2019) point out that a Bayesian inference is desirable as it is exact for any sample size.

Our results suggest there is significant sample selection in broodmare pricing which promotes using sample selection techniques when modeling hedonic prices of Thoroughbred broodmares. Broodmare prosect, age, square of age, domestic status, and the day of the session were found to have meaningful effects on the average broodmare selling price.

The rest of the paper is organized as follows. The next section presents methods employed, which are then followed by the data section. Description of data is followed by results and discussion. The last section concludes the paper.

Conceptual Model

A Heckman sample selection framework is applied to a hedonic pricing model for broodmares at the January 2020 Keenland Sale. The Heckman selection model is a two-step procedure. The initial model is

$$y_i = X_i\beta + \varepsilon_i \quad (1)$$

where y_i is the dependent variable, X_i denotes explanatory variables, β denotes parameters to be estimated, and ε_i denotes the error term assumed to follow a Gaussian distribution with mean zero and constant variance. The second equation is shown as

(2) $$Z_i\gamma + \epsilon_i > 0$$

where Z_i denotes independent variables that explain selection and may overlap with those that are in X_i, γ denotes parameters to be estimated in the selection equation, and ϵ_i is the error term that is assumed to follow the standard Gaussian distribution. Because the two models are related through the error terms, the correlation that exists between them is shown as

(3) $$corr(\varepsilon_i, \epsilon_i) = \rho$$

It is worth pointing out that equations (1) through (3) can be estimated so long samples are larger than zero using various models that are Tobit-type. Among them, we select the Heckman selection model out of preference and because it provides consistent, asymptotically efficient estimates of the parameters (Wooldridge, 2002, Green, 2003; Xu et al., 2017). Using this information, the likelihood function of the Heckman selection model is

(4) $$L = \prod_c \times [1 - \Phi(Z_i\gamma)] \cdot \prod_{uc} \Phi\left(\frac{Z_i\gamma + \rho(y_i - X_i\beta)/\sigma}{\sqrt{1-\rho^2}}\right) \cdot \frac{\phi((y_i - X_i\beta)/\sigma}{\sigma}$$

where $\prod_c, \prod_c$ are, respectively, products over censored and uncensored samples; and ϕ and Φ are the standard Gaussian and cumulative distributions, respectively. The frequentist approach would involve using maximum likelihood estimations that would require maximizing the log-likelihood form of equation (4) to obtain Heckman selection model parameter estimates. More details of doing so can be found in Heckman (1979), Wooldridge (2002), and Greene (2003).

This paper employs a Bayesian approach to estimate the model. The Bayesian approach allows us to make robust and informative statements about our findings by using credible intervals—equivalent to confidence intervals in frequentist-based econometrics (Gelman et al., 2013; Ng'ombe et al., 2020). A Bayesian credible interval is interpreted as the probability that a given value falls in that range given the model and data, notwithstanding the scarcity of data (McElreath, 2020). This is more intuitive especially that statistical inference is valid regardless of the sample size (Gelman et al., 2013; Ng'ombe and Boyer, 2019; McElreath, 2020). Motivated by these observations and the small nature of our dataset, this paper employs a Bayesian Heckman selection model.

The parameters to be estimated can be vectorized as $\kappa = [\beta, \gamma, \rho, \tau]'$, where $\beta, \gamma,$ and ρ are as previously defined and τ precision (i.e., $1/\sigma^2$). Next, we need the likelihood function for the model (equation (4)) $p(y|\kappa)$ and the prior distribution of the parameters

$p(\kappa)$ to obtain the posterior distribution of the parameters by Bayes' Theorem. The posterior distribution can be specified as

$$p(\kappa|y) \propto p(y|\kappa) \cdot p(\kappa) \tag{5}$$

Estimation of equation (5) is not trivial. Recent computer revolution (Ng'ombe and Brorsen, 2020) has resulted in the powerful tool of the Markov chain Monte Carlo (MCMC) that makes it easier to implement. More details about MCMC can be found in Gelman et al. (2013) and Gill (2013).

Empirical Model

Empirically, we model broodmare selling prices by rewriting equation (1) as

$$y = \sum_{b=1}^{5} \beta_b X_b + X_g + \sum_{m=1}^{5} \beta_m X_m + u_1 \tag{6}$$

where y is the natural log of the broodmare selling price; X_b represents breeding characteristics; and X_g, and X_m are genetic, and market characteristics, respectively. The error term u_1 is

$$u_1 \sim N(0, \sigma) \tag{7}$$

The covariates in this model are motivated by Maynard and Stoeppel (2007) and Dority et al. (2016). They argue that breeding, genetic, and market characteristics are relevant in explaining Thoroughbred broodmare auction prices. The breeding characteristics in the model are a dummy = 1 if a broodmare is a prospect, age is in years, color dummy =1 if the broodmare is black. Other variables include sire earning and sire stud fee. Stowe (2013) finds that sire stud fee is highly explained by the progeny sale price.

Poerwanto and Stowe (2010) find a positive relationship between the number of foals produced by a sire and the sire's yearlings' average selling prices. Therefore, sire representation is included into the model as a genetic characteristic. Market characteristics include a dummy = 1 if the sire is domestic and dummies for the days of the auction. In the case of broodmare auctions, each individual broodmare is not sold, and the price is only observed if the selection equation is satisfied, that is

$$\gamma_s z_s + u_2 > 0 \tag{8}$$

where z_s is a dummy = 1 if the sire has won a Triple Crown race. This can be the Kentucky Derby, Preakness Stakes, or Belmont Stakes. The error term u_2 is

$$u_2 \sim N(0,1) \tag{9}$$

$$corr(u_{1,}u_2) = \rho \tag{10}$$

In terms of priors, we impose the usual conjugate and diffuse priors for all the parameters. That is

$$\beta \sim N(b_0, B_0), \quad \tau \sim Gamma(\delta_0, \delta_1) \tag{11}$$

where b_0 and B_0 are hyper-priors assumed to be 0 and 1,000, respectively; and δ_0 and $\delta_1$are shape and scale hyper-priors which we set to 0.001 so as to impose a higher prior variance. Because we impose larger prior variances, it implies that our priors would have a negligible effect on our results. We then use MCMC to sample from the posterior. Our simulations were conducted in Stata software using the Random-walk Metropolis-Hastings algorithm (StataCorp, 2019). Our MCMC techniques involved two Markov chains with a burn-in phase of 5,000 to allow the chains to forget their initial regions (Gelman et al., 2013; Ng'ombe et al., 2020). To obtain high-quality posterior distributions, the total number of iterations were 25,000 per chain. To determine whether our chains converged to their target posterior distributions, for brevity, we checked trace and autocorrelation plots of the Markov chains. Trace plots with good mixing indicate successful convergence while autocorrelation plots that die away are by convention a sign of successful convergence of the MCMC (Gelman et al., 2013; Gill, 2013; Ng'ombe et al., 2020).

Estimating hedonic pricing models via OLS in the existence of this error correlation causes estimates to be biased because they violate the assumption of random sampling. Dority et al. (2016) does not account for sample selection processes. Heteroskedasticity may also arise. Maynard and Stoeppel (2007) account for heteroskedasticity using a Box-Cox transformation. Marion and Stowe (2016) use a Breusch Pagan test and reject the null hypothesis of heteroskedasticity. Nonetheless, our paper's methodological contribution is an empirical application of a Bayesian Heckman selection model applied to Thoroughbred broodmare auctions.

Data and Descriptive Statistics

Data on broodmare sales prices and characteristics were obtained from the January 2020 Keenland Sale at Keenland Association in Lexington, Kentucky. The sire nationality and performance data were obtained from the Blood-Horse Stallion Register and matched to corresponding broodmares. Table 1 presents the descriptive statistics.

Table 1. Descriptive Statistics.

Variable	Mean	Standard Deviation	Minimum	Maximum
Price ($)	27670.23	63181.87	0	640000
Prospect	0.511	0.5	0	1
Age in years	5.742	2.519	2	16
Black	0.468	0.499	0	1
Sire stud fee ($)	63812.34	67347.84	2000	250000
Sire earnings ($)	2080000	2260000	32400	1.05E+07
Representation	10.439	6.488	1	25
Domestic sire	0.95	0.217	0	1
Triple Crown	0.168	0.374	0	1
Session 1	0.225	0.418	0	1
Session 2	0.261	0.439	0	1
Session 3	0.187	0.39	0	1
Session 4	0.171	0.377	0	1
Session 5	0.154	0.361	0	1
Observations	524			

The sample contains 524 unique broodmares with 323 (61.6%) of those being sold. The other sale prices are recorded as zero. The average price conditional on being sold is $44,889 and ranges from $1,000 to $640,000. Broodmare prospects account for roughly 51% of the sample and average prospects have a price of $28,079 versus $27,241 of the average non-prospects. The difference, however, is statistically insignificant, with a p-value of 0.879 as shown in Figure 1.

The average broodmare in the sample is approximately six years of age. The average sire earned $2.08 million, has a stud fee of about $63,812, and is being represented 10 times. Ninety-five percent of the sires are domestic, and 16.8% of the total sires have won a Triple Crown race. A broodmare of a domestic sire on average sold for $28,379.92

versus $14,076.92. The difference is not statistically significant, with a p-value of 0.261. Figure 2 shows this comparison.

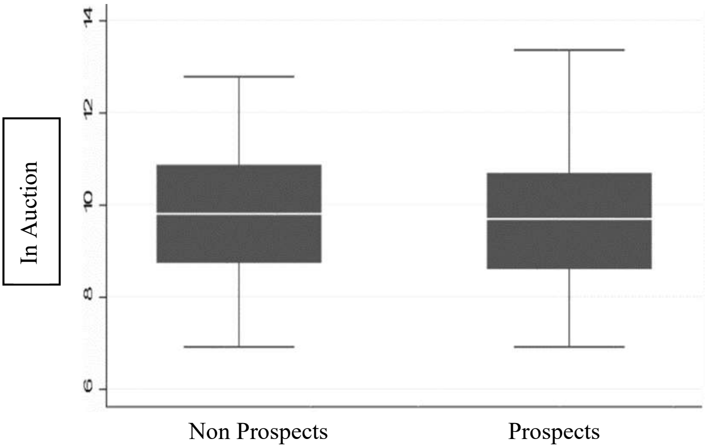

Figure 1. Price of Non-Prospects vs. Prospects.

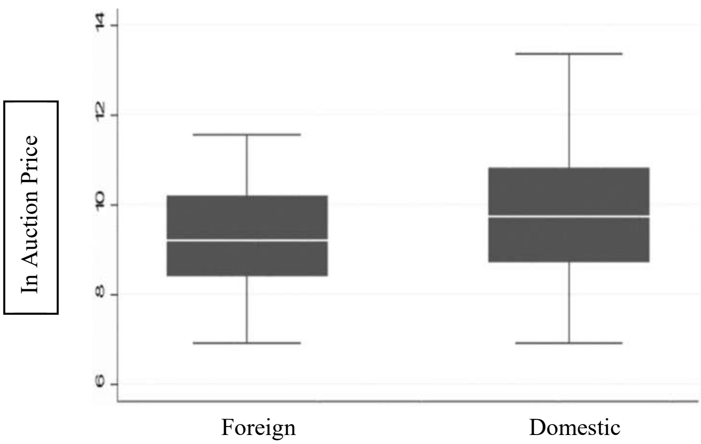

Figure 2. Price Difference Between Sire's Domestic Status.

Table 2 presents a pairwise comparison of mean price across different auction sessions. There are statistically significant differences in prices between session 1 to sessions 3, 4, and 5, respectively, as well as between 2 and 3, 4, and 5, respectively. The signs on each of these differences are negative and have management implications. Buyers may be able to receive a discounted price if they are willing to delay their purchase by attending a later auction. This inference is consistent whether using Bonferroni, Sidek, Sheffe, Tukey, SNK, Duncan, or Dunnet adjustments. Figure 3 visualizes this relationship. Dority et al. (2016) find that the longer buyers are willing to wait, the lower price that they can receive.

Table 2. Pairwise Comparisons of Mean Price Across Sessions with Bonferroni Adjustment.

Session	Contrast	Standard Error	P > t
2_vs_1	6935.513	7710.558	1
3_vs_1	-21575.94	8390.539	0.104
4_vs_1	-28729.55	8591.845	0.009
5_vs_1	-31674.73	8858.497	0.004
3_vs_2	-28511.46	8122.274	0.005
4_vs_2	-35665.06	8330.065	0
5_vs_2	-38610.25	8604.833	0
4_vs_3	-7153.605	8963.17	1
5_vs_3	-10098.79	9219.088	1
5_vs_4	-2945.185	9402.672	1

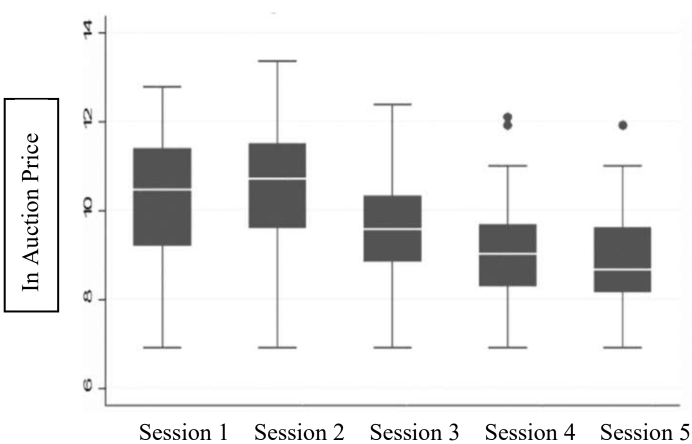

Figure 3. Price Over Session.

Results and Discussion

To show that our MCMC chains converged to their target posterior distributions, we show convergence diagnostics for variable *age* only to save space. Convergence diagnostics are shown in Figure 4. As shown in Figure 4, the trace plot indicates that each MCMC chain exhibits good mixing, which suggests successful convergence. The autocorrelation plot indicates that the terms of the chain decline toward zero as lags are increased, which also suggests successful convergence. The histogram and density plots are graphical representations of the posterior distribution of the coefficient of age for each chain.

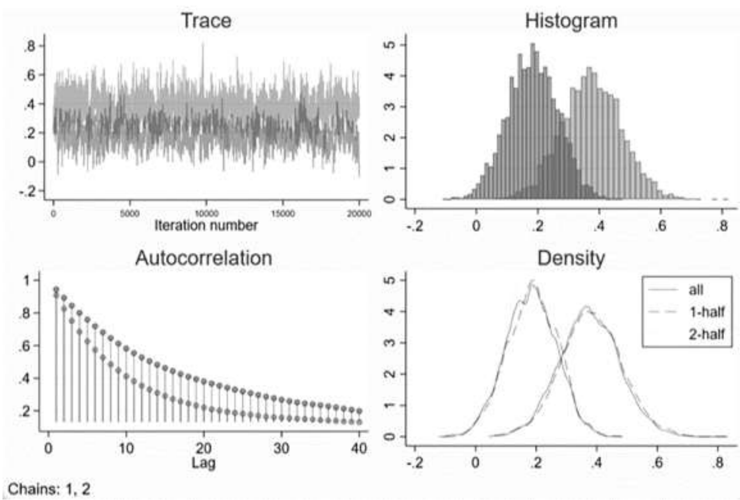

Figure 4. Convergence Diagnostic Plots for Variable Age.

Table 3 presents the posterior summary statistics from the Bayesian Heckman selection model. In terms of significance, results in Table 3 are significant if the 95% credible interval does not include the value of zero. Broodmare prospect, age, square of age, domestic status, and the session are found to have significant effects on average broodmare selling prices. *Ceteris paribus*, a broodmare prospect would peg a price of 54% more than otherwise. In terms of age, age of the broodmare has a positive effect on its selling price though the variable age square has a negative effect. This finding shows an inverted-U relationship between age and broodmare price. This implies that younger broodmares would be costlier, but, as they become older (i.e., with the turning point of 7.34 years), their price would eventually decline. This is plausible because a younger broodmare's investment portfolio would be expected to be higher in its younger age.

Table 3. Bayesian Heckman Results with Sample Selection.

Variable/Statistic	Mean	Standard Deviation	95% Credible Interval	
Dep. variable: log of price of broodmare				
Prospect	0.536	0.385	0.125	1.012
Age in years	0.279	0.164	0.043	0.539
Square of age	-0.019	0.009	-0.039	-0.004
Black	-0.041	0.306	-0.434	0.357
Log of sire earnings	0.018	0.058	-0.089	0.123
Log of sire fee	0.149	0.147	-0.072	0.353
Representation	0.017	0.025	-0.022	0.058
Domestic sire	0.966	0.274	0.556	1.394
Session 2	0.005	0.236	-0.347	0.265
Session 3	-1.145	0.505	-2.421	-0.639
Session 4	-1.518	0.198	-3.109	-1.216
Session 5	-2.266	1.006	-4.450	-1.327
Intercept	7.491	0.619	6.908	8.311
Siretcwinner	-0.077	0.124	-0.318	0.720
Intercept	0.293	0.059	0.180	0.409
Model statistics				
Athrho	-1.304	0.439	-2.238	-0.381
Log sigma	0.520	0.173	0.235	0.724
Rho	-0.829	0.172	-0.952	-0.363

Sire stud fee results are positive, which matches our expectation that a sire's stud fee is expected to increase the selling price of the broodmare. While this result is qualitatively consistent with Neiberg (2001) and Dority et al. (2016), our result is not significant. A domestic sire is associated with a 96.6% on average broodmare selling price relative to non-domestic ones, all else equal. This result ranges between 56% and 139% with a 95% probability. For managers, this means that including a domestic sire in your bloodline may increase future broodmare returns.

The result for sire representation also has management relevance. When deciding the number of mares for a sire to service, managers must trade off short-term earnings with the possibility of decreasing future value of the sire due to the possibility of an inadequate foal. Based on the insignificant results, the relationship between the sire representation and broodmare price is inconclusive.

The dummies indicating the session are all statistically significant except for the session 2 dummy. This is consistent with Dority et al. (2016) who find what they describe as buyer fatigue in these auctions. They point out that it is customary for the highest quality broodmares to be auctioned the earliest and that there may be a psychological notion that the best lot has been sold. This evidence suggests potential buyers who wait until later auction sessions incur additional risk. Managers and potential buyers should seek to attend the earliest sessions. Notice that results presented in Table 3 indicate significant sample selection. This is evidenced by the significant ρ value in the last row. This result shows that ρ lies between -0.363 and -0.952 with a 95% chance which implies that a sire winning a Triple Crown race is negatively correlated with the price of a broodmare. This result provides further evidence for the necessity to model sample selection processes. The corrected model gives managers better estimates of possible returns to sire earnings in the breeding market.

Without accounting for sample selection in such hedonic models as presented here, one would introduce bias in their results. To show that results in Table 3 are more appropriate, we estimated another model in which we tested for sample selection formally. In this model (results presented in Table A1 in appendix), we imposed $\rho = 0$ to imply that both the selection and outcome models can be estimated separately. Upon estimation, we computed a Bayes factor—a ratio of the model's marginal likelihoods (Gelman et al., 2013; Jarosz and Wiley, 2014). We found the inverse of the Bayes factor of 20.43 which suggests that model results in Table 3 are more appropriate than those reported in Table A1 (Gelman et al., 2013; Jarosz and Wiley, 2014). Stated differently, this finding suggests a very strong preference for the presence of sample selection in these data and, therefore, a Bayesian Heckman selection model.

Conclusion

This paper contributes to Thoroughbred literature by being the first to estimate a Bayesian Heckman sample selection model to the January 2020 Keenland Sales data to account for the sample selection process underlying broodmare sales. Given the documented asymmetric information and adverse selection in the Thoroughbred industry, an unbiased hedonic pricing model of broodmares stands to inform buyers of the characteristics important in determining price. This evidence may alleviate some inefficiency associated with the information gap and market failure. In an industry with roughly $175 billion in economic impact, the welfare loss from this inefficiency is likely nontrivial. Failure to account for the selection process prevalent by omitting broodmares with prices of zero from the sample will bias coefficient estimates and misinform prospective buyers, breeders, and racers. This estimation procedure, combined with the exactness of Bayesian inference, can be used in future Thoroughbred hedonic pricing analyses, whether for broodmares or yearlings.

