CELL BASED MEAT BUDGET AND IGENITY PANEL SCORES IN A COW-CALF OPERATION

By

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Abstract: The first essay examines the economic feasibility of cell-based meat. Cell-based meat has received much favorable press and is being touted as a replacement for the entire livestock industry. The question addressed here is what will it cost to produce cell-based meat in a large-scale production facility? Previous research has focused on the cost of the cell-culture medium rather than other potentially important costs. This research estimated startup, production, employment, and transportation costs in addition to available cell-culture medium costs and expected output per batch to create a full-detailed enterprise budget. Using a compilation of new data and published literature, results show the cell-based meat industry is not likely to be economically competitive with animal-derived proteins. Assuming that technology will be developed to reduce the cost of the medium including growth hormone substitutes and buying ingredients in bulk, one kilogram of cell-based meat is estimated to cost $63/kg to produce in a large-scale facility. The three major costs of production are the cell-culture medium, bioreactors, and labor. These costs make up over 80% of the overall cost of production. The second essay examines Igenity panel scores and productivity in a cow-calf operation. Igenity panel scores measure genetics and have proven helpful in feedlot and bull selection, but the cost of such testing has prevented widespread adoption. Little research, however, has been conducted to understand the relationships between genotypic panel scores and economically relevant cow-calf production variables such as weaning weights, cow weights, and birth weights, all of which are important determinants of cow-calf profitability. Understanding these relationships could lead to improvements in efficiency and profitability in the beef sector. Data from four ranches in South Central Oklahoma were used with mixed regression models to determine the relationships between economically relevant production variables and genetic panel scores. Marginal revenues were calculated for each panel score to show their effect on calf revenue, cow revenue, and dystocia. Some factors such as tenderness, average daily gain, residual feed intake, and marbling had negative effects on cow-calf profitability.

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CHAPTER I

CELL BASED MEAT BUDGET

Abstract

Cell-based meat has received much favorable press and is being touted as a replacement for the entire livestock industry. The question addressed here is what will it cost to produce cell-based meat in a large-scale production facility? Many of the funders behind this industry hope to reduce the environmental and land impacts of our current agricultural system. Although the initial goal is to use animal stem cells for cell cultivation, many firms want to be independent of animals in the long-term. The industry is evolving each day, so there is still much uncertainty on what the final product will cost. Previous research has focused on the cost of the cell-culture medium rather than other potentially important costs. This research estimated startup, production, employment, and transportation costs in addition to available cell-culture medium costs and expected output per batch to create a full-detailed enterprise budget. Using a compilation of new data and published literature, results show the cell-based meat industry is not likely to be economically competitive with animal-derived proteins. Assuming that technology is developed to reduce the cost of the medium including growth hormone substitutes and buying ingredients in bulk, one kilogram of cell-based meat is estimated to cost $63/kg to produce in a large-scale facility. The three major costs of production are the cell-culture medium, bioreactors, and labor. These costs make up over 80% of the overall cost of production.

Introduction

Mark Post created the first cell-based hamburger in 2013 with a cost exceeding $200,000 (Post, 2014; Kadim et al., 2015), and it has been a worldwide race to see who is the first to hit the supermarket shelves with cell-based meat. Cell based meat is not a substitute for plant-based meat. Instead, it is an edible biomass grown from animal stem cells in a factory (Mattick et al., 2015). Fresh lean trimmings, in both beef (90% fat content) and pork (72% fat content), are a comparable product to cell-based meat. The wholesale price of lean pork is $3.75/kg and lean beef is $6.17kg in the current market (AMS, 2021). The question addressed here is can cell-based meat compete with current meat products, both traditional and plant-based, on price?