A broodmare prospect, age, square of age, domestic status, and the day of the auction session are all significant factors in broodmare prices. Managers can implement this information into their buying and breeding strategies. Further studies may examine other variables, such as dam characteristics, sprinting speed, or breeder characteristics for significance, but should be aware of the modelling issues addressed in this paper. Additionally, it is noteworthy to mention that the current study uses few control variables due to data limitations. Admittedly, this is an important caveat. Thus, future studies using econometric methods employed in this paper should also consider including more control variables than used here.

Appendix

Table A1. Bayesian Heckman Results without Sample Selection.

Variable/Statistic	Mean	Standard Deviation	95% Credible Interval	
Dep. variable: log of price of broodmare				
Prospect	0.015	0.377	-0.462	0.538
Age in years	-0.036	0.288	-0.355	0.339
Square of age	-0.002	0.016	-0.023	0.016
Black	0.144	0.137	-0.137	0.412
Log of sire earnings	-0.100	0.110	-0.239	0.047
Log of sire fee	0.263	0.079	-0.116	0.405
Representation	-0.007	0.019	-0.040	0.024
Domestic sire	0.567	0.217	0.157	1.003
Session 2	0.141	0.178	-0.189	0.489
Session 3	-0.523	0.273	-0.928	-0.073
Session 4	-1.251	0.227	-1.559	-0.827
Session 5	-1.524	0.252	-2.007	10.870
Intercept	8.663	2.308	6.548	10.870
Siretcwinner	0.015	0.377	-0.318	0.282
Intercept	-0.036	0.288	0.178	0.414
Model statistics				
Athrho	0.000	0.009	-0.018	0.020
lnsigma	0.213	0.046	0.129	0.298

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An Empirical Analysis of Factors Influencing Households' Demand for Omega-3 Enriched Eggs in the United States

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A Tobit model is estimated using the 2016 Nielsen Homescan panel data on household purchases to analyze the impact of socioeconomic variables on the demand for omega-3 eggs in the United States. Own price, price of conventional eggs, household income, and a set of household demographic characteristics emerge as statistically significant determinants of the quantity purchased of omega-3 eggs. The demand for omega-3 eggs is found to be elastic, conventional eggs are substitutes for omega-3 eggs, and omega-3 eggs are a normal good and a necessity.

Key words: Censored Demand, Nielsen Homescan Data, Omega-3 Eggs, Tobit Model

Appropriate healthy diets and food rich in health benefits are considered to be an integral part of a healthy lifestyle for consumers. In their diets, consumers regard food as an effective means for reducing risk of many diseases and for staying mentally and physically fit. The fast development of the food industry has been possible by using up-to-date technologies that would provide consumers with a large variety of food product categories possessing different beneficial nutrients. One of the notable developments in the food industry is related to the introduction of functional foods.

According to the American Dietetic Association (2009), functional foods are those that include whole foods and fortified, enriched, or enhanced foods that have a potentially beneficial impact on health when consumed regularly and at effective levels as part of a varied diet. Some functional foods are enriched with nutrients and vitamins to have health benefits. For instance, oatmeal is a functional food due to its content of soluble fiber that can help lower cholesterol levels, or, as a functional food, orange juice can be enriched with calcium to enhance bone health. Also, many products such as milk, eggs, yogurt, and peanut butter can be enhanced with beneficial omega-3 fatty acids to be classified as functional foods. The three important omega-3 fatty acids include alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), with ALA being present primarily in plant oils (flaxseed, soybean, and canola), while DHA and EPA can be found in fish and other seafoods (U.S. Department of Health and Human Services, 2015). According to a Mintel report (2008), enriched eggs are one of the demanded foods in the list of omega-3 fortified products. Omega-3 enriched eggs come from hens whose

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feed is supplemented with an omega-3 source like flax seeds and they are higher in omega-3s than conventional eggs (Imran et al., 2015).

The demand for eggs has increased in the United States over the past few years with the per capita consumption reaching 277 eggs in 2017 (U.S. Department of Agriculture, 2019). At the same time, due to many health attributes associated with omega-3 products, the market for them has been on the rise as well. In 2018, the global omega-3 market was estimated at $2.29 billion and is projected to expand at a compound annual growth rate of 7.4% from 2019 to 2025 (Grand View Research, 2019). Per the Mintel report (2008), approximately 47% of respondents who bought omega-3 products said they regularly purchased omega-3 capsules or pills. Also, about 46% of these respondents said they regularly purchased omega-3 enriched eggs. Other popularly purchased omega-3 food products included cereal (40%), milk (39%), yogurt (38%), and oily fish (37%).

Omega-3 enriched eggs are an excellent and affordable source of various important nutrients for healthy diets of nutritionally vulnerable segments of the population facing limited food budgets. At the same time, growing consumer awareness of health attributes has positively contributed to the demand for omega-3 enriched eggs. However, many stores, along with omega-3 enriched eggs, also offer conventional eggs, thereby contributing to a rather competitive retail landscape in the egg market. As such, research is needed to better understand patterns of omega-3 enriched egg consumption across diverse demographic groups that would provide information for the sake of better positioning of omega-3 eggs relative to a competitor (for example, conventional eggs) and would result in recommendations geared toward the improvement of the nutrient adequacy of these demographic groups. This study provides that information by conducting a household-level demand analysis of omega-3 enriched eggs in the United States.

The overall purpose of this analysis is to provide insights into the determinants of the U.S. households' demand for omega-3 enriched eggs. More specifically, the objectives of this analysis are to: (1) compute the market penetration for omega-3 enriched eggs; (2) determine unconditional and conditional economic factors (such as prices) and household demographic characteristics that impact the quantity purchased of omega-3 enriched eggs; (3) compute unconditional and conditional own-price, cross-price, and income elasticity of demand for omega-3 enriched eggs; and (4) calculate the changes in the probability of purchasing omega-3 enriched eggs resulting from a change in a household demographic characteristic for omega-3 enriched egg consuming households.

The empirical findings from this study are expected to enhance our understanding of household demand behavior with respect to omega-3 enriched eggs in the United States and, at the same time, can be of significance to different stakeholders. In particular, they can help omega-3 enriched egg manufacturers and distributors in designing corresponding pricing and promotional strategies in order to maximize sales revenues, in generating demand forecasts to assist in input procurement and inventory management, and in developing marketing strategies geared towards specific demographic groups outside of their traditional consumer base. Additionally, the findings from this study can help egg manufacturers gain insight into drivers of household consumption behavior and their implications for omega-3 enriched eggs, which is information that can be used in developing new products geared towards current and new customer base. Furthermore, the findings from this study can shed light on price differences associated with omega-3 enriched eggs and conventional eggs, providing beneficial information to stores selling differentiated eggs in facilitating pricing decisions. In addition, policy-makers can use the empirical results from this study to identify potential economic and demographic barriers to increasing omega-3 enriched egg consumption and formulate corresponding policies to overcome these barriers for nutritionally vulnerable demographic groups. Finally, the empirical findings from this study can benefit domestic egg producers in their production decisions and policy-makers in their effort to formulate programs directed at boosting the U.S. egg industry.

The rest of the paper proceeds as follows. The next section deals with the literature review, which is followed by the presentation and discussion of the Tobit model. Then, the empirical specification of the Tobit model and the estimation procedure are discussed. The data used in this study are presented and discussed in the following section. The subsequent section provides the discussion of the empirical results from the Tobit model estimation. Concluding remarks and recommendations for future research are outlined in the final section.

Literature Review

Previous research has been helpful in providing insights into the demand for omega-3 enriched eggs and contributing to our understanding of the drivers that affect their consumption. In particular, to assess the effects of Canadian consumers' health consciousness, health behavior, their attitudes towards the issues concerning animal welfare, environmental impacts, reading labels, and engineered foods, and demographic characteristics (gender, age, number of minors in the household) on their willingness to pay for omega-3 and vitamin-enriched eggs, Asselin (2005) estimated a conditional logit model using data from the stated preference survey conducted in March 2005. The estimation results indicated that consumers' health consciousness and health behavior were positively associated with their willingness to pay for the functional attributes present in omega-3 enriched eggs. In addition, the price and the perception of benefits from consuming engineered foods were found to be negatively associated with the utility gained from the consumption of omega-3 enriched eggs. The impact of demographic characteristics was statistically insignificant.

In their study, Chase et al. (2009) analyzed the effects of household demographic variables (household head's age and education, household's region of residence, income, and presence of children in the household), awareness of the Nutrition Facts table and Canada's Food Guide, and consideration of health benefits on the purchases of omega-3 enriched eggs, milk, yogurt, and margarine in Canada. The ordered probit model was estimated for each omega-3 enriched product using Nielsen Homescan data from March 2005 to March 2006. The dataset was also supplemented with the information regarding households' knowledge of the Nutrition Facts table and Canada's Food Guide, as well as consideration of health benefits when buying foods from a survey involving the same Nielsen participant households for a total of 7,947 observations. According to the empirical results, the residence region emerged as a significant driver of omega-3 enriched egg purchases, with the households from most of the Canadian regions being more likely to frequently purchase omega-3 enriched eggs. Higher-income households and households with heads with progressively higher levels of education were more likely to frequently purchase omega-3 enriched eggs. Households with heads aged 65 and older were more likely to purchase omega-3 enriched eggs, compared to households with heads of any other age category. Households with children were more likely to never purchase omega-3 enriched eggs, compared to households without children. Reading the Nutrition Facts table positively affected the likelihood of households frequently purchasing omega-3 enriched eggs. Finally, consideration of health benefits when buying food was found to be positively associated with the probability of frequently purchasing omega-3 enriched eggs.

By estimating a logit model and applying household-level data derived from Nielsen Homescan panels ranging from 1998 through 2007 and containing 1,565,320 observations, Shiratori (2011) analyzed the impacts of a set of household demographic characteristics on the likelihood of purchasing omega-3 enriched eggs in the United States. As well, the logit model was augmented to incorporate media indices related to the health and developmental benefits of increasing the use of omega-3 fatty acids in human diets. According to the estimation results, household size negatively impacted the probability of purchasing omega-3 enriched eggs. Household income was a key factor positively impacting the probability of purchasing omega-3 enriched eggs. Likewise, the age of the household head was found to be positively associated with the probability of purchasing omega-3 enriched eggs. Households that had heads with a college degree had a higher probability of purchasing omega-3 enriched eggs. Households residing in urban areas were more likely to purchase omega-3 enriched eggs. Relative to households residing in the South, households from the East were more likely and the households from the Central and Western regions were less likely to purchase omega-3 enriched eggs. Seasonal dummies suggested that the probability of purchasing omega-3 enriched eggs was higher in spring and fall than in summer. The price of regular eggs positively impacted the probability of purchasing omega-3 enriched eggs, while the coefficient associated with the own price of omega-3 enriched eggs was not statistically significant. Having a discounted sale deal for regular eggs decreased the probability of purchasing omega-3 enriched eggs. Finally, both media indices concerning the health and developmental benefits of increasing the use of omega-3 fatty acids in human diets were positively associated with the probability of purchasing omega-3 enriched eggs.

Heng (2015) analyzed the demand for conventional and specialty eggs by estimating a Berry, Levinsohn and Pakes random coefficient logit model and using household-level data from Nielsen spanning from April 2008 to March 2010. Egg products were defined based on combinations of product characteristics including egg manufacturer brand, shell color, organic production, and health benefits associated with omega-3 and vitamins (i.e., nutrient-enhanced). The estimation results showed that the own-price elasticity of the private-label nutrient-enhanced eggs was -2.221, while that of the various brand-name nutrient-enhanced eggs ranged from -3.090 to -4.318, indicative of elastic demand for specialty eggs. Also, the calculated cross-price elasticities among brand-name nutrient-enhanced eggs ranged from 0.001 to 0.054, suggestive of substitutability relationship among specialty eggs.

Given the findings from prior studies, the present analysis makes several contributions to the literature. First, unlike prior studies, the present analysis focuses solely on the household-level demand for omega-3 enriched eggs in the United States, while directly accounting for censoring present in the data. Second, the present analysis furnishes two sets of marginal effects and corresponding demand elasticities, with one set pertaining to all the households regardless of the fact if they purchased omega-3 enriched eggs or not, and the other set concerning only the households that purchased omega-3 enriched eggs. Third, the present analysis additionally provides information on the change in the probability of being above zero-consumption level in response to a change in household demographic variables. Fourth, the model that the present analysis estimates is extended by including a few household demographic variables that were not considered in previous research.

The Tobit Model

When using household-level data, researchers usually have to deal with situations wherein households have zero consumption levels of products over the time period under study. A similar issue is encountered in Nielsen's Homescan panel data for household purchases employed in the present analysis when they reported no purchases of omega-3 enriched eggs spending zero dollars on them. Applying the ordinary least squares method to the sub-sample that contains only non-zero purchases without allowing for zero purchases leads to sample selection bias (Heckman, 1979) and inconsistent parameter estimates (Wooldridge, 2002). To circumvent this problem, a Tobit model (also called a censored regression model) is used in the present study where the explained variable is censored from below with the lower limit being zero purchases of omega-3 enriched eggs. The following discussion on the Tobit model is borrowed from McDonald and Moffitt (1980).

The stochastic model that the Tobit model is based upon is given as follows:

(1) $$y_i = \begin{cases} \mathbf{X}_i\beta + u_i, if\ \mathbf{X}_i\beta + u_i > 0 \\ 0\ if\ \mathbf{X}_i\beta + u_i \leq 0, i = 1,2,\ldots,N \end{cases},$$

where $i = 1,2,\ldots,N$ represents the number of observations, y_i is the regressand, $\mathbf{X}_i$ is a vector of regressors, β is a vector of conformable unknown parameters, and u_i is an independently distributed disturbance term following normal distribution with zero mean and constant variance. Leaving out the individual subscripts for notational convenience, the unconditional expected value of y_i, $E(y)$, is given by

(2) $$E(y) = \mathbf{X}\beta F(z) + \sigma f(z) \text{ and}$$

and the conditional expected value of y_i, $E(y^*)$ is as follows:

(3) $$E(y^*) = \mathbf{X}\beta + \sigma f(z)/F(z),$$

where the normalized index value $z = \mathbf{X}\beta/\sigma$, $f(z)$ is the unit normal density and F(z) is the cumulative distribution function. The unconditional marginal effect measuring the overall impact of a change in an independent variable on the dependent variable is defined as follows:

(4) $$\frac{\partial E(y)}{\partial \mathbf{X}} = \beta F(z).$$

The conditional marginal effect measuring the impact of a change in an independent variable on the dependent variable for $y_i > 0$ is defined as follows:

(5) $$\frac{\partial E(y^*)}{\partial \mathbf{X}} = \beta\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right).$$

McDonald and Moffitt's (1980) decomposition linking changes in the conditional and unconditional expectations to each other is given by the following:

(6) $$\frac{\partial E(y)}{\partial \mathbf{X}} = F(z)\left(\frac{\partial E(y^*)}{\partial \mathbf{X}}\right) + E(y^*)\left(\frac{\partial F(z)}{\partial \mathbf{X}}\right).$$

Thus, the total change in y can be partitioned into two parts: (1) the change in y of those above the limit, weighted by the probability of being above the limit, and (2) the change in the probability of being above the limit, weighted by the expected value of y if above the limit.

Empirical Specification and Estimation Procedure

In this study, the quantity purchased of omega-3 enriched eggs is hypothesized to be affected by the own price, the price of conventional eggs, and a set of household demographic characteristics. Mathematically, the empirical specification of the Tobit model reflecting this relationship has the following form:

(7) $$Q_{omega3i} = \alpha_0 + \alpha_1 P_{omega3i} + \alpha_2 P_{convi} + \alpha_3 I_i + \alpha_4 \mathbf{Z}_i + \varepsilon_i,$$

where $i = 1,2,\ldots,N$ is the number of observations, $Q_{omega3i}$ is the quantity purchased of omega-3 enriched eggs, $P_{omega3i}$ is the price of omega-3 enriched eggs, P_{convi} is the price of conventional eggs, I_i is household income, $\mathbf{Z}_i$ is a vector of household demographic characteristics, αs are unknown parameters to be estimated, and ε_i is the error term.

Table 1 shows the description of the variables used in this analysis along with indicating the corresponding base categories for each group of demographic variables. Household demographic characteristics pertain to size, presence of children, age, employment status, education level, marital status, race, and ethnicity of the household head. All the household demographic characteristics are operationalized and included in the model as dummy variables. In the Nielsen Homescan panel data, household income is reported in brackets and is expressed in thousand dollars. The household income variable is operationalized by recording the median point for a bracket to reflect the actual income for a particular household. For example, a bracket of \$5,000-\$7,999 has a value of \$6,500 recorded as an actual household income.

In the Nielsen Homescan panel data, prices are not reported. As such, unit values (henceforth prices) found by dividing reported total dollar sales (expenditures) by reported volume sold are used as proxies for prices of omega-3 enriched eggs and conventional eggs. For households that reported zero purchases of omega-3 enriched eggs or conventional eggs and, hence zero expenditures, the corresponding prices had to be imputed. This imputation was accomplished by regressing actual prices of omega-3 enriched eggs and conventional eggs on household income, household size, and the region in which the household resided, as suggested by prior studies (Kyureghian, Capps, and Nayga, 2011; Alviola and Capps, 2010; Dharmasena and Capps, 2014). The household income captures various levels of product quality as it is reflected by the price of the product, household size captures the differences in socio-economic and demographic conditions and their influence on price, and household region accounts for the spatial variation in price. The predicted values for both prices were generated using the estimated regression models to complete the price imputation process for both omega-3 enriched egg price and conventional egg price.

Another issue with prices relates to the endogeneity in prices, since the latter account for not only the market price variations, but also quality variations which are affected by the composition of household purchases over the individual products (Deaton, 1988; Dong, Shonkwiler, and Capps, 1998; Dong and Kaiser, 2005). Following previous studies (Alviola and Capps, 2010; Dharmasena and Capps, 2014), the endogeneity issue present in the prices was addressed by using the predicted values for both prices generated during the imputation process above because those predicted values were generated based on the household income, size, and region used as instruments. As a result of the price imputation, the issues related to missing prices and endogeneity were handled.

Finally, the empirical Tobit model with the natural logarithmic form of prices and income (semi-log model) was run given its superiority to the model with linear prices and income associated with the efficiency and significance of parameter estimates. For the discussion of marginal effects and elasticities, we follow Dharmasena and Capps (2014). The unconditional marginal effect associated with the price variable (both the price of omega-3 enriched eggs and the price of conventional eggs) in the semi-log model is as follows

$$(8) \qquad \frac{\partial E(y)}{\partial p} = \frac{\alpha F(z)}{p^u},$$

where p^u is the unconditional mean price computed using all observations (unconditional sample). The conditional marginal effect associated with the price variable (both the price of omega-3 enriched eggs and the price of conventional eggs) in the semi-log model looks as follows:

(9) $$\frac{\partial E(y^*)}{\partial p} = \frac{\alpha}{p^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right),$$

where p^c is the conditional mean price computed using the conditional sample (censored sample). The unconditional marginal effect associated with the household income variable in the semi-log model is given by

(10) $$\frac{\partial E(y)}{\partial I} = \frac{\alpha_3 F(z)}{I^u},$$

where I^u is the unconditional mean household income computed using all observations (unconditional sample). The conditional marginal effect associated with the household income variable in the semi-log model is

(11) $$\frac{\partial E(y^*)}{\partial I} = \frac{\alpha_3}{I^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right),$$

where I^c is the conditional mean household income computed using the conditional sample (censored sample). Unconditional and conditional own-price, cross-price, and income elasticities of demand for omega-3 enriched eggs are calculated using the corresponding marginal effects. In particular, unconditional own-price elasticity of demand for omega-3 enriched eggs (e^u_{omega3}), cross-price elasticity of demand for omega-3 enriched eggs with respect to the price of conventional eggs ($e^u_{Qomega3\_Pconv}$), and income elasticity of demand for omega-3 enriched eggs (e^u_I) calculated at the sample means are as follows, respectively,

(12) $$e^u_{omega3} = \frac{\alpha_1 F(z)}{P^u_{omega3}} \frac{P^u_{omega3}}{Q_{omega3}{}^u} = \frac{\alpha_1 F(z)}{Q_{omega3}{}^u},$$

(13) $$e^u_{Qomega3\_Pconv} = \frac{\alpha_2 F(z)}{P^u_{conv}} \frac{P^u_{conv}}{Q_{omega3}{}^u} = \frac{\alpha_2 F(z)}{Q_{omega3}{}^u},$$

and

(14) $$e_I^u = \frac{\alpha_3 F(z)}{I^u} \frac{I^u}{Q_{omega3}{}^u} = \frac{\alpha_3 F(z)}{Q_{omega3}{}^u}.$$

Conditional own-price elasticity of demand for omega-3 enriched eggs (e_{omega3}^c), cross-price elasticity of demand for omega-3 enriched eggs with respect to the price of conventional eggs ($e_{Qomega3\_Pconv}^c$), and income elasticity of demand for omega-3 enriched eggs (e_I^c) calculated at the sample means look as follows, respectively,

(15) $$e_{omega3}^c = \frac{\alpha_1}{P_{omega3}^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right)\frac{P_{omega3}^c}{Q_{omega3}{}^c} = \frac{\alpha_1}{Q_{omega3}{}^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right),$$

(16) $$e_{Qomega3\_Pconv}^c = \frac{\alpha_2}{P_{conv}^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right)\frac{P_{conv}^c}{Q_{omega3}{}^c} = \frac{\alpha_2}{Q_{omega3}{}^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right),$$

and

(17) $$e_I^c = \frac{\alpha_3}{I^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right)\frac{I^c}{Q_{omega3}{}^c} = \frac{\alpha_3}{Q_{omega3}{}^c}\left(1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right).$$

Finally, from equation (6), changes in the probability of being above the limit for purchasing omega-3 enriched eggs resulting from a change in an independent variable ($\frac{\partial F(z)}{\partial \mathbf{X}}$) can be obtained as follows:

(18) $$\frac{\partial F(z)}{\partial \mathbf{X}} = \frac{1}{E(y^*)}\left(\frac{\partial E(y)}{\partial \mathbf{X}}\right) - F(z)\left(\frac{\partial E(y^*)}{\partial \mathbf{X}}\right).$$

Data

The data for the present analysis are obtained from the Nielsen Homescan panel for calendar year 2016[1], which contains information on 63,150 households in the United States. Nielsen Homescan panels are the largest on-going household scanner data survey system, tracking purchases made by households. Nielsen Homescan panel data consist of daily retail food purchases for at-home use along with household demographic characteristics (age, education level, employment status, and marital status of household

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[1] The conclusions drawn from the Nielsen data are those of the researcher(s) and do not reflect the views of Nielsen. Nielsen is not responsible for, had no role in, and was not involved in analyzing and preparing the results reported herein.

heads, household size, presence of children in the household, household income, etc.). Every participating household is given a handheld scanner to scan universal product codes of all purchased products after each shopping trip to upload the purchase records (product description and characteristics, quantity purchased, expenditure, and promotion information) to Nielsen.

For the present analysis, household-level cross-sectional data ranging from January 1 through December 27, 2016, and pertaining to omega-3 enriched eggs are used, serving as a baseline study in the consideration of household demand for omega-3 enriched eggs. Omega-3 enriched eggs were disentangled from other types of eggs using the universal product code description. For each cross-sectional unit (i.e., household), purchases of omega-3 enriched eggs are aggregated. The household demographic characteristics used in the demand estimation for omega-3 enriched eggs are related to household size, presence of children in the household, household head's age, employment status, education level, marital status, race, and ethnicity. Operating under the assumption that the female head is mainly responsible for decision-making concerning grocery purchases, a female head is considered the household head. In the absence of a female head in the household, a male is considered the household head.

Descriptive statistics of the variables used in this analysis are shown in Table 1. In Table 1, the information regarding economic variables such as price and quantity of omega-3 enriched eggs and conventional eggs is given for both the unconditional sample and conditional sample. The unconditional sample reflects information for all the households included in the analysis (whether they purchased omega-3 eggs or not) and consists of 63,150 observations. The conditional sample contains information regarding those households that purchased omega-3 enriched eggs at least once during calendar year 2016 and consists of 12,712 observations. As such, the market penetration for omega-3 enriched eggs is 20.13%.

The price variable used in the estimation of the Tobit model is computed by dividing total expenditure by the quantity purchased of eggs and is expressed in dollars per count, while the quantity variable is expressed in counts (i.e., the measurement unit is one egg). The unconditional mean price of omega-3 enriched eggs and conventional eggs is $0.2/count and $0.134/count, respectively, suggesting that omega-3 enriched eggs on average are more expensive than conventional eggs. The unconditional average quantity purchased of omega-3 enriched eggs is 45.910. The conditional average price of omega-3 enriched eggs is $0.198/count and $0.135/count for conventional eggs, indicating that omega-3 enriched eggs are higher-priced relative to conventional eggs. The conditional average quantity purchased of omega-3 eggs is 228.071 and the average household income is $59,608.

Table 1. Description and Descriptive Statistics of the Variables Used in the Analysis.

Variable	Units of Measurement	Mean	Standard Deviation
Unconditional price of omega-3 eggs	dollars per count	0.20	0.019
Unconditional price of conventional eggs	dollars per count	0.134	0.016
Unconditional quantity of omega-3 eggs	count	45.910	127.435
Conditional price of omega-3 eggs	dollars per count	0.198	0.017
Conditional price of conventional eggs	dollars per count	0.135	0.014
Conditional quantity of omega-3 eggs	count	228.071	197.817
Household income	thousand dollars	59.608	29.340
Household size: one member		0.246	0.430
Household size: two members		0.409	0.492
Household size: three members		0.144	0.351
Household size: four members		0.121	0.326
Household size: five members and more*		0.080	0.271
Presence of at least one child below 18 years		0.239	0.427
Presence of no children below 18 years*		0.761	0.427
Age of the household head less than 25 years		0.006	0.078
Age of the household head between 25-44 years		0.244	0.430
Age of the household head between 45-64 years		0.505	0.500
Age of the household head 65 years and greater*		0.245	0.430
Employment status: employed, working hours less than 35 hours/week		0.180	0.384
Employment status: employed, working hours more than 35 hours/week		0.393	0.488
Employment status: unemployed*		0.427	0.495
Education level: less than high school degree		0.019	0.138
Education level: high school only		0.238	0.426
Education level: some college degree only		0.297	0.457
Education level: at least college degree*		0.445	0.497
Marital status: married		0.646	0.478
Marital status: widowed		0.071	0.258
Marital status: divorced or separated		0.144	0.351
Marital status: single*		0.138	0.345
Race: White		0.812	0.391
Race: Black		0.106	0.308
Race: Asian		0.034	0.182
Race: other (non-Black, non-White, non-Asian)*		0.047	0.212
Hispanic ethnicity		0.066	0.249
Non-Hispanic ethnicity*		0.934	0.249
Region: East		0.380	0.485
Region: Central		0.425	0.494
Region: West*		0.195	0.396

Notes: a. For the unconditional and demographic variables the sample size is 63,150, while for the conditional variables the sample size is 12,712. b. Asterisk indicates the base category. c. Researcher(s) own analyses calculated (or derived) based in part on 2016 Nielsen data from The Nielsen Company (US), LLC and marketing databases provided through the Nielsen Datasets at the Kilts Center for Marketing Data Center at The University of Chicago Booth School of Business.

The household size measures the number of household members and is divided into five groups, ranging from one-member households to households with five and more members. Almost 41% of the sample households are those with two members. The characteristic of the age and presence of children less than 18 years old is classified into two groups: at least one child less than 18 years of age present in the household and no children in the household below 18 years of age. A little more than three-quarters of households (76.1%) report not having children of less than 18 years of age. The age of the household head characteristic is classified into four categories from "less than 25 years" to "65 years and greater". Slightly over half of the sample households (50.5%) have heads aged between 45 and 64 years. Employment status reflects whether household heads are employed for less than 35 hours per week, for more than 35 hours per week, or are unemployed. About 43% of the sample households have heads that are unemployed.

Education level represents the level attained by the household heads and is divided into four categories: less than high school degree, high school degree only, some college only, and at least college degree. About 45% of the sample households have heads with at least a college degree. Marital status of household heads is divided into four categories: married, widowed, divorced or separated, and single. Married household heads account for a little less than two-thirds of the sample (64.6%). Race of the household head is classified as White, Black, Asian, and other. White household heads account for 81.2% of the sample. Household ethnicity is classified as Hispanic origin or not Hispanic origin. The vast majority of households (93.4%) report heads of non-Hispanic origin.

Empirical Results

The parameter estimates and their standard errors from the Tobit regression for omega-3 enriched eggs obtained using the PROC QLIM procedure of the Statistical Analysis Software (SAS) version 9.4 are shown in Table 2. These Tobit parameter estimates do not provide direct intuitive economic interpretation. However, they indicate statistically significant determinants of the quantity purchased of omega-3 enriched eggs and are also used in the computation of more meaningful marginal effects and demand elasticities.

As the estimation results in Table 2 show, the statistically significant determinants of the quantity purchased of omega-3 enriched eggs include own price, price of conventional eggs, household income, household size, age of the household head, and household head's employment status, education level, marital status, and ethnicity. The corresponding mean unconditional and conditional marginal effects, as well as the mean change in the probability of being above the limit for change in every demographic variable for omega-3 enriched eggs, are also presented in Table 2. While Table 2 reports these estimation results at the three conventional significance levels (1%, 5%, and 10%), the actual interpretation and discussion of all marginal effects and the change in the probability are done based on the 5% significance level and one at a time, holding the effects of other variables constant.

The R-square statistic is computed by squaring the correlation between the predicted and observed values of quantity purchased of omega-3 enriched eggs. It is equal to 0.032, meaning that predicted values share 3.2% of their variance with the dependent variable. Per the estimation results in Table 2, even though the mean unconditional marginal effects are lower in value compared to the mean conditional marginal effects, however, both marginal effects are similar in terms of their signs, except for the education level of having only a high school education.

Table 2. Tobit Regression Results, Mean of Unconditional and Conditional Marginal Effects, and Mean Change in the Probability of Being above the Limit for Change in every Demographic Variable for Omega-3 Eggs.

Variable	Estimate	Standard Error	Mean Unconditional Marginal Effects	Mean Conditional Marginal Effects	Mean Change in the Probability
Log price of omega-3 eggs (dollars per count)	-2661.206***	66.912	-532.526***	-622.373***	
Log price of conventional eggs (dollars per count)	1578.650***	46.293	315.899***	369.197***	
Log of household income (thousand dollars)	204.182***	5.561	40.858***	47.752***	
Household size: one member	341.091***	16.337	68.255***	79.771***	0.253***
Household size: two members	250.983***	12.424	50.223***	58.697***	0.186***
Household size: three members	199.077***	11.230	39.837***	46.558***	0.148***
Household size: four members	174.498***	10.800	34.918***	40.810***	0.130***
Presence of at least one child below 18 years	11.448	8.589	2.291	2.677	0.009
Age of the household head less than 25 years	-25.320	30.217	-5.067	-5.922	-0.019
Age of the household head between 25-44 years	-25.284***	8.107	-5.060***	-5.913***	-0.019***
Age of the household head between 45-64 years	-32.836***	6.174	-6.571***	-7.679***	-0.024***
Employment status: employed, working hours less than 35 hours/week	-9.255	6.410	-1.852	-2.164	-0.007
Employment status: employed, working hours more than 35 hours/week	-39.279***	5.697	-7.860***	-9.186***	-0.029***
Education level: less than high school degree	-41.249**	17.476	-8.254**	-9.647**	-0.031**
Education level: high school only	-49.477***	6.102	9.901***	-11.571***	0.060***
Education level: some college degree only	-8.934*	5.336	-1.788*	-2.089*	-0.007*
Marital status: married	27.705***	9.022	5.544***	6.479***	0.021***
Marital status: widowed	16.408	11.141	3.283	3.837	0.012
Marital status: divorced or separated	19.839**	8.854	3.970**	4.640**	0.015**
Race: White	-17.376	11.127	-3.477	-4.064	-0.013
Race: Black	-3.949	12.761	-0.790	-0.924	-0.003
Race: Asian	-0.110	15.969	-0.022	-0.026	-0.0001
Hispanic ethnicity	49.532***	9.373	9.912***	11.584***	0.037***
Intercept	-2469.110***	77.704			
Sigma	397.485***	2.940			
Log Likelihood	-111922				
R-square	0.032				

*Notes: a. * = .10 level (10%), ** = .05 level (5%), *** = .01 level (1%). b. Number of observations for unconditional estimates is 63,150, while that of conditionals is 12,712. c. Researcher(s) own analyses calculated (or derived) based in part on data from The Nielsen Company (US), LLC and marketing databases provided through the Nielsen Datasets at the Kilts Center for Marketing Data Center at The University of Chicago Booth School of Business. d. The R-square statistic was calculated as a squared correlation coefficient between the actual and predicted values of the dependent variable.*

As such, the discussion of the results in Table 2 is done in terms of the mean conditional marginal effects and the corresponding mean change in the probability of being above the limit for change in a demographic variable for omega-3 enriched eggs. Household size emerges as an important factor impacting the quantity purchased of omega-3 enriched eggs. Compared to household size equal to or greater than five members, one-member, two-member, three-member, and four-member households are on average 13%-25% more likely to purchase omega-3 enriched eggs and, on average, buy 41-80 more eggs. Age of household heads is a key factor in purchasing omega-3 enriched eggs. Households that have heads who are between 25 and 44 years old and between 45 and 64 years old are, on average, 1.9% and 2.4%, respectively, less likely to purchase omega-3 enriched eggs and buy, on average, about six and eight eggs less, respectively, relative to households headed by a person aged 65 and above.

Households that have employed heads working more than 35 hours per week on average purchase about nine omega-3 enriched eggs less with an average probability of 3%, compared to households that have unemployed heads. Household heads' education level plays an important role significantly affecting purchases of omega-3 enriched eggs. In particular, compared to households that have heads with at least a college degree, households that have heads with less than a high school degree are, on average, 3% less likely to purchase omega-3 enriched eggs and buy, on average, about 10 eggs less. High school-educated household heads are, on average, 6% more likely to buy omega-3 enriched eggs and purchase on average about 12 eggs less, relative to households that have heads with at least a college degree.

Marital status also is an important factor impacting households' purchases of omega-3 enriched eggs. The probability of purchasing omega-3 enriched eggs, on average, increases by about 2% for households that have married heads and they purchase, on average, six more eggs in comparison to the reference group of households that have single heads. In addition, households with divorced or separated heads, on average, purchase about five omega-3 enriched eggs more than the households with single heads with an average 1.5% greater probability. Finally, households with Hispanic heads, on average, purchase about 12 more omega-3 enriched eggs than households headed by a non-Hispanic head with an average of 3.7% greater probability. It needs to be noted that these empirical findings are consistent with the results obtained in the studies by Chase et al. (2009) and Shiratori (2011).

The mean of unconditional and conditional own-price, cross-price, and income elasticities of demand for omega-3 enriched eggs calculated at the sample means and using the corresponding parameter estimates from the Tobit model are presented in Table 3. Across the three demand elasticities, absolute values of unconditional elasticities are slightly less than their conditional counterparts. The means of the unconditional and conditional own-price elasticity of demand for omega-3 enriched eggs are negative, in accordance with the law of demand, and are equal to -2.335 and -2.729, respectively. These own-price elasticities of demand suggest that for a 1% increase in the price of omega-3 enriched eggs, on average the mean unconditional and conditional quantity purchased of omega-3 enriched eggs goes down by 2.335% and 2.729%, respectively, everything else held constant. Additionally, both values of the own-price elasticities imply that the demand for omega-3 enriched eggs is elastic, necessitating a decrease in own price for the sake of raising sales revenues in the short-run for omega-3 enriched eggs manufacturers. These results are consistent with a prior study by Heng (2015), who estimated the own-price elasticity of the private-label nutrient-enhanced eggs (omega-3 and vitamin enriched) to be -2.221, while that of the various brand-name nutrient-enhanced eggs went from -3.090 to -4.318, revealing an elastic demand for specialty eggs.

Table 3. Unconditional and Conditional Demand Elasticities from the Tobit Model and Demand Elasticities from Heckman's Two-Stage Procedure for Omega-3 Eggs.

Elasticity	Mean Unconditional (Tobit)	Mean Conditional (Tobit)	Heckman
Own-price elasticity of demand for omega-3 eggs	-2.335	-2.729	-3.633
Cross-price elasticity of demand for omega-3 eggs wrt to the price of conventional eggs	1.385	1.619	1.228
Income elasticity	0.179	0.209	0.015

Notes: a. Estimation results from Heckman's two-stage procedure are available upon request. b. Researcher(s) own analyses calculated (or derived) based in part on data from The Nielsen Company (US), LLC and marketing databases provided through the Nielsen Datasets at the Kilts Center for Marketing Data Center at The University of Chicago Booth School of Business.

The mean of the unconditional cross-price elasticity of demand for omega-3 enriched eggs with respect to the price of conventional eggs is 1.385, meaning that, as anticipated, conventional eggs are a substitute product for omega-3 enriched eggs and that a 1% increase in the price of conventional eggs increases the mean unconditional quantity purchased of omega-3 enriched eggs by 1.385%, everything else held constant. As well, the mean of the conditional cross-price elasticity of demand for omega-3 enriched eggs with respect to the price of conventional eggs is 1.619, again, expectedly suggesting that conventional eggs are a substitute product for omega-3 enriched eggs and that for every 1% increase in the price of conventional eggs, the mean conditional quantity purchased of omega-3 enriched eggs goes up by 1.619%, everything else held constant. This finding is consistent with the one obtained by Heng (2015) who also found a substitutability relationship among specialty eggs.

The mean unconditional and conditional values of the income elasticity of demand for omega-3 enriched eggs are 0.179 and 0.209, respectively. These positive values demonstrate that omega-3 enriched eggs are a normal good and are a necessity. Also, for every 1% increase in household income, the mean unconditional and conditional quantity purchased of omega-3 enriched eggs increase by 0.179% and 0.209%, respectively, holding everything else constant. This finding is in agreement with prior studies that confirmed household income as a major contributor to the purchase of omega-3 enriched eggs (Chase et al., 2009; Shiratori, 2011).

For the purpose of comparison, Table 3 also shows the estimates of own-price, cross-price, and income elasticities of demand associated with omega-3 eggs obtained from the Heckman two-stage sample selection model. These estimates reveal no qualitative difference between them and the estimates of demand elasticities from the Tobit procedure. In particular, the estimate of the own-price elasticity of demand from Heckman's two-stage procedure (-3.633) indicate an elastic demand for omega-3 eggs. Also, the estimate of cross-price elasticity of demand for omega-3 eggs with respect to the price of conventional eggs (1.228) reveal a substitutability relationship between omega-3 and conventional eggs. Finally, the estimate of income elasticity of demand from Heckman' s two-stage procedure (0.015) suggests that households view omega-3 eggs as a normal good and a necessity. While both the Tobit and the Heckman procedures are designed to handle the issue of zero purchases (i.e., censoring in dataset), in the present analysis, the Tobit model was chosen because it provides more information relative to the Heckman procedure. First, the Tobit model yields two sets of marginal effects and elasticities, conditional and unconditional, as opposed to only conditional marginal effects and elasticities estimated by the Heckman two-stage procedure. Second, the change in the probability of being above the limit for change in an independent variable can be obtained from the Tobit model, with no such information estimated by the Heckman two-stage procedure.

Concluding Remarks and Recommendations for Future Research

This study estimates a Tobit model to investigate the impact of prices, household income, and household demographic characteristics on the quantity purchased of omega-3 enriched eggs, employing data developed from the Nielsen Homescan panel for calendar year 2016. The study computes the market penetration for omega-3 enriched eggs to be 20.13%. Also, according to the estimation results, the own price of omega-3 enriched eggs, the price of conventional eggs, household income, as well as a number of household demographic characteristics, emerge as significant factors influencing the quantity purchased of omega-3 enriched eggs, information that can be useful in formulating policies targeting vulnerable demographic groups in an attempt to improve their nutrient adequacies.

Per the own-price demand elasticity estimate, the demand for omega-3 enriched eggs can be classified as elastic, suggestive of consumer sensitivity to omega-3 enriched egg price changes. To take advantage of this fact, omega-3 enriched egg manufacturers are advised to lower their prices in order to maximize their short-run revenues from sales. At the same time, elastic demand for omega-3 enriched eggs implies that manufacturers of this type of eggs will be impacted by tax and will be unable to pass any cost increase onto consumers, to the extent that the demand is elastic.