Previous studies examined consumer preference (Van Loo et al., 2020), media costs (Specht, 2020), and the economics of current production capabilities (Risner et al., 2021). In a small-scale model under current capabilities, cell-based meat can have production costs over $400,000/kg without technological adaptation of the media and production processes (Risner et al., 2021). A small-scale model is classified as a single, small bioreactor process, compared to the four large bioreactors evaluated in this paper and other studies. A bioreactor process is large-scale if it is big enough to fill a large warehouse. Specht addressed the cost of the media used to culture the cells and the potential to reduce this cost by changing medium components and introducing areas where technological innovation is needed (Specht, 2020). This paper contributes to published studies by considering all potential costs for a large-scale operation. A full-detailed enterprise budget was created for a large-scale cell-based meat firm estimated to produce an annual 560,000 kilograms with quotes from bioreactor manufacturers, transportation and labor costs, electrical costs, and scalable media costs (Specht, 2020). The three largest costs are the cell-culture medium, the bioreactors, and labor. Other potential variable costs are discussed to demonstrate that they are relatively small. Lastly, a sensitivity analysis is performed to measure the price elasticity of cell-based meat and identify potential cost reductions on wholesale price.

Cell-Based Meat

This product goes by many names, cell-based, cell-cultured, in-vitro, or even lab-grown meat, but they all refer to the formation of muscular skeletal tissue that resembles traditional meat in taste, texture, and nutrition. Cell-based meat offers a protein alternative for those who do not like the taste and texture of traditional meat, are concerned about their environmental impact, or are concerned about the ethics of utilizing animals for consumption (Stephens et al., 2018). The long-term goal of cell-based meat producers is to eliminate stem-cell use to eliminate consumers' ethical concerns (Kadim et al., 2015). Although this technology has been rapidly evolving, there are difficulties in scaling production to meet consumer demand.

Cell-based meat requires technology consistent with pharmaceutical production plants. Scientists start with stem cells from a muscle they are replicating induce these cells to grow and proliferate (Kadim et al., 2015). Cells are placed in a small bioreactor. The bioreactor supports a biologically-active environment and looks similar to fermentation tanks in breweries or equipment used in pharmaceutical manufacturing. Temperature and Oxygen in the bioreactor are vital to the cell-culturing process (Kadim et al., 2015). The cell-culture medium is the most important component of the process, and the medium includes growth hormones, nutrients, and other important components for the cells to replicate. Without the liquid medium to promote growth, the cells do not divide and grow. To form muscular fibers, a framework is provided for the cells to scaffold (Kadim et al., 2015). As the cells rapidly divide, they are moved through a series of larger and larger bioreactors ranging from 200L to 20,000L. Cells are harvested using two methods. The first harvest method removes all cells from the bioreactor in a single harvest and therefore requires the process to restart. In the second method, a percentage of the cells are harvested from the bioreactor, ranging from 50% to 90%, and the cells continue to grow and increase the total production for each batch (Specht, 2020). After harvest, the cells are then prepared for packaging and the used media is deactivated and then disposed.

Enterprise Budgeting

Enterprise budgeting techniques are used to calculate individual production costs associated with large-scale cell-based meat production (NRCS, 2000). The final enterprise budget is shown in Table I-1 and has an estimated production cost of $63/kg. The enterprise budget is separated into two categories, operating expenses and fixed costs. Operating expenses are 71% of the final cost and include water, transportation, repairs and maintenance, electricity, labor, packaging, and the cell-culture medium. Interest on operating capital is calculated with an interest rate of 6% and assumes the operating loan is paid out in two installments across the year. Fixed costs include capital recovery expenses (i.e. depreciation and interest) for the bioreactors, cold storage facility, insurance, building lease, and computer infrastructure. The three big cost categories are the cell-culture media (31%), the bioreactors (28%), and labor (28%). Each of these cost categories are considered and assumptions behind the numbers are explained. In terms of infrastructure and location, it is assumed for this exercise that this firm is located in San Francisco, California because of its proximity to funding, competitors, and potential consumers. This location exhibits a tradeoff between a higher cost of labor and a lower cost of transportation to consumers as compared to other locations considered.