According to the positive cross-price elasticity of demand for omega-3 enriched eggs with respect to the price of conventional eggs, conventional eggs are found to be substitutes for omega-3 enriched eggs. This result can be used by omega-3 enriched egg manufacturers and distributors to form demand forecasts to facilitate decisions associated with input procurement and inventory management in response to conventional egg price changes. Finally, the value of the income elasticity of demand for omega-3 enriched eggs imply that they are a normal good and a necessity, which is a significant piece of information for manufactures and policy-makers for predicting changes in household purchases of omega-3 enriched eggs for a given change in household income.

A few recommendations for future research are worth mentioning. First, future research would benefit by also considering factors associated with purchase channels (conventional supermarkets, supercenters, wholesale clubs, etc.), households' health status, and households' away-from home consumption of omega-3 enriched eggs. Second, it would be beneficial for future research to include the time dimension into analysis to capture the potential dynamics in the household buying behavior dealing with omega-3 enriched eggs. Third, it is recommended that future research replicate this study with more current data.

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System Design and Co-Product Streams: Does Technological Choice Matter for Aquaponic Profitability?

Grace Gibbons and Tanner McCarty

Population growth, urbanization and climate change will create future challenges for agribusiness. One particularly vexing challenge will be producing more food using less land and water. Aquaponics offers the potential to overcome these obstacles, but a lack of research providing insight into managerial decision-making in this industry limits its effectiveness. This research is particularly lacking in the realm of aquaponic technological selection. This study compares the expected profitability of four leading aquaponics production systems. It compares expected net present value for coupled and decoupled aquaponic platforms, with and without a co-product capture for organic fertilizer. Technological choice has a considerable impact on aquaponic profitability. Expected net present value estimates ranged from $87,507 to $156,599 across the four technological combinations considered. Decoupled platforms combined with an organic fertilizer co-product capture provided the highest expected net present value. This result holds under a variety of economic conditions.

***Key words**:* Aquaponics, Benefit Cost Analysis, Techno Economic Analysis, Benefit Cost Analysis

A combination of world population and income growth are expected to increase food demand by 50% in 2050 (Pinstrup-Andersen, 2018). This increase in food demand, combined with tightening input constraints for land and water, creates a complex problem for agricultural managers. How to produce more with less? Managers' abilities to solve this problem while remaining profitable, environmentally sustainable, and socially equitable influences both their firm's future viability and the standard of living worldwide. Aquaponics presents a potential solution to this problem.

Aquaponics production enables the production of both vegetables and fish in one controlled system. The hydroponically grown vegetables utilize and purify the wastewater from the aquaculture subsystem (Palm et al., 2018). This feature allows aquaponic operations to produce the same vegetable output as traditional field production, while requiring only 5-14% of the water and 9.5% of the land (Addy et al., 2017; Kiss et al., 2015; Pinstrup-Anderson, 2018; Van Ginkel, Igou, and Chen, 2017). Aquaponic systems also have efficient feed conversion ratios for protein production. Fish require less feed per kilogram of added growth than other animal-sourced foods such as

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beef, mutton, and goat (Tilman and Clark, 2014). Aquaponic operations exploit these efficiencies by symbiotically raising fish and vegetables in a system that preserves water, conserves space, maximizes feed to food conversion, and reduces pollution.

In addition to enhancing technical efficiency, aquaponic products contain food attributes that resonate with a growing market demographic. Attributes such as locally, sustainably, and organically produced are desired by a growing segment of the market and can command a price premium (Hughes et al., 2017; Nemati and Saghain, 2018; Rankin et al., 2011; Tavella and Hjortso, 2012; Vega-Zamora et al., 2013). Fish and vegetables grown through aquaponics often contain these attributes. The ability to produce food on small sections of non-arable land near urban centers is another aquaponic benefit. This location flexibility could both lower food transport's energy footprint while allowing greater access of fresh produce within under-served food desserts.

Despite the aforementioned benefits, success of early entrants into the nascent aquaponic production U.S. market is mixed. Disparity in outcomes of entrants, such as Superior Fresh's continued expansion and Urban Organics bankruptcy, suggests management decisions for aquaponics operations matter. Plant managers make dozens of decisions on technological choices such as hydroponic production methods, system designs, and operation size. The problem is there is scant research comparing the economic viability across these different technologies. This leaves aquaponic managers without enough information to choose the optimal technological selection. We use Techno Economic Analysis (TEA) and comparative statistics to address this problem. We use production data from engineering literature and incorporate price data for the inputs/outputs associated with each technology. We focus our analysis on two key decisions influencing the profitability of an aquaponics operation: 1) the use of a coupled or decoupled production system; and 2) whether to capture discharged fish sludge to produce an organic fertilizer co-product. We estimate the profitability of these technologies under four different technological combinations. We address the following questions: a) Is the benefit of having higher tomato yields of the decoupled system worth the higher water cost? b) Is the additional revenue associated with processing fish sludge into organic fertilizer warranted after considering the increased cost?

Background

Previous Research

Fish and crops have been symbiotically produced for thousands of years (Goddek et al., 2015). It was not until 1977 that Ludwig Naegel created the first model of modern aquaponics in Germany. He raised tilapia in a recirculating aquaculture system while growing iceberg lettuce and tomatoes in the hydroponic subsystem (Palm et al., 2018). Since then, numerous studies have examined the engineering and chemistry behind aquaponics operations. However, only a few studies have quantified the economic factors behind them. The majority of these economic studies evaluated the profitability of one specific aquaponics operation at the University of the Virgin Islands (Bailey et al., 1997; Rakocy et al., 2011; Simonetti, 2015). Another study evaluated small-scale aquaponics in Hawaii finding that while aquaponics is profitable, its success is sensitive to output price (Tokunaga et al., 2015). Another study used an international survey to analyze the profitability, methods, and yields of 257 small operations. Less than one-third of the respondents in that study were profitable (Love et al., 2015). All previous economic studies lacked economic analysis governing technological selection.

A smaller strand of research has quantified management/technological decisions for aquaponic production. Quagrainie et al. (2018) compared the profitability of aquaponics to hydroponics. They found that aquaponics is more profitable if the crops are sold at an organic premium. They also compared aquaponics operations of three varying sizes and found aquaponics experiences economies of scale. Petrea et al. (2016) compared the deep-water culture hydroponic subsystem technique to the light expanded clay aggregate hydroponic subsystem technique and found that light expanded clay aggregate led to higher profitability. Bosma et al. (2017) quantified the impact fish and vegetable choice has on the profitability of aquaponics. Yet research comparing the economic viability of system design choices (the structure of the aquaponic system, holding all other subsystem techniques constant) and the inclusion of co-product streams is non-existent. This research fills the gap by conducting a TEA of four same-sized aquaponics operations. We compare two different prominent system designs with and without the option of implementing an organic fertilizer co-product capture to determine the most profitable technological combination.

Technological Explanation

The coupled system, also referred to as the closed-loop or balanced system, is the original aquaponics system design. It operates in a unidirectional flow of water. As shown in Figure 1, water runs from the fish rearing tanks through the nitrifying bacteria (biofilter), to the hydroponic troughs, and directly back to the fish rearing tanks.

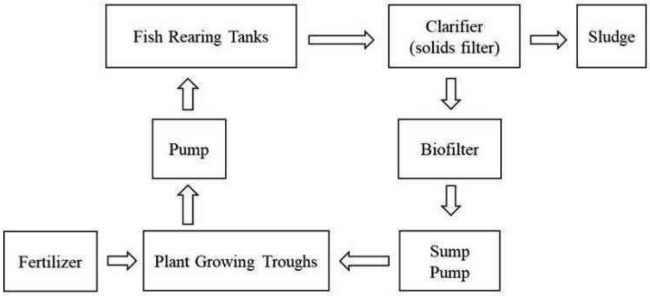

Figure 1. Coupled Aquaponic System Design.

A more recent system design is the decoupled or open-loop system. The decoupled system operates similar to the coupled system from the fish-rearing tanks to the hydroponic troughs for plant production. The key difference in this system, as shown in Figure 2, is that water is discharged or treated before fresh water is pumped into the fish-rearing tanks.

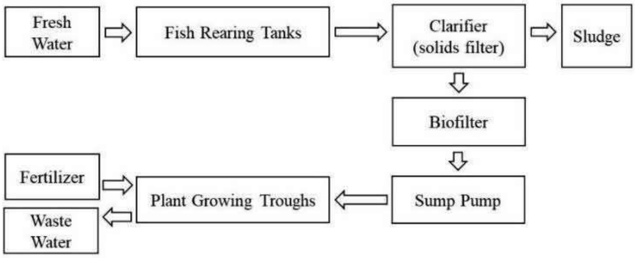

Figure 2. Simplified Decoupled Aquaponic System Design.

The decoupled system allows better control over water pH, temperature, and other nutrient levels compared to the coupled system. This leads to higher vegetable yields. The drawback to the decoupled technology is that it requires more water. This leads to a higher operating cost (Pattillo, 2017). An engineering study comparing input requirements and vegetable output across these two systems found decoupled systems achieve a 36% higher vegetable yield and comparable fish yields compared to coupled systems (Monsees, Kloas, and Wuertz, 2017). This same study also found decoupled systems require approximately 2.6 times the water. Management decisions require understanding this tradeoff's effect on a project's net present value (NPV) and, thus, is a key part of our analysis.

Aquaponic margins on fish and vegetables are small. Thus managers could consider additional revenue streams. The implementation of co-product streams enhances profitability in other agricultural industries. Corn ethanol plants rely on co-product revenue from dried distillers' grains to maintain profitability. Wineries follow the same strategy by using leftover skins, seeds, and stems to make grappa. All aquaponics systems use a clarifier tank to collect the fish waste too large for the plants to absorb. Typically, this sludge is treated and discharged when the clarifier tank gets cleaned. This sludge could be collected and dried to sell as organic fertilizer. While the profitability of fertilizer capture has not been explored within the aquaponic literature, the technology has been adopted by the commercial aquaculture plant Fishcat Farms (Dodd, 2013). This process yields additional revenue, but also requires additional costs. Without measuring these effects, it is not obvious which is greater. The implications an organic fertilizer co-product stream could have on NPV makes it a key component of our analysis.

Methods

Model

We compare the economic viability of four different technological combinations (the coupled system against the decoupled system with and without a co-product stream) using Techno-Economic Analysis. TEA is a framework that combines economic and engineering data to measure the economic attractiveness of alternative technological options. This article pulls existing data for aquaponic machinery and input requirements, plant and fish outputs, and best management practices from the engineering literature for each technology. It then adds price data for the inputs/outputs associated with the given technology. The economic desirability of each technology is then recovered by calculating the NPV of each technology by weighing the disparate future costs and benefits over the life of each project. Equation 1 explains the NPV calculation where T denotes the life of the project, t represents the number of years in the future where costs and benefits occur, and δ denotes the discount rate. B_t represents total benefits in a given year and C_t represents total costs for that year.

$$(1) \qquad NPV = \sum_{t=0}^{T} \frac{B_t}{(1+\delta)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+\delta)^t}$$

After conducting a TEA for the four technology combinations under baseline assumptions, we calculate the NPV for all combinations under varying assumptions to test the validity of the results in different economic situations. To check the robustness of our results, we use comparative statics analysis. Comparative statistics is useful to evaluate how results, in this case NPV, changes in response to exogenous parameters such as price received or input cost. This is of particular interest to aquaponics because the price of locally grown organic vegetables, price of locally raised fish, the cost of water, the cost of labor, and the manager's discount rate all vary across time and location.

Data and variables

To compare the economic viability of coupled and decoupled systems, we required a study that tested them both at the same scale. A previous study, henceforth referred to as study #1, compared the scientific parameters of a closed loop and an open loop prototype system performed in Berlin, Germany (Monsees, Kloas, and Wuertz, 2017). Study #1 used the same-sized fish-rearing tanks and hydroponic grow areas for both technologies to determine input requirements and outputs for each system. The aquaculture units of both systems were intermediate-commercial size with 240 ft^3 of fish-rearing area while the hydroponic units were pilot size, growing 15 tomato plants each.

To compare the profitability of both technologies at an intermediate-commercial size, the hydroponic units needed to be scaled up to a size that matched the aquaculture unit. There was a second study that examined an optimized decoupled aquaponics system at the intermediate-commercial size in the same facility, henceforth referred to as study #2 (Kloas et al., 2015). The goal of study #2 was to operate a decoupled aquaponic system where the ratio of fish to plants provided favorable plant growing conditions. Since the difference in coupled and decoupled systems occurs after hydroponic plant production, we assumed that an optimized coupled system would have a similar-sized hydroponic growing area as an optimized decoupled system. We used this information to modify the original plant growth area parameters of study #1 to match the plant growing area demonstrated by study #2 for both systems. Overlaying the parameters of the optimized decoupled hydroponic subsystem from study #2 was the pilot size hydroponic subsystem of study #1 created the means for which the coupled and decoupled systems could be consistently compared at the intermediate-commercial level. We then retrieved prices for each piece of equipment and inputs required for each system to estimate costs. Tables 1 and 2 show the parameters used in the TEA for the coupled and decoupled systems, respectively. We applied local estimations of water and electricity costs from rates in Park City, Utah. We chose Park City because its relatively dry climate makes water-conserving technology more interesting and its high per capita income would increase consumer willingness to pay for local, organic, sustainable produce.

To be consistent between studies #1 and #2, we asumed an aquaponic production system of tomato and tilapia. Tomato price data came from the Utah State University Extension on Utah Farmers Market and Grocery Store Pricing data from 2016-17 (USU Extension, 2017). In 2019 dollars, organic slicing vine tomatoes had an average price of $2.67 and a yearly standard deviation of $0.56.[1] We used this mean and standard deviation to model a normal price distribution with @RISK software. TEA draws from within this normal distribution to provide stochastic NPV values depending on fluctuating tomato prices. By creating stochastic pricing, we quantify the risk of prices going up or down. Tilapia price data came from the U.S. Department of Agriculture's (USDA) Quick Stats (USDA National Agricultural Statistics Service (NASS), 2018). Although there was no time series of data, the 2018 national average and standard deviation for the price received for food-size tilapia provided the most recent data available.[2] The average tilapia price of $2.68 and standard deviation of $1.32 were used (USDA NASS, 2018).

Each system holds 363 tomato plants on a six-month cycle, 726 tomato plants a year (Kloas et al., 2015). A tomato plant in the coupled system produces 13.45 lbs. of tomatoes while a plant in the decoupled system produced 18.08 lbs. (Monsees, Kloas, and Wuertz, 2017). We estimated yearly output in the coupled system at 9,762 lbs. of tomatoes, while the decoupled system was 13,124 lbs. The improved pH and temperature control in the decoupled system increases tomato productivity (Monsees, Kloas, and Wuertz, 2017). The yearly output of tilapia was 1,964 fish per year of approximately 1.5 lbs., an expected 2,946 pounds of tilapia for both systems.

The primary cost difference between coupled and decoupled systems comes from differences in water requirements. Water usage rates for each system were determined in two parts: 1) the initial water needed to fill the system; and 2) the yearly water usage. Study #2 provides an estimated water requirement for a decoupled system. The intermediate commercial-scale decoupled system showed a 3.83% daily water usage in a 3,434 -gallon system, or 48,008 gallons per year. We estimated the water requirement for the coupled system by taking the water requirement for a commercial decoupled system in study #2 times the ratio of water requirements between coupled and decoupled pilot

[1] These tomatoes did not have a sustainability certification and serve as a conservative price range.

[2] Average price of all tilapia sold. This price range is conservative for a locally and sustainably produced fish.

systems in study #1. In the pilot study, the coupled system used 507 gallons while the decoupled system used 1,311 gallons (Monsees, Kloas, and Wuertz, 2017). This means a coupled system consumes 38.7% of the water that a decoupled system consumes, or 18,579 gallons per year.

Collecting and drying the fish waste requires constructing a box to dehydrate the sludge. This requires four planks of wood to hold a tarp. The water is dumped into the tarp and dries from one to four weeks. Tables 3 and 4 show the cost and benefit of adding on a fertilizer capture system for coupled and decoupled systems, respectively. We assumed local weather conditions representative of Park City, Utah, to estimate evaporation rates and months where fertilizer capture is feasible. Fertilizer capture only works in months when water evaporates. Evaporation rates used in this research correspond to Provo, Utah, since it is the closest geographical data point to Park City. The data suggested eight months of evaporation occurs in the area (Western Regional Climate Center, 2005). In March, 2.59 inches evaporate. The wastewater from the first week of March would not fully evaporate until the first week of April. As summer approaches, it takes less time for the water to evaporate. In order to accommodate the month of March, five boxes need to be constructed. After that, the five boxes would not be needed until September and October, when evaporation rates slow down again. This makes for 31 weeks of waste collection. The boxes would fill up 3.32 inches with the 1,500L of water. The percent of dry weight of the wastewater at this point is 0.2% for the decoupled system, and 0.18% for the coupled system (Monsees, Kloas, and Wuertz, 2017). In order to achieve the required 35% dry weight, the volume would decrease to 8.57L for the decoupled system and 7.71L for the coupled. Once the fertilizer reaches the desired dry weight percentage, it is weighed, packed into bags, and sold. Over a year, this captures 586 lbs. of fertilizer ($1,172) for the decoupled system and 527 lbs. of fertilizer ($1,054) for the coupled system.

Table 1. Coupled System Parameters.

Item	Details	Quantity	Price	Total Cost	Source
Fixed Costs Coupled Aquaponic System					
Fish tank	1.7m^3	4	$563.44	$2,253.74	(Tank and Barrel, 2019b)
Aerator/blower	20 W	1	$107.96	$107.96	(Amazon, 2019)
Biofilter tank	2m^3	1	$1,166.36	$1,166.36	(Tank and Barrel, 2019a)
Biofilter media	1605 m^2	1	$45.00	$45.00	(Algae Barn, 2019)
Clarifier	1.9 m^3	1	$1,166.36	$1,166.36	(Tank and Barrel , 2019a)
Plumb piping		1	$449.19	$449.19	(Bailey et al., 1997)
Pump	10L/min	1	$216.83	$216.83	(Cole Palmer, 2019)
Sump tank	200 gal	1	$502.60	$502.60	(Bailey et al., 1997)
Heating system	10L/20,000W	1	$1,920.00	$1,920.00	(Aquaponic Source, 2019)
Water quality kit	-	1	$319.28	$319.28	(Simonetti, 2015)
Back-up power system	12 V	1	$268.00	$268.00	(Endless Food Sys, 2019)
Lighting timer	1725 W	1	$20.59	$20.59	(Hydro Farm, 2019)
Sodium discharge lLamps	600W	54	$42.85	$2,313.63	(Growers House, 2019)
NFT system	363 plant capacity	1	$2,999.00	$2,999.00	(Greenhouse Megastore, 2019)
Greenhouse structure	ft^2	1,000	$32.23	$32,225.67	(Robbins, 1999)
Temp control installation	ft^2	1,000	$3.30	$3,299.30	(Robbins, 1999)
Water to fill system[a]	Kilo-gallons	3.434	$8.85	$30.39	(Park City, 2019)
Water hookup cost[a]	3/4" meter	1	$801.94	$801.94	(Park City, 2019)
Yearly Operating Costs Coupled System					
Fish feed Aller-Aqua	lbs	1,701	$0.91	$1,543.40	(Ruvu Fish Farm, 2019)
Tilapia fingerlings	fingerling	1,964	$0.56	$1,099.84	(FAO, 2019)
pH adjustors (CaCO3)	lbs	165.1	$0.20	$33.02	(FeedX, 2019)
Tomatoes	726 seeds	726	$170.40	$170.40	(Johnny's Seeds, 2019)
Rock wool cubes	10*10*4.3 cm	726	$0.60	$435.60	(Floraflex, 2019)
Fertilizer Krista K plus	lbs	74	$1.89	$139.96	(M.B. Ferts, 2019)
Fertilizer CalciNit	lbs	28.82	$1.35	$38.97	(M.B. Ferts, 2019)
Fertilizer Manna Lin M	gallons	2.24	$26.44	$59.15	(Hauert Manna, 2019)
Fertilizer $KHCO_3$	lbs	32	$4.25	$136.00	(Ingredi, 2019)
Variable water cost[a]	kilo-gallons	18.58	$8.85	$164.40	(Park City, 2019)
Base monthly water fee	3/4" meter fee	12	$65.52	$786.24	(Park City, 2019)
Electricity - aerator 200W	kWh	1,752	$0.08	$141.21	(Electricity Local, 2019)
Natural gas - water heater	ft^3	312.15	$4.31	$1,345.36	(Natural Gas Local, 2019)
Electricity - 54 SDL's 600W	kWh	70,956	$0.08	$5,719.05	(Electricity Local, 2019)
Electricity - greenhouse	kWh	10,000	$0.08	$806.00	(Electricity Local, 2019)
Electricity - timer 1725W	kWh	5,037	$0.08	$405.98	(Electricity Local, 2019)
Depreciation	straight line	1	$3,154	$3,154	Author Calculations
Yearly Coupled Revenue					
Tomatoes	lbs	9,762	Mean:$2.67 SD: $0.56	$26,064.54	(USU Extension, 2017)
Tilapia	lbs	2,946	Mean:$2.68 SD: $1.315	$7,895.28	(USDA NASS, 2018)

a Park City, Utah.

Table 2. Decoupled System Parameters.

Item	Details	Quantity	Price	Total Cost	Source
Fixed Costs Decoupled Aquaponic System					
Fish tank	1.7m^3	4	$563.44	$2,253.74	(Tank and Barrel, 2019b)
Aerator/blower	20 W	1	$107.96	$107.96	(Amazon, 2019)
Biofilter tank	2m^3	1	$1,166.36	$1,166.36	(Tank and Barrel, 2019a)
Biofilter media	1605 m^2	1	$45.00	$45.00	(Algae Barn, 2019)
Clarifier	1.9 m^3	1	$1,166.36	$1,166.36	(Tank and Barrel, 2019a)
Plumb piping		1	$449.19	$449.19	(Bailey et al., 1997)
Pump	10L/min	1	$216.83	$216.83	(Cole Palmer, 2019)
Sump tank	200 gal	1	$502.60	$502.60	(Bailey et al., 1997)
Heating system	10L/20,000W	1	$1,920.00	$1,920.00	(Aquaponic Source, 2019)
Water quality kit		1	$319.28	$319.28	(Simonetti, 2015)
Back-up power system	12 V	1	$268.00	$268.00	(Endless Food Sys, 2019)
Lighting timer	1725 W	1	$20.59	$20.59	(Hydro Farm, 2019)
Sodium discharge lamps	600W	54	$42.85	$2,313.63	(Growers House, 2019)
NFT system	363 plant capacity	1	$2,999.00	$2,999.00	(Greenhouse Megastore, 2019)
Greenhouse structure	ft^2	1,000	$32.23	$32,225.67	(Robbins, 1999)
Temp control installation	ft^2	1,000	$3.30	$3,299.30	(Robbins, 1999)
Water to fill system[b]	kilo-gallons	3.434	$8.85	$30.39	(Park City, 2019)
Water hookup cost[b]	3/4" meter	1	$801.94	$801.94	(Park City, 2019)
Yearly Operating Costs Coupled System					
Fish feed Aller-Aqua	lbs	1,701	$0.91	$1,543.40	(Ruvu Fish Farm, 2019)
Tilapia fingerlings	fingerling	1,964	$0.56	$1,099.84	(FAO, 2019)
pH adjustors ($CaCO_3$)	lbs	161.9	$0.20	$32.38	(FeedX, 2019)
Tomatoes	726 seeds	726	$170.40	$170.40	(Johnny's Seeds, 2019)
Rock wool cCubes	10*10*4.3 cm	726	$0.60	$435.60	(Floraflex, 2019)
Fertilizer Krista K plus	lbs	74	$1.89	$139.96	(M.B. Ferts, 2019)
Fertilizer CalciNit	lbs	28.82	$1.35	$38.97	(M.B. Ferts, 2019)
Fertilizer Manna Lin M	gallons	2.24	$26.44	$59.15	(Hauert Manna, 2019)
Fertilizer KHCO3	lbs	32	$4.25	$136.00	(Ingredi, 2019)
Variable water cost[b]	kilo-gallons	48	$8.85	$424.80	(Park City, 2019)
Base monthly water fee	3/4" meter fee	12	$65.52	$786.24	(Park City, 2019)
Electricity - aerator 200W	kWh	1,752	$0.08	$141.21	(Electricity Local, 2019)
Natural Gas - water heater	ft^3	312.148	$4.31	$1,345.36	(Natural Gas Local, 2019)
Electricity - 54 SDL's 600W	kWh	70,956	$0.08	$5,719.05	(Electricity Local, 2019)
Electricity - greenhouse	kWh	10,000	$0.08	$806.00	(Electricity Local, 2019)
Electricity - timer 1725W	kWh	5,037	$0.08	$405.98	(Electricity Local, 2019)
Depreciation	straight line	1	$3,154.59	$3,154.59	Author Calculations
Yearly Decoupled Revenue					
Tomatoes	lbs	13,124	Mean: $2.67 SD: $0.56	$35,041.08	(USU Extension, 2017)
Tilapia	lbs	2,946	Mean: $2.68 SD: $1.315	$7,895.28	(USDA NASS, 2018)

b Park City, Utah.

Table 3. Fertilizer Capture Added to Coupled System Parameters.

Item	Details	Quantity	Price	Total Cost	Source
Fixed Costs Fertilizer Capture Added to Coupled System					
Wood planks	2in x 8in x 12ft	10	$8.33	$83.30	(Lowe's, 2020a)
Wood planks	2in x 8in x16ft	10	$11.61	$116.10	(Lowe's, 2020b)
Tarps	15ft 2in x 19ft 6in	5	$34.99	$174.95	(Harbor Freight, 2020)
Labor	1 hour/box	5	$20.00	$100.00	Author Calculations
Scales		1	$69.00	$69.00	(U-Line, 2020a)
Yearly Operating Costs Fertilizer Capture Added to Coupled System					
Bags	2 lb. bags	263	$0.15	$39.45	(Alibaba, 2020)
Ties	6" ties	263	$0.01	$1.58	(U-Line, 2020b)
Labor	labor hours	69	$8.50	$589.00	Author Calculations
Yearly Revenue for Fertilizer Co-Product Added to the Coupled System					
Fertilizer	Bags	263	$4.00	$1,052.00	(Fishnure, 2020)

Table 4. Fertilizer Capture Added to Decoupled System Parameters.

Item	Details	Quantity	Price	Total Cost	Source
Fixed Costs Fertilizer Capture Added to Decoupled System					
Wood planks	2inx8inx12ft	10	$8.33	$83.30	(Lowe's, 2020a)
Wood planks	2in x 8in x16ft	10	$11.61	$116.10	(Lowe's, 2020b)
Tarps	15ft 2in x 19ft 6in	5	$34.99	$174.95	(Harbor Freight, 2020)
Labor	1 hour/box	5	$20.00	$100.00	Author Calculations
Scales		1	$69.00	$69.00	(U-Line, 2020a)
Yearly Operating Costs Fertilizer Capture Added to Decoupled System					
Bags	2 lb. bags	293	$0.15	$43.95	(Alibaba, 2020)
Ties	6" ties	293	$0.01	$1.76	(U-Line, 2020b)
Labor	labor hours	69	$8.50	$589.00	Author Calculations
Yearly Revenue for Fertilizer Co-Product Added to the Decoupled System					
Fertilizer	Bags	293	$4.00	$1,172.00	(Fishnure, 2020)

Results

Techno-Economic Comparison of 4 Available Technology Combinations

This article set out to answer two key questions: 1) Is the benefit of having higher tomato yields of the decoupled system worth the higher water cost?; and 2) Is the additional revenue associated with processing fish sludge into organic fertilizer warranted after considering the increased cost in storage, labor hours, and fertilizer bags? Figure 3 displays the results to both questions. It shows the expected NPV and associated cumulative distribution function (CDF) of all four technology combinations.

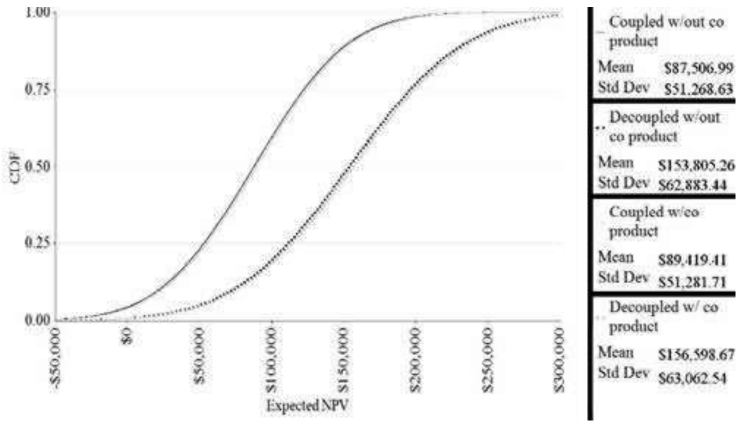

Figure 3. CDF for NPV Associated with each Technological Combination.

The TEA suggests the highest expected NPV occurs for the decoupled system with fertilizer capture at $153,805. Decoupled systems are preferred over coupled in all combinations. They become even more profitable with fertilizer capture. These differences matter. The most profitable technology combination, decoupled with fertilizer capture, yields an expected NPV that is $69,092 (79%) higher than the least profitable technology combination, coupled without fertilizer capture. Decoupled systems with fertilizer capture also contain the lowest probability of negative returns at 0.7%. We attribute the superior performance of decoupled systems to the relative importance of increased tomato yields against increased water cost. The increase in the present value of revenue associated with a switch from coupled to decoupled is $68,276. Present value of cost only increases by $1,981 when switching from a coupled to decoupled system. Higher water use drives this increase in cost. Park City has three categories of water pricing: fixed, base, and variable. The fixed cost of connecting a pipe to a business and the monthly base rate is the same for both systems. Only the variable cost of water differed. The decoupled system requires 4 kilo-gallons of water per month as opposed to the coupled systems that requires 1.55 kilo-gallons of water per month. The variable cost of water is only $8.85 per kilo-gallon. The variable cost of water had to increase to $192 per kilo-gallon to make a manager indifferent between a coupled and decoupled system.

Fertilizer capture marginally benefitted both systems, especially in the decoupled system which releases slightly more sludge (Monsees, Kloas, and Wuertz, 2017). Implementing fertilizer capture increased the NPV of the decoupled system by $2,797 and the coupled by $1,915. Fertilizer capture is cheap to implement and operate, but produces limited output. Both systems efficiently convert fish waste to biomass and can only operate fertilizer capture for eight months. The coupled system produced 526 pounds of organic fertilizer per year and the decoupled produced 586 pounds. This technology would be more attractive in a larger operation or in a region with higher evaporation rates.

Comparative Static Analysis of Key Parameters

Table 5 displays the impact on NPV from a shift of tomato prices by one standard deviation above and below the mean across the four technological combinations. The organic tomato price has a large impact on expected NPV across all technological combinations. Aquaponics managers should carefully consider the local market in which they plan to locate. Local markets that have a high willingness to pay for organic/local/sustainable/fresh produce will be more attractive. The marketing channel an aquaponic manager decides to sell through could also be important. For instance, selling a “premium” product to upscale restaurants could achieve higher prices than selling at the local farmers’ market. It depends on local market characteristics.

Table 5. Comparative Static – Tomato Price.

Technological Combination	Expected Tomato Price		
	$2.11/lb	$2.67/lb	$3.23/lb
Mean NPV coupled w/out co-product	$45,925	$87,505	$129,085
Mean NPV coupled w/co-product	$47,842	$89,422	$131,003
Mean NPV de-coupled w/out co-product	$97,906	$153,805	$209,707
Mean NPV de-coupled w/co-product	$100,700	$156,599	$212,501

Similarly, Table 6 summarizes comparative static results for a change of tilapia prices by one standard deviation above and below the mean across the four technological combinations. Tilapia price fluctuations impacted the NPV of each technology, but the impact was smaller than that of tomatoes despite having a larger standard deviation. This means that while consumers’ willingness to pay for locally produced tilapia matters, it is less of a driving factor than tomatoes. This is unsurprising since the present value of tilapia revenue across all systems is only $60,052. Conversely, the present value of tomato revenue is $266,525 in decoupled and $198,304 in coupled systems. Tilapia adds its real value to aquaponics operations in the sense that it reduces fertilizer cost and increases tomato price by allowing for an organic certification.

Assuming tilapia as the fish choice in both systems was necessary due to the lack of existing data for other fish under the technologies considered. It also allows this research to focus on the technological combinations themselves. However, there are implications to that assumption. Coupled systems run a compromised water pH for both fish and plants, making it challenging to raise high-value sensitive fish like trout or salmon. An advantage of decoupled systems is that their increased control over pH avoids this compromise. This makes raising higher priced sensitive fish such as salmon or trout easier. Superior Fresh follows this strategy with a modified decoupled system that treats and recirculates 99% and discharges the other 1% of its water (Superior Fresh, 2020). This increased control over water pH allows it to successfully raise salmon.[3]

Table 6. Comparative Static – Tilapia Price.

Technological Combination	Expected Tilapia Price		
	$1.37/lb	**$2.68/lb**	**4.00/lb**
Mean NPV coupled w/out co-product	$58,039	$87,505	$117,083
Mean NPV coupled w/co-product	$59,956	$89,422	$119,000
Mean NPV de-coupled w/out co-product	$124,341	$153,805	$183,384
Mean NPV de-coupled w/co-product	$127,135	$156,599	$186,179

The literature varies in labor cost assumptions. Bailey et al. (1997) claimed an operation of similar size to ours requires one manager. Simonetti (2015) argues that an aquaponics plant roughly three times the size of ours requires one manager and one employee. In other cases, volunteers support production. The University of the District of Columbia implemented an aquaponics facility run by community volunteers and supervised by the college's land-grant centers (O'Hara, 2015). A manager may require varying levels of labor, depending on community or university involvement, knowledge of aquaponics, and ability to work for themselves. Table 7 compares the expected NPV of an operation which requires a manager, a manager plus an additional part-time worker, and a manager plus an additional full-time worker. We followed the literature and assumed the full-time manager/owner, present in all cases, was the residual claimant of any positive NPV, and paid themselves based upon that (Bailey et al., 1997; Simonetti, 2015; Tokunaga et al., 2015). Paid labor is the amount of labor that is required in addition to the manager's time.

[3] Coupled and decoupled systems do not always follow a neat dichotomy. Superior Fresh's system is decoupled because it treats the water before going back to the fish tanks. This separates each subsystem and allows control over each. They pay for this control with higher capital and electricity costs, but could instead use more fresh water.

Table 7. Comparative Static – Labor.

Technological Combination	Additional Paid Labor Requirement		
	None	1 part-time worker	1 full-time worker
Mean NPV coupled w/out co-product	$87,505	$20,267	-$46,971
Mean NPV coupled w/co-product	$89,422	$22,184	-$45,053
Mean NPV de-coupled w/out co-product	$154,262	$86,568	$19,331
Mean NPV de-coupled w/co-product	$156,601	$89,363	$22,125

Labor requirements greatly affect the economic viability of all technological combinations. The decoupled system is more resilient in maintaining its economic profitability under higher labor requirements than the coupled system, but decreases 86% with even one additional full-time worker. The economic reality is even less favorable if one considers the manager's opportunity cost. Managing an aquaponic facility requires a certain degree of knowledge and skill. For the operation size considered, an aquaponics manager would likely achieve a higher expected return working in a different industry over the 15-year project life. For an aquaponics manager to receive a satisfactory return on their labor, they would either need to operate in markets with high prices for organic, locally, and sustainably grown fish and vegetables, locations that value aquaponic community or university involvement, or a larger operation.

In Table 8 we summarize the comparative statics on the discount rate to allow potential investors to specify their own desired rate of return. Previous NPV analyses in literature used discount rates from 6% (Simonetti, 2015) to 20% (Bailey et al., 1997). Higher discount rates made all projects less attractive This is unsurprising due to the relatively large upfront investments and steady stream of income over time associated with aquaponics operations.

Changing the expected level of tomato price, tilapia price, labor requirement, and discount rate all had a meaningful effect on the expected NPV of each technological combination. This was especially true for the level of hired-labor requirement. None of these comparative statics, however, changed the optimal technological combination. The only possible scenario considered that could make a manager prefer a coupled system to a decoupled system is one in which the variable cost of water becomes over 20 times more expensive than it currently is for a plant operating in Park City. Due to the controlled environment within aquaponics, yield variability is low and is not expected to affect the outcome of the investment barring extenuating circumstances.

Table 8. Comparative Static – Discount Rate.

Discount Rate	Mean NPV of Technological Combination			
	Coupled w/out co-product	Coupled w/co-product	De-coupled w/out co-product	De-coupled w/co-product
5%	$138,103	$140,912	$228,581	$232,587
6%	$125,917	$128,512	$210,578	$214,292
7%	$114,889	$117,289	$194,281	$197,732
8%	$104,885	$107,108	$179,497	$182,707
9%	$95,790	$97,853	$166,054	$169,047
10%	$87,505	$89,422	$154,262	$156,601
11%	$79,941	$81,725	$142,623	$145,236
12%	$73,021	$74,683	$132,391	$134,838
13%	$66,673	$68,229	$123,010	$125,306
14%	$60,852	$62,300	$114,393	$116,549
15%	$55,491	$56,844	$106,462	$108,489

Discussion

The results of our TEA and comparative static analysis imply that a decoupled aquaponics system paired with fertilizer capture represents the most economically attractive technological combination from the options considered in this analysis. These results hold true across the range of parameters for price, input cost, discount rate, and labor considered. This takeaway provides a degree of generalizability in optimal technological selection across a range of market primitives, meaning that decoupled systems with fertilizer co-product capture will provide the highest expected return of the technologies considered for tomato and tilapia production across a range of locations. This gives aquaponic managers a technological basis for optimal plant management.

The primary consideration for aquaponics plant feasibility is labor cost. Even favorable labor estimates state that aquaponics is labor-intensive, requiring one full-time manager. Under baseline assumptions, the most profitable combination provides an NPV of $156,601 for which the manager is the residual claimant. This is the equivalent to a yearly salary of $20,589 over 15 years. A full-time manager running an intermediate commercial-scale plant is unlikely to find success in aquaponics. However, aquaponic production may still be economically desirable in two situations. The first, there is a positive relationship between consumer income and willingness to pay for food attributes such as organically and sustainably produced, and locally grown. If a plant locates in a region of high consumer income or can contract with an upscale restaurant specializing in such goods, the aquaponics plant will receive a price above the baseline assumptions for tomatoes and tilapia in this analysis.

The second, the most successful aquaponics operations are among the largest in the world, such as Superior Fresh, Ourobros Farms, and Rogue Aquaponics. Studies by Quagrainie et al. (2018) and Bailey et al. (1997) argue that aquaponic production experiences considerable economies of scale. Quagrainie et al. (2018) reported the per unit cost of producing tilapia and basil to decrease by 18% when increasing the scale of an aquaponics plant from 5,000 lbs. of tilapia per year to 10,000 lbs. of tilapia per year (our aquaponic unit is 2,946 lbs. per year). This reduction in per unit cost was driven by an increasing marginal product of labor. Doubling the output of tilapia and basil only required a total of 31.2 hours of labor in comparison to 24 hours of total labor under initial conditions. In other words, increasing labor input by 36% doubled the amount of output.[4] If we applied the same assumption to our analysis doubling aquaponic capacity (to 5,892 lbs. of fish per year) at a decoupled fertilizer capture plant, the NPV would increase to $379,356 under baseline assumptions. This results in a more attractive yearly managerial salary of $49,875 for a plant that is still smaller than industrial scale.

From our analysis, we ascertain that labor is the primary variable for dictating aquaponic profitability. While aquaponics is not profitable enough to incentivize managers to enter full-time aquaponic production for a mid-size commercial plant, it becomes more attractive in high-value markets and larger operations. While we do not have existing data to quantify the economies of scale that would occur for each technological combination considered in this study, it would be surprising if economies of scale were substantively different from those explored by Quagrainie et al. (2018) and Bailey et al. (1997). It would also be surprising if it changed the optimal technological selection. The difference in expected NPV between the two system designs will still be driven by tomato yield versus water cost. Coupled and decoupled systems of the same size have similar labor and capital requirements so both technologies should experience similar economies of scale.

Conclusions

Worldwide agricultural practices will need to adjust to the resource constraints enforced by nature in order to meet food security demands in the future. The ability to produce more food under tightening economic, environmental, and social constraints is a vexing problem for which aquaponics offers a solution. This article gives a road map to the

[4] We assumed constant manager time commitment and that paid workers provided the 36% increase in labor.

technological combination offering the highest odds of success—decoupled systems with fertilizer capture. Tomato and tilapia prices each have a large effect on a project's expected NPV. However, the most important factor is the labor requirement. Projects requiring large amounts of labor or expensive labor are not viable. It is unlikely that even the best technology available would give managers a sufficient return for their time to operate an intermediate commercial-scale plant considered in this study. However, doubling the plant size would make aquaponic production more attractive under baseline assumptions, if the technologies considered in this study experience similar economies of scale to the system found by Quagrainie et al (2018).

Further economic research on aquaponics is necessary. Our analysis focused on a technological choice that was likely to have a large effect on economic viability, while allowing direct comparison across all four combinations considered. While the decisions we analyzed are important for aquaponic plant profitability, dozens of other important technological/managerial decisions warrant further research. Choices between subsystem layouts, subsystem technologies such as growing-bed medium, or other co-product streams such as charging for tours of the plant are a few of the decisions that could additionally affect profitability.

The literature could also benefit from more studies optimizing fish and vegetable choices. We assumed tomatoes and tilapia for aquaponic production as they were the most popular in the literature and were the given choice in the studies used to retrieve our technological parameters. Swapping different combinations of plants and fish into our analysis wouldn't have allowed us to hold all else constant while comparing technologies. However, aquaponic technology can grow different crops than tomatoes such as basil or lettuce. A wide range of fish species are possible as well; Superior Fresh currently raises Atlantic salmon. It sells processed salmon cuts at approximately $21/lb. (over 7.4 times the price of tilapia). Different species of plants and fish have different growth rates and associated costs than tomatoes and tilapia and warrant their own independent analysis. Additional cost benefit analyses quantifying the economies of scale associated with specific aquaponic technologies would also be helpful. Expanding an aquaponic manager's insight into optimal choice of technology, crop, fish, and scale provides the best opportunity for investments to be successful. These studies would also enhance the potential for aquaponics to run operations that are profitable, sustainable.

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A Supply Perspective on the Feasibility of a Georgia-Branded Beef Program

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The feasibility of a local branding scheme for Georgia's beef industry is explored by determining producers' participation interests and supply decisions. Specifically, the analysis will focus on producers' participation interests by ascertaining their supply decisions crucial in ensuring the feasibility of the proposed program. Two primary state territories—North and South Georgia—are analyzed to discern important regional considerations for selecting and designing either a central or a regional beef-processing model. Heckman selection model results provide important contrasting expectations of North and South beef farmers. The model's considerations include processing capacity, strategic location (accounting for each regional producer's revealed tolerable hauling distances), and pricing (factoring premium expectations related to acceptable hauling distances in each region). Results indicate that as the hauling distance to the centrally located facility increases, the premium that producers desire to make the endeavor worthwhile increases. The most appropriate and practical solution then is to consider the establishment of separate regional processing facilities that will cater to each region's producers' differentiated demands and expectations for hauling distances and pricing as well as their diverse demographic and structural attributes.

Key words: Beef Farmers, Hauling Distances, Local Branding, Price Premiums, Willingness to Supply

In recent years, consumer tastes have shifted in a different direction (Hu et al., 2012). Across the United States, buyers are becoming increasingly aware of several characteristics of the food they purchase. One trend that has shown no sign of slowing down is the increased demand for food that is locally sourced, fresher than alternatives, and perceived as better. This can be seen with the rise in popularity of organic food, as well as the emergence of the farm-to-table restaurant model. Several studies have shown that consumers are willing to pay more for food that they perceive as being of a higher quality, especially food that has been branded as being from one's own state. The source of this approval could very well stem from a sense of pride and an allegiance to one's home state, or supporting local agricultural enterprises, but it is clear that this growth in demand has created several opportunities for producers.

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Naasz, Jablonski, and Thilmany (2018) point out that, although the popularity of local food has grown in the recent past, the actual definition of "local" is still somewhat vague. While the U.S. Department of Agriculture broadly defines local as a 400-mile radius from the source, state-branding programs actually simplify the marketing dynamics, allowing producers the opportunity to participate based on geographic location alone. Consequently, state branding programs have been on the rise to take advantage of changes such as consumer preferences and behavior. A study by Hu et al. (2012) contends that Kentucky and Ohio consumers express willingness to pay premiums for food packaged and labeled in a manner that indicated they were produced locally in their home state or in a nearby state. Hu et al. (2012) find that strategic branding and packaging of the products are very effective indicators in determining if consumers would purchase or not.

In Georgia, the prospect of state branding is explored in its beef industry, which constitutes a significant part of the state's agricultural economy. Beef cattle is the state's sixth largest cash commodity (Kane, 2019) with more than 23,000 farmers producing beef in farms located in almost all its counties in 2018. Annual cash receipts of the Georgia beef industry totaled $262 million in 2018. The distribution of cattle farming is skewed, however, with 83% of cattle farmers in Georgia owning less than 100 head. Although this is the majority of farmers in the state, they only own 46% of the state's cattle, with 13% of the state's farmers owning 54% of the cattle population. Consumers in the Southeast are willing to pay a price premium for beef products, especially grass-fed and organically raised (Wong et al., 2010).

This study evaluates the feasibility of applying a local branding scheme to the beef industry in Georgia from the perspective of the producer-suppliers of cattle. Specifically, the analysis will focus on producers' participation interests by ascertaining their supply decisions crucial in ensuring the feasibility of the proposed program. The analysis will be segmented into two primary state territories—North and South Georgia—to discern important regional indicators that may aid in the final selection of the location of either a central or two (or more) regional beef processing facilities.

Proposed State-Branded Beef Program in Georgia

A handful of states have already implemented local branding programs for the state as a whole, as well as for specific food niches. Among these is the Georgia Grown program that has created a great sense of pride among Georgia growers and buyers alike. Along these lines, is an opportunity to create a state-branded beef program to take advantage of consumer demand evolving in a similar manner. Producers can potentially reap benefits if consumers are willing to pay premiums for higher quality beef that is also branded as being home-raised in Georgia. For farmers who run smaller cow-calf operations, the opportunity to completely restructure their businesses to participate in this program could seem very daunting as other studies contend (Escalante and Turvey, 2006). Some will take on the associated risks, while others may decide not to participate and carry on as they are. Larger ranches that have always operated as feedlots have less risks to undertake, and the opportunity to participate in a state-branded beef program could be perceived as an option to make their enterprises more profitable.

An important consideration in implementing a state-branded beef program is the requirement for producers to haul their cattle to a centrally located facility. For purposes of this study, the hypothetical hauling location was arbitrarily set at Macon, a city located in Central Georgia. Macon is very close to the geographic center of Georgia, and is a major commercial crossroad in the state. For larger cattle operations already hauling to locations outside the state, participating in the state-branded beef program is feasible. Those who are not already doing so will have to factor the related costs into the expansion plans for their cattle enterprises. Just like any business decision, there needs to be a return on capital and time to make this change worthwhile. In this research, very specific data regarding distances producers are willing to haul and the premiums received in return for hauling those longer distances will be thoroughly discussed.

This branding program derives its motivation from the Georgia Grown program, which is a state-level marketing, community, and economic development platform that has been conceived to ultimately boost the growth of the state's local economies. Specifically, the program creates and expands marketing opportunities for local producers, who are enjoined to forge cooperative marketing efforts for the sake of efficiently bringing their products to agribusinesses, institutions, and consumers across the state. Beyond marketing, producers also enjoy educational benefits through opportunities to learn product packaging and distribution techniques aimed at large institutional clients. The program was re-launched in 2012 to ensure more effective producer coordination and marketing assistance. These initiatives translated into tremendous marketing, financial, and economic benefits to producers and their local communities (Johnson, 2020; White, 2016).

Even if the changes in revenue and cost figures indicate that there is great opportunity for producers to take advantage of a state-branded beef program in Georgia, the program itself still must be successfully implemented. Georgia Grown has shown how logos contribute to marketing effectiveness. Its logo is recognized across the entire state due to its packaging and design. Anyone familiar with Georgia Grown could likely spot the logo amongst other food products in a supermarket or elsewhere. Such has been a serious concern of many producers in states where branded beef programs have been evaluated previously. The branding and packaging must stand apart from the crowd for it to be effective. This warrants further marketing and branding efforts should this program be feasible, and it is expected to be a concern among Georgia producers.

On the surface, the prospects for this program seem promising. There are cattle producers in all 159 Georgia counties, and the state's population is nearing 10.7 million people, ranking eighth out of 50 states (U.S. Census Bureau, 2017). That population is expected to keep growing, and an estimated 10.7 million people in the state could be potential beef consumers. Through an effective marketing and branding strategy, the Georgia beef industry could make a name for itself in the near future. If producers are willing to take on the risks of expanding their production to meet the needs of this state-branded program, all of the components of this sales channel should be aligned with one another and ready to succeed.

Other State Branding Programs

Georgia is just one of several states where research has been conducted to evaluate the feasibility of a beef program. For instance, research in New Jersey offered insight into the Jersey Fresh Program. Govindasamy et al. (1998) summarizes how New Jersey producers were surveyed in a very similar fashion to this research. While their initial results indicate that larger landowners are less likely to be willing to participate in the program, further analysis offers a different perspective. Larger landowners would actually be more willing to participate if the program would be effectively implemented. Major concerns among the larger landowners include a cautious and suspect view of the marketing and branding strategies of the program. Nearly a decade later, Babcock et al. (2007) examines a similar scenario in Iowa. The research predicted that strategic packaging to help differentiate the beef that consumers deemed higher quality would be viewed favorably by producers. Successfully implementing this branding should have resulted in consumers being drawn to the high-quality meat and following through by purchasing it. While producers did view the branding strategy this way, it was also found that producers were of the opinion that the criteria for what constituted higher quality beef was extremely important as well.

Recently, research was conducted in Tennessee on the feasibility of a state-branded program for beef, nearly identical to the Georgia program being evaluated in this research. While McLeod et al. (2018) employed a similar methodology to ours, the cattle industry in Tennessee is vastly different from that in Georgia. Tennessee's head count for cattle accounts for 3% of the total inventory for the nation, yet only 7% of these cows are finished within state borders. The Tennessee beef industry primarily consists of cow-calf enterprises that supply feedlots in other states, primarily in the Midwest region. It was determined that, in Tennessee, there was in fact a consumer willingness to pay for premium beef. It was also determined that 67% of Tennessee producers would be willing to participate in a state-branded program regardless of the size of a premium, if it was profitable. Again, the biggest challenge in this case was the fact that the Tennessee cattle industry, as a whole, primarily focuses on shipping calves out of state. Potential changes in costs and overall business structure necessitate further research in Tennessee.

Although producers in states such as Tennessee will face challenges in restructuring their businesses to meet the changing tastes of consumers, Drouillard (2018) highlights that it has been done in the past. A very significant change that happened in the beef industry nationwide was when producers swiftly acted to vertically integrate and change their business models to cater to the booming demand for certified Angus beef in the late 1970s. Today, there are roughly 90 certification programs for beef at the federal level, and 80 of those programs came into fruition after 2000. It appears that the time is right for Georgia producers to opt in to a state-branded program for beef. Past research has indicated that consumer demands have shifted towards a local product, and they are more likely to buy a product that sells at a premium if the branding and packaging strategy is effectively implemented. On the production side, previous research has shown that producers have aggressively responded to industry changes in the past. Not only that; producers in several states have indicated that the branding and packaging strategy is a main concern, but that they would be willing to participate in a state-branded program if it could be effectively implemented and their participation would lead to profitability.

Methodology

A survey was created and distributed online among members of the Georgia Cattlemen's Association (GCA). The GCA was chosen as an avenue to reach producers due to the pivotal role it plays in the Georgia beef industry as a whole. The GCA is an integral part of the Georgia beef industry with members located in every corner of the state. Georgia can be defined regionally as north or south and, while the exact line that separates the two can be defined geographically, the cultural debate of what separates north versus south can continue on endlessly. For purposes of this research, it was deemed appropriate to define north versus south based on the four districts of The University of Georgia's County Extension Services. These districts are defined as Northeast, Northwest, , and Southwest. The respondents' regional grouping was determined using the zip code they provided in their survey responses. The producer survey was created in and distributed online via the Qualtrics survey tool in 2018.

The survey generated 272 responses, of which 159 supplied complete responses. Of this sample size, 101 were North Georgia farmers while 58 were based in South Georgia.

Descriptive Statistics

Table 1 presents a descriptive statistical summary for the 159 respondents from the two Georgia regions. Comparative figures indicate that, for both regions, the beef industry is primarily operated by male producers mostly in their 50s in age and generating an average of about $80,000 net income. Beef operations in North Georgia, however, comprise a larger proportion of their farm businesses (about 53% versus 42% for their peers in South Georgia). While North Georgia farm businesses are relatively smaller in acreage, their pastures account for about 68% of their farm size (55% in the South). This trend lends more to the inherent regional agronomic differences whereby North Georgia farmland is usually less fertile and conducive to crop farming. Hence, North Georgia farmers are more inclined to operate livestock operations.

South Georgia beef farms lean more towards the single proprietorship business model. Farms from both regions have almost the same level of interest in participating in the branding program, but North Georgia farms would tend to supply more cattle (average of 56 heads) than South Georgia farms (49 heads on average).

Table 2 presents a comparison matrix for the regional averages for maximum distances producers are willing to haul their cattle at specified premium rates. Table 3 tabulates the minimum premiums expected by producers for hauling their cattle across specified distances.

Based on those tabulations, North Georgia beef producers are willing to haul their cattle farther distances across all three specified premium rates. On average, these producers are willing to extend their hauling distances from 3 to 7 miles more than the average distances registered by their South Georgia peers at certain premium rates.

Overall, farms in both regions prescribe premiums that increase with the hauling distance. Regional trends indicate that South Georgia farms demand lower minimum premiums across all five categories of distance ranges. At 50 miles of hauling distance (second shortest distance), the South Georgia premium is $1.80 lower than the North Georgia premium. At the farthest hauling distance category (over 100 miles), the premium difference is $5.00, in favor of North Georgia farms' average premium.

Table 1. Descriptive Statistics of Survey Data for North and South Georgia Respondents.

Variables	NORTH GEORGIA		SOUTH GEORGIA	
	Mean	Standard Deviation	Mean	Standard Deviation
Annual cattle run	149.257	408.049	140.0172	196.065
Finishing dummy variable*	0.139	0.347	0.103	0.307
Beef Income as percentage of total income	53.342	33.302	42.241	31.573
Willingness to participate dummy variable	0.683	0.468	0.638	0.485
Number of cattle if participating	56.139	114.485	48.879	67.146
Max miles will travel for $7.50 premium	36.881	21.678	33.879	32.963
Max miles will travel for $13 premium	61.634	33.272	59.414	41.919
Max miles will travel for $26 premium	120.297	41.188	112.931	57.781
Premium expected for hauling 25 miles	10.406	6.039	8.353	7.246
Premium expected for hauling 50 miles	12.193	6.687	10.388	8.885
Premium expected for hauling 75 miles	16.728	7.52	14.095	10.543
Premium expected for hauling 100 miles	21.125	7.306	17.871	10.53
Premium expected for hauling over 100 miles	23.411	5.684	18.414	11.33
Grass fed dummy variable	0.436	0.498	0.466	0.503
UGA Extension participation dummy variable	0.97	0.171	0.948	0.223
Master cattlemen certification dummy variable	0.485	0.502	0.483	0.504
Farm size (acres)	395.219	687.226	492.707	798.338
Pasture proportion of total acres	0.678	0.437	0.55	0.319
Federally inspected facility dummy variable	0.238	0.428	0.362	0.485
Sole proprietor dummy variable	0.673	0.471	0.879	0.329
Age (years)	53.03	16.617	50.431	15.587
Education (multinomial variable)	4.228	1.555	4.431	1.656
Male dummy variable	0.861	0.347	0.914	0.283
Pretax income ($)	88096.06	18798.76	80172.41	23535.44

Note: * *The Finishing dummy variable is analyzed vis-à-vis excluded categories of other types of operations (feeder and feedlot). All other dummy variables are usual binary categories where the label corresponds to the attribute that takes a value of 1 and 0 otherwise. For instance, the male dummy variable takes a value of 1 for male respondents and 0 for female respondents.*

Table 2. Maximum Distance Willing to Haul for a Specified Premium.

Premium	Maximum Miles Willing to Haul	
	NORTH	SOUTH
$7.50	36.88	33.88
$13.00	61.63	59.41
$26.00	120.3	112.93

Table 3. Minimum Premium Necessary to Haul a Specified Distance.

Distance (Miles)	Premium Expected ($ per cwt)	
	NORTH	SOUTH
25	10.41	8.35
50	12.19	10.39
75	16.73	14.09
100	21.12	17.87
Over 100	23.41	18.41

Heckman Selection and Outcome Models

The Heckman selection approach was employed to relate two producers' primary participation decisions. The first decision is the producer's willingness to participate in the program, which is captured by a binary decision variable (1 for willingness to participate and 0 otherwise). The second decision variable captures the extent of participation as indicated by the number of cattle that the willing producer would supply to the program.

The Heckman modeling technique aptly accommodates these two decisions. The binary participation decision variable is the basis of the selection equation while the cattle supply decision among willing producers defines the outcome equation. As laid out in Greene (2003), the basic Heckman model is defined as follows:

(1) *Selection Mechanism:* $z_i^* = \gamma'' w_i + \mu_i$

$$z_i = 1 \quad if\ z_i^* > 0,$$
$$z_i = 0 \quad if\ z_i^* \leq 0,$$
$$\text{Prob}(z_i = 1) = \varphi\,(\gamma' w_i),$$
$$\text{Prob}(z_i = 0) = 1 - \varphi\,(\gamma' w_i)$$

(2) *Outcome Model:* $y_i = \beta' x_i + \varepsilon_i,\ \ if\ z_i = 1$

The first phase of the Heckman selection approach is the probit estimation technique that results in the first equation. This selection equation's dependent variable is the value of 1 or 0 for the producer's answer as to whether they are willing to participate in the branded beef program. Answers for "No" or "Maybe" were combined for the dummy variable 0, as "Maybe" responses were not a definitive "Yes." The willing producers who figured in the first equation are then further analyzed in the outcome equation for the determinants of their degree of participation. This degree of participation is measured as the head of cattle they would be willing to supply to the program. Specifically, the expanded forms of these equations are given as:

(3) $$z_i^* = \gamma_0 + \gamma_1 \text{DEM} + \gamma_2 \text{STRC} + \gamma_3 \text{MILE} + \mu_{i,}$$

(4) $$y_i = \beta_0 + \beta_1 \text{STRC} + \beta_2 \text{PREM} + \beta_3 \text{MILE} + \mu_{i,}$$

Both selection and outcome equations include the STRC variables that represent structural characteristics pertaining to the farm business (income, farm size, and nature of operations). The DEM variables are demographic attributes usually describing the farm operator (such as age, gender, educational attainment, and other qualifications). The PREM variables represent the handful of questions asked of producers in regard to the premiums that could be received for hauling cattle to the centrally located facility. The MILE variables in the selection equation refer to the distance questions asked also pertaining to the distance willing to haul to the central facility.

Results

Table 4 presents the results of the Heckman estimation applied to the North and South Georgia models. Significant results of the LR test of independence applied to both regional models justify the adoption of the Heckman estimation techniques as the dependence of the selection and outcome decisions are confirmed.

Selection (Participation) Decisions

North Georgia producers' decisions to participate in the program are significantly influenced by a number of demographic attributes. Younger operators, with higher levels of education and income levels, tend to be more interested in patronizing the program. These producers usually view university outreach services as providing useful assistance in their business decisions. In this region, prospective program participants might consist of beef farms with smaller herd sizes, but operating larger tracts of farmland. Moreover, North Georgia farmers usually engaged in grass-fed beef production also express significant interest in participating in the program.

Table 4. Results of the Heckman Selection Model.

Variables	NORTH GEORGIA MODEL				SOUTH GEORGIA MODEL			
	Selection		Outcome		Selection		Outcome	
	Willing to participate		Degree of participation		Willing to participate		Degree of participation	
	Coefficient	Standard Errors	Coefficient	Standard Errors	Coefficient	Standard Errors	Coefficient	Standard Errors
Intercept	-2.794***	0.334	84.021***	15.246	0.664*	0.356	33.797*	20.342
Age	-0.009*	0.006			-0.001	0.007		
Male	-0.225	0.581			-0.916***	0.322		
Education	0.126***	0.015			0.013	0.0463		
Pre-tax income	8.36E-06***	2.37E-06			6.20E-06	7.46E-06		
Federally inspected facility	-0.182	0.254			0.146	0.409		
Willing to use UGA Extension	1.056***	0.117			-0.300**	0.131		
Master Cattleman certified	0.147	0.115			0.295	0.296		
Annual cattle run	-0.001***	2.72E-04	0.242	0.012	0.005***	0.002	0.359***	0.045
Farm size	0.004***	4.54E-04	0.009	0.008	-0.001**	0	-0.027**	0.012
Grass-fed	0.502**	0.24	-15.732	11.038	-0.782*	0.468	-21.098	15.016
Finishing			-62.150***	14.763			-19.523	17.973
Min premium necessary to haul 25 miles			1.055*	0.567			-2.213**	1.034
Min premium necessary to haul 100 miles			-1.343**	0.585			0.525	0.737
Min premium necessary to haul 100+ miles			0.093	1.001			2.517**	0.986
Max miles willing to haul for $7.50 premium			-0.033	0.059			-0.278	0.242
Max miles willing to haul for $13.00 premium			-0.307***	0.06			-0.504**	0.206
Max miles willing to haul for $26.00 premium			0.073	0.102			-0.216	0.162
MODEL STATISTICS								
Log likelihood	-382.31				-207.507			
Wald chi square	1.17E+07***				2.76E+06***			
LR test of independence (chi square)	46.17***				26.78***			

*Note: ***, ** and * denote significance at the 99%, 95% and 90% confidence levels, respectively.*

Results for South Georgia producers present a different profile of interested participants. Except for the similar result for the gender dummy variable, the typical South Georgia program participant has a larger cattle herd size, but operates relatively smaller tracts of farmland and are engaged in cattle growing methods other than the grass-fed model.

These contrasting results then provide some basis for foregoing the establishment of a central processing facility scheme. Appropriate regional processing facilities may need to be designed properly and appropriately to serve the seemingly differentiated profiles of prospective program participants in the two regions.

Outcome (Supply) Decisions

Results obtained from the outcome equations present more interesting contrasts between the two regional models. In the North Georgia model, non-finishing operations have the tendency to supply more head to a processing facility. Producers in this region also would supply more head for higher premiums even at a 25-mile distance. They would tend to supply less even for higher premiums offered for distances of about 100 miles. They would also supply less cattle for longer distances given a $13 per cwt. premium.

The latter result is the only similar result obtained for South Georgia producers. These producers would supply less cattle even for higher premiums offered for a 25-mile distance (which is in direct contrast to the result obtained for their peers in the North). South Georgia beef farmers also would supply more cattle if offered higher premiums for distances over 100 miles. Moreover, higher cattle supply levels can be expected from farms with larger herd sizes, but operating smaller tracts of farmland.

The outcome equation results further provide striking contrasts between the premium and hauling distance expectations of farmers from the two regions. These results should provide important indications of more relevant specifications of each regional processing facility—such as the processing capacity, strategic location (according to the region's producers' revealed extent of hauling distances), and pricing (considering the premium expectations related to hauling distances acceptable to producers in each region).

Summary and Conclusion

If Georgia consumers are willing to pay premiums for beef that is locally sourced, it is reasonable to assume that producers are willing to change business practices to accommodate these buyers. The demographical and financial characteristics of the survey respondents are very diverse and offer an accurate representation of Georgia beef producers in both the northern and southern regions of the state. Georgia's beef industry is made up of farmers at every stage of production, and the results of this research have shown that several are capable and willing to participate in the opportunities provided by this potential state-branded program.

The concept of a state-branded beef program is nothing new. As we have seen over the past 20 years, there has been similar research conducted in different regions of the United States. The concerns of producers have been pretty consistent in every scenario. Just like in any business, the core of the research has been focused on evaluating if producers are willing to take on the risks associated with adopting these new business practices, if not completely restructuring their businesses altogether.

A unique aspect of our research has been the high possibility of producers needing to haul to a centrally located facility to participate in the program. This is definitely a big obstacle for smaller producers, but we have seen that the larger producers are willing to take this on. In order for this to be worthwhile, producers want higher premiums for the cattle they haul to the centrally located facility. It makes perfect sense that as the hauling distance to the centrally located facility increases, the premium that producers desire to make the endeavor worthwhile increases. The most appropriate and practical solution then is to consider the establishment of separate regional processing facilities that will cater to each region's producers' differentiated demands and expectations for hauling distances and pricing, as well as their diverse demographic and structural attributes.

While it is feasible to take on the additional costs associated with participating in the program, any concern over the marketing and branding effectiveness of the program will have to be addressed if the project moves along. It has been a concern of producers in other states, and just like any business endeavor, an effective marketing campaign will be key to success. In doing so, the state-branded beef will stand out in supermarkets and, hopefully, build loyal customers after the first purchase. Due to several research endeavors in the past indicating that consumers are willing to pay premiums for local food, it seems that the state-branded beef program in Georgia has the opportunity to capture increased profits for producers. The branding and marketing effort will warrant further research and strategizing. If executed effectively like Georgia Grown, it could make a difference for the long-term success of a state-branded beef program.

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My State's Better: Development of a State Pride Scale for Use in Market Research

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State branding programs have become an integral part of many food marketing efforts throughout the United States. State pride may play a role in consumers' demands for local food products that satisfy desires for connectedness through the food supply chain. However, little research has studied measures of consumers' state pride, i.e. ethnocentrism. In this study, we develop and calculate consumers' state pride scores based on survey responses from consumers across an eight-state region. We find that most consumers do not have extremely high or low levels of state pride, but the probability of choosing one's own state brand is predominately affected by their state pride score..

Key words: Ethnocentrism, Exploratory Factor Analysis, Market Research

In recent decades, a majority of market research has concentrated on the factors that affect consumers' evaluations of one label relative to another. Food marketers have endeavored to keep up with an ever-evolving emphasis on labels such as local, organic, natural, non-GMO, eco-friendly, humane, and free of artificial additives. Geo-proximity terms are most commonly associated with local food labels, but there has been little consensus among consumers as to the distance from which the food could be sourced and still be considered "local" (Durham, King, and Roheim 2009; Holcomb et al., 2018). The U.S. Congress first realized the difficulty of defining "local" consistently across all U.S. Department of Agriculture (USDA) programs when developing the 2008 Farm Bill, eventually deciding to use the rather ambiguous range of 400 miles. Still, every U.S. state has developed a state branding program for in-state-sourced foods and agricultural products (Onken and Bernard, 2010). State marketing programs, some of which have been active for decades, use state resources to compete against neighboring states by bolstering their own state's brand through coordinated marketing programs. In short, the debate about the value of local foods and the impacts of domestic product promotion

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programs is still ongoing and worth investigating (Johnston et al., 2018; Khachatryan et al., 2018; Holcomb et al., 2018).

The intentions of these state marketing efforts are closely associated with "beggar-thy-neighbor" trade policies between countries, which assumes that residents of a given country will place a higher value on own-country products relative to those from neighboring countries or a multi-country region (Neill et al., 2020). Choosing a domestically produced good over a foreign-sourced alternative is referred to as consumer ethnocentrism, and "…gives the individual a sense of identity, [and] feelings of belongingness" (Shimp and Sharma, 1987, pg. 280). In regard to U.S. food marketing, a more economically focused question is: Does consumer ethnocentrism exist at the state or regional level?

State branding programs function on the presumption that states' residents have a latent preference for own-state products, but this presumed belief system has rarely been tested in the literature—especially considering the impacts of neighboring state brands. Understanding consumers' perceptions of "local" and their beliefs toward own-state and neighboring state brands are vital to effective evaluation of the impacts of state marketing programs. This is not to say that all marketing programs serve to help identify consumers' latent preferences, as one could argue that many marketing efforts are designed to change preferences. In the case of state branding programs, if the belief is that consumers already prefer local food products, then the marketing efforts are revealing the latent attribute. More specifically, state branding programs focus on the state's brand or logo rather than any specific supplier, product, or any non-geographical product characteristic (Holcomb et al., 2018)

As suggested by a growing literature, beliefs play a significant role in estimating consumer willingness to pay for various attributes and could bias policy implications if not explicitly accounted for within model estimates (Lusk, Schroeder, and Tonsor, 2014; Neill and Williams, 2016; Howard et al., 2020). Our approach is to test the validity of an adapted generalized ethnocentrism (GENE) scale and determine if resulting ethnocentric (state pride) scores affect the explanatory power of consumer choice models for state-branded products (Neuliep and McCroskey, 1997). This will aid in studying the importance of subjective beliefs in consumer choice problems.

This research addresses the problem of measuring state pride and including it in assessments of consumers' food choices. While this study only adds a small piece to the research on local foods research, the literature on developing a state pride scale is sparse and only tests the scale with respect to one state. This study develops a state pride scale for each state of an eight-state region and tests the effects of corresponding state pride scores on state brand choice under equal price competition. The purpose of developing such a scale is to provide a measure of personal beliefs to be utilized in future research on consumers' local food purchasing decisions.

We hypothesize that average state pride scores do not vary significantly across the eight states but play a statistically significant role in consumers' preferences for their own state brands. Since state pride is a primary motivator for state food marketing programs, our study directly assesses whether these marketing programs are successfully appealing to this specific consumer behavior. Additionally, the results of this study will assist marketing managers from the chosen eight-state region in identifying appropriate target markets for state brands and labels.

Ethnocentrism and State Brands

The concept of ethnocentrism, as credited by Sumner (1906), is generally understood as the systems in which social groups interact; specifically, through "ingroup" and "outgroup" mentalities. These mentalities often regard the actions, beliefs, or the characteristics of the ingroup more favorably than those of the outgroup (Weber, 1994). However, such feelings tend to serve as protectionary measures for the central ingroup to maintain esteem and status, as opposed to blaming outgroups for negative behaviors (Weber, 1994). Due to the implications of such behaviors, ethnocentrism has been studied from various sociological fronts (e.g. ethnicity, religion, nationality), with a variety of measures causing Neuliep and McCroskey (1997) to develop the GENE scale to serve as a standardized measure of ethnocentrism.

Where previous studies had focused on the sociological implications of ethnocentrism, Shimp and Sharma (1987) were the first to apply this concept to consumer behavior, coining the term "consumer ethnocentrism." The authors wanted to measure national pride beliefs held by American consumers and their impacts on the demand for foreign-made products. Thus, they developed their consumers' ethnocentric tendency scale (CETSCALE). This scale became a popular method in determining consumer ethnocentrism. As international trade has increased over time, interest in this area of study has grown. Over the years, marketers have attempted to understand how consumer demographics, lifestyle choices, and many other attitudes and beliefs (such as conservatism, patriotism) may impact these tendencies (Josiassen, Assaf, and Karpen, 2011; Sharma, Shimp, and Shin, 1995; Kaynak and Kara, 2002; Lusk, Schroeder, and Tonsor, 2014; Neill and Williams, 2016; Osburn, Holcomb, and Neill, 2020).

Other areas of study focus on how ethnocentric tendencies comingle with country of origin effects and any domestic country biases to ultimately affect consumer perception and demand for imported products (Lantz and Loeb, 1996; Watson and Wright, 2000;

Balabanis and Diamantopoulos, 2004). Lantz and Loeb (1996) determined, in the case of low involvement products with no price differences, country of origin is an important factor. A few studies went further to determine whether preference for different product categories changed as domestic options became available (e.g., Watson and Wright, 2000; Balabanis and Diamantopoulos, 2004). This was especially relevant to recent country of origin labeling (COOL) policy considerations for many meat products. Consumer ethnocentrism was not taken into account in many COOL consumer studies (Lusk and Anderson, 2004; Loureiro and Umberger, 2005), so preliminary studies about COOL program implementation did not account for whether consumers cared about the origin of their meat products. The COOL program was eventually rescinded due to strong consumer beliefs about domestically produced meat as they discounted imported meat products quite heavily (Loureiro and Umberger, 2005).

International food markets are not unique in the use of consumer predispositions for product differentiation techniques. Many state agricultural (food) programs attempt to increase demand through the inclusion of labeling and quality characteristics important to consumers, and the literature is rife with examples of the impacts these labels have on consumers' preferences (e.g., Carpio and Isengildina-Massa, 2009; Hand and Martinez, 2010; Nganje, Hughner, and Lee, 2011; Ostrom, 2006; Patterson et al., 2003; Khachatryan et al., 2018). However, creating and maintaining brand loyalty is a key goal of these programs. In the process of differentiating their products, many state agricultural programs draw upon consumer ethnocentrism for their marketing strategies. This occurs when state-specific symbolisms or culturalisms are used for promotional slogans or product logos and labels in an attempt to invoke consumers' state pride (Onken and Bernard, 2010).

One such state-pride scale was developed by Johnston et al. (2018) for a similar evaluation of state-operated agricultural marketing programs. The work of Johnston et al. (2018) uses the cultural values scale (CVSCALE) and hypothesize how each component affects state pride and state brand consumption. This study aligns more with a sub-component of collectivism and determines how consumers view their state as compared to others. Moreover, this study is only concerned about developing a scale to measure state pride and determine if that, in turn, affects state brand consumption.

Data

The data were obtained from an online survey performed by Survey Sampling International, Inc. (SSI) and was distributed to an eight-state region in December 2015. Specifically, the surveyed states were Arkansas, Colorado, Kansas, Louisiana, Missouri, New Mexico, Oklahoma, and Texas. Questions regarding respondents' demographics, residence (county and state) as well as questions designed to ascertain respondents' ethnocentric tendencies were included in the survey. Demographics of participants across the eight-state region are provided in Table 1. The sample was collected as a stratified sample to be representative of each state's population. The sample has more female respondents, but a large majority are primary shoppers for their households.

Table 1. Demographic Summary Statistics for Each State and Region.

Demographics		Arkansas	Colorado	Kansas	Louisiana	Missouri	New Mexico	Oklahoma	Texas	Region
Primary shopper										
Yes		88.90%	85.50%	89.30%	88.50%	91.60%	84.30%	88.30%	90.50%	88.70%
No		11.10%	14.50%	10.70%	11.50%	8.40%	15.70%	11.70%	9.50%	11.30%
Gender										
Male		23.80%	36.60%	30.10%	27.20%	29.30%	33.40%	27.60%	37.80%	30.80%
Female		76.20%	63.40%	69.90%	72.80%	70.70%	66.60%	72.40%	62.20%	69.20%
Children under 18										
Yes		39.50%	28.00%	41.60%	39.30%	38.80%	29.20%	44.40%	37.80%	37.70%
No		60.50%	72.00%	58.40%	60.70%	61.20%	70.80%	55.60%	62.20%	62.30%
Number of people in household										
	1	16.30%	19.40%	16.30%	17.00%	16.20%	20.60%	15.60%	16.30%	17.00%
	2	34.70%	43.70%	33.40%	32.60%	36.20%	41.50%	32.40%	34.30%	52.80%
	3	20.80%	15.30%	20.50%	22.30%	19.20%	15.20%	19.10%	22.70%	19.70%
	4	17.20%	12.80%	16.60%	15.70%	14.10%	11.80%	18.70%	16.00%	15.50%
	5+	11.10%	8.90%	13.20%	12.50%	14.30%	10.80%	14.10%	10.70%	12.00%
Education level										
Less than high school		3.00%	1.50%	1.20%	2.50%	2.10%	1.50%	1.90%	1.70%	1.90%
High school/ GED		21.10%	8.20%	13.90%	23.00%	20.50%	12.80%	19.10%	17.00%	17.20%
Some college		30.80%	20.40%	25.30%	25.70%	26.20%	29.50%	27.30%	26.60%	26.10%
2-year college degree		12.10%	9.90%	13.60%	10.50%	10.90%	10.80%	12.50%	10.60%	11.30%
4-year college degree		21.70%	34.70%	29.00%	25.90%	24.90%	26.30%	24.90%	29.00%	27.30%
Master's degree		8.80%	17.70%	13.00%	9.70%	11.70%	14.00%	10.40%	11.60%	12.10%
Doctoral degree		0.90%	2.70%	1.90%	1.10%	1.60%	2.00%	2.20%	1.30%	1.70%
Professional degree (JD, MD)		1.60%	4.90%	2.10%	1.60%	2.20%	3.20%	1.60%	2.10%	2.40%
Age	18-25	15.90%	10.20%	13.60%	17.10%	11.80%	12.30%	12.80%	13.30%	13.40%
	26-34	17.80%	15.30%	20.70%	17.60%	21.80%	15.20%	22.20%	20.90%	19.20%
	35-49	25.20%	22.10%	24.70%	26.80%	24.80%	21.10%	27.80%	25.80%	25.10%
	50-65	29.90%	33.70%	29.70%	28.50%	30.60%	30.20%	26.10%	27.40%	29.50%
	65+	11.20%	18.70%	11.20%	10.00%	11.00%	21.10%	11.00%	12.70%	12.90%
Approximate annual income										
less than $30,000		35.20%	18.00%	24.10%	29.20%	26.70%	32.70%	26.50%	21.20%	25.90%
$30,000-$59,999		35.50%	27.10%	29.50%	32.50%	36.50%	30.50%	34.70%	34.40%	32.80%
$60,000-$89,999		17.00%	19.70%	25.30%	18.00%	19.00%	16.50%	20.40%	22.40%	20.00%
$90,000-$119,999		6.50%	12.90%	10.00%	9.80%	9.60%	9.30%	9.00%	9.80%	9.70%
$120,000-$149,999		3.60%	11.10%	5.60%	5.40%	3.20%	4.70%	5.30%	6.40%	5.80%
$150,000 or more		2.10%	11.20%	5.50%	5.20%	4.90%	6.40%	4.10%	5.90%	5.70%
Observations		802	1,003	686	1,000	1,002	430	994	1,010	6,927

The information used in this study was part of a larger survey to analyze consumer preferences for various geographic-based marketing labels. As part of this study, the focus is to develop a state pride scale and test whether this new variable affects consumer choice for one's own state brand. In the following sections, we discuss the scale formation, test the scale validity using exploratory factor analysis, and assess the effectiveness of the scale in determining the probability that a consumer will choose their own state brand.

Methodology

Scale Development

The general concept of ethnocentrism has been studied under a variety of scales, methods, and subtypes. As previously mentioned, Shimp and Sharma (1987) developed a commonly used scale to measure consumer ethnocentric tendencies (CETSCALE), originally targeting the American perspective of purchasing foreign-made versus American-made products. Although the CETSCALE has been used to determine consumer purchase behavior across several cultures and countries, Sharma (2015) argued that the scale had limitations regarding its validity, dimensionality, and cross-cultural measurement invariance. The author also argued against the original CETSCALE definition of consumer ethnocentrism, believing it more accurately reflected a consumer's "affective reactions, cognitive bias and behavioral preference" toward domestic and foreign products.

Neuliep and McCroskey (1997) aimed to develop a more accurate, generalized ethnocentrism scale to standardize the ethnocentrism determination. Their findings suggested that a generalized ethnocentrism scale (GENE) with explanatory factor analysis provided a better measure of ethnocentrism than other scales which may be capturing both ethnocentrism and other factors (e.g. patriotism). The authors stated that the GENE scale "was written to reflect a conceptualization of ethnocentrism that may be experienced by anyone, regardless of culture" (Neuliep and McCroskey, 1997, pg. 390). For this study, a modified version of the revised GENE scale was used.

The revised GENE Scale, which is still used extensively in the psychology literature to measure ethnocentrism (Morris, Savani, and Fincher, 2019), used 24 statements, half worded positively, and half worded negatively, to determine the level of ethnocentricity. For this study, only the revised GENE Scale statements with factor loadings of 0.70 or greater were used as a basis in development of our state pride scale. Statements with a higher factor loading have a larger impact on consumers for a specific latent factor. Elimination of several of the original revised GENE was also based on the ability to translate the statements to be state-specific. Many of the scale items below our 0.70 cutoff value were not transferable between an international and state context. With these restrictions in place, half of the original statements remained: seven worded positively and five negatively. The original 12 statements were modified to reflect individual sentiments on the state, rather than national, level to create the state pride scale. For each statement, respondents were asked to rank their sentiments from strongly disagree to strongly agree. Table 2 contains the 12 statements used and indicates whether they are intended to represent the positive or negative factor.

Table 2. Adapted Statements from the Revised GENE Scale for Use in Exploratory Factor Analysis.

Statement Number	Statement	Positive	Negative
1	My state should be the role model for other states	X	
2	Most people from other states just don't know what's good for them	X	
3	Most people in my state just don't know what is good for them		X
4	Most people would be happier if they lived like people in my state	X	
5	My state is backward compared to most other states		X
6	Other states should try to be more like my state	X	
7	My state is a poor role model for other states		X
8	Lifestyles in other states are not as valid as those in my state	X	
9	People in other states could learn a lot from people in my state	X	
10	Other states are smart to look to my state	X	
11	I respect the values and customs of other states		X
12	My state should try to be more like other states		X

Note: Positive and Negative refers to the factor classes identified by Neuliep and McCroskey (1997).

An additional “trap” question was included to ensure that respondents were actively participating in the survey. The trap question identifies inattentive or rapid responders who have the potential to skew any statistical analysis (Malone and Lusk, 2018). These types of questions are increasingly common in psychology and political science literature (Berinsky, Margolis, and Sances, 2014; Oppenheimer, Meyvis, and Davidenko, 2009) and predominately used to decrease incorrect inferences from survey data. Those who answered the trap question incorrectly were not included in any analysis. About 8% of the participants answered the trap question incorrectly.

Exploratory Factor Analysis

Exploratory factor analysis (EFA) using principle components analyses with varimax rotation was applied to the state pride scale for individual states and for the pooled eight-state region (Gorsuch, 1974; Inman et al., 2019). EFA is used to better understand the underlying structure of data. More specifically, EFA examines all pairwise relationships between individual statements on a scale and constructs latent factors from said variables (Osbourne and Banjanovic, 2016). Conceptually, EFA examines the shared variances from a principle components model each time a factor is created. The factors are created as weighted linear combinations of the shared variance (Osbourne and Banjanovic, 2016). EFA allows for error to enter the model where variables, in our case statements about state pride, fall into various factors. The purpose of this analysis is to ensure that our adaptations of the revised GENE statements do not significantly alter the way consumers perceive the relative importance of the statements and corresponding factors.

Using statements in Table 2 and the consumer panel, we expect to find the same positive sentiments in Factor 1 and negative sentiments in Factor 2 within the EFA. To ensure that each question reflected a meaningful statement to consumers, only those statements with a factor loading of 0.40[1] or higher were kept for state pride score calculations. The order of statements was randomized between participants to reduce any order effects. Any statements that had factor loadings greater than or equal to 0.40 in more than one factor were removed from state pride score calculations, as is the common practice in EFA (Gorsuch, 1974). Elimination of the cross-loading factors was not done without considerable thought. Because the original scale items with a "negative" connotation were reverse coded, it was vital to have a clear distinction between factors to which the scale item belonged. This is not an uncommon practice in the literature, though it is heavily debated (Yong and Pearce, 2013). The EFA was performed using SAS 9.4 software and the PROC FACTOR command.

Probability of Choosing One's Own State Product

Fluid milk was used as the basis for product comparisons across states. We recognize that milk consumption has decreased in recent decades, but fluid milk remains a staple food item commonly purchased by U.S. households with an average annual per capita consumption of 146 pounds (USDA-Economic Research Services, 2019). Although

[1] The value was chosen as it was the minimum loading value in Neuliep and McCroskey's (1997) study, as is standard in psychology literature.

advances in transportation methods and logistics have allowed milk to be transported over longer distances, milk remains a relatively locally/regionally marketed and almost completely generic commodity. Furthermore, the packaging for a gallon of milk is similarly generic, with almost-identical opaque plastic jugs as the industry standard. The generic nature of a gallon of fluid milk allows for state-to-state comparisons with minimal quality differences/perceptions other than those directly related to the product label.

Within the survey, participants completed a choice experiment relating to preferences for state branded milk[2]. At the end of the choice experiment, each participant was presented with all available options (milk options with each of the eight state brands, a regional brand, and a national brand) at equal prices. From the choice question with equal prices, the probability of person, *i*, residing in state, *j*, choosing their own state's brand can be estimated. Further, we can determine the impact of one's state pride score on the probability and how that varies across states. The probability of choosing one's own state is as follows:

$$\Pr(Y_{ij} = 1) = \frac{\exp\left(\beta_1 + \boldsymbol{\theta X_i} + \alpha_1 Z_{ij}\right)}{1 + \exp\left(\beta_1 + \boldsymbol{\theta X_i} + \alpha_1 Z_{ij}\right)} \quad (1)$$

where Y_{ij} is a binary variable for choosing one's own state; $\boldsymbol{X_i}$ denotes demographic variables for respondent *i*; and Z_{ij} denotes the state pride variable for participant *i* residing in state *j*. Since only demographic data and the state pride scale data were collected through the survey, no other variables related to participants' social, economic, or psychological attributes were available for inclusion. Equation (1) is modeled following a logit specification for each state. The logit analysis is performed using SAS 9.4 and the PROC LOGISTIC command.

Results

Exploratory Factor Analysis

Results showed that a majority of the statements flagged the same latent factor as experienced by Neuliep and McCroskey (1997). However, there were a few exceptions, which can be seen in Table 3. Across all eight states and the regional analysis, a third

[2] See Neill, Holcomb, and Lusk (2019) and Osburn, Holcomb, and Neill (2020) for a deeper discussion of the choice experiment. This study does not use any of the standard choice experiment data for analysis.

factor was revealed in which the following statement was isolated: "I respect the values and customs of other states." Although most of the states isolated this statement in a third factor, New Mexico had a strong negative correlation with that statement. In addition, New Mexico isolated Statements 2 and 8 in Factor 3. Arkansas, Colorado, Kansas and the region as a whole reflected double factors (1 and 2) for the statement "Most people from other states just don't know what's good for them." This scale item also cross loaded in factors 1 and 3 for Missouri. This is reasonable as the statement mostly cross loaded with the negative factor and was negatively correlated with statement 11, yet positively correlated with Factor 1. This is similar to what occurred in the other instances when the scale item cross loaded in Factor 2. Otherwise, we confirm that Factor 1 is the positive sentiment and Factor 2 is the negative sentiment latent classes as in Neuliep and McCroskey (1997). The two double-flagged[3] statements (2 and 8) were disregarded in any ethnocentrism calculations. Elimination of the double-flagged statements was due to the inconsistency of how our sample viewed the scale items. If the scale items were left in the pride calculations, we would have created bias in our estimates.

After reexamining the original statements, we determined that the wording of the third factor reflected a neutral sentiment rather than the intended positive or negative wording. The wording seems to invoke a desire for unity across the survey participants since they inhabit the same aggregated geopolitical boundary (i.e. country). Thus, Factor 3 is deemed a "unity" factor. The unity factor among all states was relatively similar which is unsurprising since all the states are located in the south central/southwest region of the United States. Since this scale item was originally found to be negative in the revised GENE and clearly does not align with the other positive scale items, this scale item was deemed to align with the negative factor in our study. All the remaining statements represent information that significantly influenced one factor. The adapted statements align well with the revised GENE factors, which means that our results are not significantly different from previous literature. Thus, the EFA results from our sample on state pride statements explain a significant portion of the variance and are useful for creating a state pride score.

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[3] Double-flagged statements are those that have factor loadings above 0.4 in two different latent classes/factors.

Table 3. Factor Analysis Results by State and Region.

Statement	Arkansas (N=802)			Colorado (N=1,003)			Kansas (N=686)			Louisiana (N=1,000)			Missouri (N=1,002)			New Mexico (N=430)			Oklahoma (N=994)			Texas (N=1,010)			Eight-State Region (N=6,927)		
	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3	F1	F2	F3
1	71*	-20	1	81*	-11	7	69*	-22	6	71*	-12	10	80*	-8	11	73*	-7	-8	71*	-13	4	80*	-13	6	75*	-16	7
2	64*	45*	-20	47*	48*	-30	77*	45*	-12	62*	36	-32	48*	32	-45*	31	27	66*	53*	40*	-36	71*	32	-22	62*	43*	-28
3	14	77*	-8	7	77*	-10	24	84*	9	19	78*	-5	8	76*	-12	4	75*	18	9	80*	4	16	81*	-5	13	81*	-2
4	73*	-8	-4	80*	-2	0	78*	-12	9	76*	-6	8	77*	-8	-8	81*	5	7	78*	-4	7	84*	-5	4	80*	-5	4
5	-14	73*	4	-11	80*	5	-22	74*	-3	-14	77*	8	-5	84*	7	-12	74*	-9	-17	74*	1	-6	82*	0	-14	80*	6
6	83*	-2	13	84*	-2	2	77*	-21	1	80*	-10	-3	84*	-2	0	75*	-8	18	80*	-7	-1	84*	-8	4	83*	-9	2
7	-22	78*	10	-29	73*	0	-21	76*	3	-30	70*	2	-32	74*	-5	-30	69*	0	-26	71*	-1	-15	82*	4	-25	76*	3
8	62*	20	-37	51*	21	-40*	69*	2	-31	60*	14	-34	49*	20	-43*	31	3	57*	56*	23	-9	74*	20	-17	63*	21	-33
9	73*	-18	19	81*	-8	3	71*	-17	12	73*	-11	21	83*	-9	7	75*	-9	-9	77*	-15	10	79*	-12	9	78*	-12	13
10	80*	-11	10	81*	-10	11	67*	-31	-1	74*	-15	1	82*	-4	10	64*	-24	-2	74*	-17	6	78*	-12	9	77*	-16	8
11	15	20	94*	19	18	95*	3	18	98*	15	19	94*	22	22	94*	37	22	(-87)*	18	27	92*	3	13	97*	14	22	97*
12	-17	78*	20	-4	80*	23	-11	76*	11	-14	70*	15	-2	83*	23	-5	73*	-8	-8	75*	18	-2	82*	19	-8	79*	18
Eigenvalue	3.95	2.85	1.23	4.1	2.92	1.4	4.46	3.56	1.2	4.24	3.04	1.25	4.07	2.83	1.65	3.92	3.12	1.78	4.48	3.27	1.38	4.6	3.17	1.09	4.35	3.22	1.27

*Note: * denotes values that meet the threshold flagging criterion.*

State Pride Score Formation and Descriptive Statistics

To create an accurate pride score for each state, we use the remaining 10 statements from the factor analysis. Respondents used a five-point Likert scale to identify their level of agreement with each of the opinions or statements, ranging from strongly disagree to strongly agree. For those statements reflecting positive home-state sentiments, “strongly disagree” equaled one and “strongly agree” equaled five. The negative home-state sentiments were reverse coded. As previously mentioned, the unity statement was considered a negative statement to follow Neulip’s and McCroskey’s (1997) method and have a balance of positive and negative statements. From there, the coded statements were summed together to develop a general, or base, pride score for each survey participant.

The prospective pride score has the following ranges: 10-20 (extremely low), 21-30 (somewhat low), 31-40 (somewhat high), and 41-50 (extremely high). Although each sample had respondents reflecting the extremely low scores, none of the respondents were extremely ethnocentric with the highest scores ranging from 34 (Kansas participants) to 37 (Louisiana participants). Even though consumer pride scores were similar among states, the specific composition of the distributions varied. Table 4 discloses the first three moments of each distribution (means, standard deviations, and skewness) for the eight-state pride scores along with the overall region score. The averages themselves varied little across states, but provided a ranking of states by state pride score: Colorado, Texas, Missouri, Arkansas, Oklahoma, Kansas, Louisiana, and New Mexico. Results from both the state and regional levels indicate that a majority of state residents have low to average pride scores. This result is somewhat expected as most consumers responded to the unity question with a four or five on the Likert scale. Texas and Colorado have significantly higher means from the rest of the states, while New Mexico is statistically lowest (though Louisiana is not statistically different from New Mexico).

Table 4. Descriptive Statistics of State Pride Scores by State and Region.

State/Region	Mean	Standard Deviation	Skewness
Arkansas	25.483	4.527	-0.899
Colorado	26.577	4.088	-1.086
Kansas	25.042	4.973	-0.967
Louisiana	24.729	4.973	-0.815
Missouri	25.508	4.342	-0.957
New Mexico	24.104	4.894	-0.572
Oklahoma	25.339	4.991	-0.925
Texas	26.476	4.759	-1.204
Region	25.407	4.693	-0.928

Skewness varies by more than one across the eight states. Skewness indicates the direction and magnitude for which the distribution of state pride scores is skewed from a symmetric normal. Across all states, state pride is negatively skewed (left-tailed), which means the mode and median of the distribution is higher than the mean. In other words, more than 50% of the sample has a state pride score above the mean for each state. The same result of skewness is exhibited in the regional mean, suggesting that aggregation will also lead to a majority of the sample having an above-average state pride score.

Probability of Choosing One's Own State Product

From the state-specific logit models in Table 5, we find that most demographic variables do not affect the probability of choosing one's own state-branded milk. However, for a point increase in a person's state pride score, there is a statistically significant increase in the probability of one choosing their own state-branded milk product, excluding Kansas residents. For example, the average marginal effect of state pride for each of the states are as follows: 0.009 for Arkansas, 0.015 for Colorado, 0.011 for Kansas, 0.008 for Missouri, 0.009 for New Mexico, 0.011 for Oklahoma, and 0.005 for Texas. Thus, the range of effects of a one-point increase in state pride scores on the probability of choosing one's own state product is 0.5% to 1.5%. This points to the idea that state pride does play a statistically significant role in consumer choice and could be an important consideration for marketing state-branded products. However, the effect is relatively small. Considering the average state pride score for every state is around 25, the marginal effect has little impact on actually choosing one's own state-branded milk product. Even with small marginal effects, the results demonstrate the importance of incorporating consumer beliefs into consumer choice models. Thus, despite weak empirical validity, there is a strong case for including some measure of subjective beliefs to increase the explanatory power of the model.

Table 5. Logit Analysis for Probability of Choosing One's Own State-Branded Milk Option under Equal Prices.

Parameter	Arkansas	Colorado	Kansas	Missouri	New Mexico	Oklahoma	Texas
Intercept	-1.77*	-2.08*	-0.08	-1.45*	0.11	-1.60*	-1.39*
Female	0.07	0.16	0.18	0.25	0.1	0.08	0.2
Children	-0.43	-0.13	0.14	-0.25	-0.36	0.27	-0.24
Household size	0.03	-0.01	-0.01	0.06	0.09	-0.1	0.02
Education (Base: Professional Degree)							
Less than high school degr	-0.84	-0.5	-0.22	-0.48	-2.73	0.53	-0.83
High school/GED	0.03	-0.28	-0.29	-0.22	-2.23	-0.09	-0.25
Some college	0.17	0.28	-0.3	-0.02	-1.37	0.08	0.12
2-year degree	0.09	0.16	-0.02	0.02	-1.51	0.06	0.18
4-year degree	-0.09	0.40*	0.02	0.18	-1.16	0.33	0.45*
Master's degree	0.19	0.38*	0.03	0.15	-1.06	0.04	0.24
Doctoral degree	-0.15	-0.33	0.37	0.69	12.11	-0.67	-0.11
Age (Base: Older than 65)							
18-25	-0.29	-0.19	-0.25	-0.24	-0.57*	-0.15	-0.18
26-34	0.07	-0.22	0.04	-0.04	-0.23	-0.09	0.06
35-49	0.27	0.03	0.04	0.1	0.28	0.2	0.13
50-65	-0.08	0.30*	0.25	0.13	0.18	0.11	0.09
Income (Base: $150,000 or more)							
Less than $30,000	-0.18	-0.18	-0.43*	-0.31*	-0.29	-0.60*	-0.22
$30,000 to $59,999	0.03	-0.16	-0.27	-0.02	0.07	-0.07	-0.01
$60,000 to $89,999	0.05	0.18	0.01	-0.13	0.02	0.1	0.08
$90,000 to $119,999	0.3	-0.14	-0.04	0.02	-0.49	0.4	-0.01
$120,000 to $149,999	0.44	0.22	0.06	0.4	0.43	0.28	0.35
Primary shopper	0.76*	0.24	0.15	0.48	0.32	0.17	0.02
State price score	0.03*	0.07*	0.01	0.03*	0.04**	0.05*	0.02*
-2 Log L	1021.57	1168.52	989.24	1368.32	511.25	1223.71	1338.19

*Note: * denotes significance at 5% or higher. Standard errors are suppressed for readability, and are available upon request.*

Implications for State Branding Programs and Marketing Managers

Given the factor analysis results and state pride score calculations, it appears that state agricultural programs should not solely rely on state pride as the driving force for in-state marketing promotions. While a majority of our survey respondents did not fall into the extremely low level of state pride, very few were found to be extremely high. Further, the average score fell in the middle of the "somewhat low" state pride score range, which further indicates that solely targeting consumer pride would not guarantee long-term success for the program. More specifically, the state pride score elicited in this study is an indicator of people's general ethnocentric beliefs. This translates to marketing efforts by testing the latent marketing message of state branding programs. As previously stated, it was found that ethnocentric beliefs are rather low by our measurement tool. So, marketing efforts that focus on the "pride" aspect of state branding are potentially less effective than marketing efforts focusing on the "local" aspect. Thus, continuing to utilize state pride alongside other differentiating techniques (local, farmer/producer characteristics, targeting the state's most recognized commodities, quality, etc.) is potentially the more impactful alternative for marketing managers. This conclusion is derived from an analysis of preferences for the generic commodity of fluid milk and only further research can determine if these state pride results can be generalized to a variety of other products. However, this research represents a further step in understanding how consumers' beliefs (ethnocentrism) affect their choices.

For state branding programs, this research highlights the fact that ethnocentrism does matter when using these marketing programs to promote food products. However, state-level ethnocentrism may not be as important a factor when compared to demographic variables and other factors not captured in this study. The results of the logit model confirm that demographics are the most important drivers in determining which consumer segments are most likely to purchase local- and state-branded products, which is key for marketing managers. Moreover, marketing managers cannot solely rely on a population's ethnocentric tendencies as a motivator for purchasing state-branded products. Some state samples did have stronger beliefs than others, such as Colorado consumers, which means appealing to ethnocentric beliefs would have marginally better impacts on increasing purchases. As for a state like Kansas, consumers' ethnocentric beliefs are not statistically significant drivers of purchasing decisions. As the previous literature has found, subjective beliefs can bias consumer choice models and it is important to find ways to accurately measure these beliefs (Howard et al., 2020).

One limitation of the research is the inability to determine whether this scale accurately captures state pride relative to other scale options. If this modified GENE scale does accurately measure state pride/ethnocentrism, these lower scores may indicate there is less variation in ethnocentrism across sub-regions (states) within a country, rather than across countries. The ability to compare this modified GENE scale to an expanded scale or alternative scale, such as that in Johnston et al. (2018), would strengthen the validity of the findings. Regardless, further testing among different regions of the United States would prove beneficial for this scale's validation. There may also be differences across regions of the country that include multiple states. Again, this would need to be tested further. Another limitation of this study is the absence of other important factors which affect consumer choice such as social/family situations, local economic conditions, and other psychological factors beyond ethnocentrism.

Ideally, the survey would have also benefited from more information about the respondents, such as their longevity as residents in their current state. Respondents' relationships with neighboring states (e.g. as a former resident for work reasons or as a college student) and proximity to neighboring states' borders may be factors for consideration in future research. Such information may help researchers and state marketing programs further identify areas of relatively greater state pride, where state-branded products may attract greater brand loyalty and willingness-to-pay compared to the "average" state consumer.

From the logit model, it is obvious that each state marketing program must evaluate its own consumers. There is much variation in how demographic information affects the probability of choosing one's own state product, which contributes the intricacies of measuring consumers' state pride. This information, however, will help state marketing programs modify advertising techniques to achieve greater returns from program investments. The results also provide a basis for further research on the potential of regional branding programs and the collective ethnocentrism across subsets of states. Since the factor analysis revealed a third factor, which we consider a unity factor, the ethnocentrism scale statements could be used to further investigate the collective marketing potential for regional programs.

These results prove that marketing managers must perform their due diligence when selecting their target markets and marketing strategies for state-branding efforts. The probability of choosing one's own state brand under equal price competition is increased by increases in our study's state pride measure. This means that our scale confirms our hypothesis and theoretical assumptions about state pride and state food marketing programs. However, there is still much variation in the state pride effect across states. This suggests that the brand marketing programs in some states are more effective at eliciting responses based on ethnocentrism than others. In other words, much like the sizes and shapes of U.S. states, the relative pride levels of states' citizens reflect notable variations.

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