Medium Cost

The fluid in which the cells are grown is known as the cell culture medium. The medium currently being used includes fetal bovine serum (made from the blood of fetuses obtained when pregnant females are slaughtered). Fetal bovine serum is expensive and will not provide a long-term solution. The hope is to eventually be independent of animals. All medium components and costs in this budget come from Specht (2020). Specht (2020) considers alternative scenarios of using the Essential 8 medium that is currently used for stem cell reproduction in the pharmaceutical industry. Specht's estimates are used as the cost of the medium. The Essential 8 medium includes a basal media plus seven other critical components. The basal media has 52 components. Although the Essential 8 medium has not been proven to be functional at the large-scale food manufacturing level, it is the most complete medium that can be purchased for this purpose. Most, if not all, of the large cell-based meat startups will have created their own medium protected by intellectual property rights. Major components of the basal medium by weight are salt, D-Glucose, and HEPES (Specht, 2020). The HEPES is a major cost and is used to control the pH of the solution. As cells grow, they produce lactic acid and so there is a limit to how long the medium is used without being replenished.

Specht analyzed 5 different scenarios that include varying assumptions about the Essential 8 medium (see Table I-2). The *Base Case*, also used in the economic analysis by Risner et al. (2021), was reported to cost \$376.80/L, or \$7.5 million per each 20,000L batch. The *Base Case* assumes 2020 production capabilities while using the Essential 8 basal media and includes growth hormones FGF-2 and TGF-β. These two hormones make up a majority of the cost, so Specht considers other production options. Specht's *Scenario D* uses hypothetical substitutes for the growth hormones FGF-2 and TGF- β. *Scenario D* is used since it provides a realistic approach for production consistent with the technology and innovation needed to compete with traditional meat. *Scenario D* assumes a cost of \$3.74/L according to Specht (2020). Note that Specht has additional scenarios that reduce the cost even further. Specht argues that reducing the cost of the basal medium and Vitamin C are realistic possibilities.

There is a great deal of uncertainty about how much media is needed. This budget uses Specht's below-average media use, which means a 50% harvesting scenario with 10 harvests for each batch and yields 19,250 kg from each bioreactor every 51 days (Specht, 2020). The 50%

harvesting scenario reduces media use since it keeps the same media in each bioreactor for up to two times as long as a 100% harvesting scenario. This scenario also provides for more cell replications and a larger output. Four bioreactor lines staggered for constant output will produce 548,400 kg of cell-based protein each year. Production assumptions include 24-hour production 365 days a year and fully operational equipment. Other production possibilities (i.e. maintenance downtime and equipment malfunctions) are addressed in the sensitivity analysis. Harvesting a portion of the cells from the final bioreactor increases output per batch without taking the time to restart from the beginning of the process. This can be done for up to ten iterations (Specht, 2020). Each batch, including the ten harvests, was estimated to use 100 kl of cell-culture medium. The medium is assumed to be transferred between bioreactors without draining and replacing it. New medium is added to fill the bioreactors to their desired volume. The medium is assumed be flushed and replaced four times throughout the production process. Note that this analysis of the medium was conducted under optimistic medium conditions and is assumed to use the top level of efficiency specified by Specht (2020). Also note that cell structure may not be able to withstand these conditions, but technological advancements are expected in this area. These medium conditions do not currently exist as the medium needs to be replaced somewhere between every 2-6 days, but it is cost prohibitive to assume this for production.

Under these assumptions, the cell-culture media is the largest annual production cost equal to $10.78 million, or $19.66/kg. This cost was calculated assuming that growth hormones can be replaced with cost effective substitutes that do not currently exist. The medium is expected to cost just under $75,000 per 20 kl used (Specht, 2020). This cost is calculated assuming seven total harvests each year. The partial harvest only occurs in the final largest bioreactor.

Bioreactor Cost

The next major cost of production is the bioreactors. Four bioreactor lines are assumed for production. These lines will include equipment for media preparation, upstream process, and deactivation. One bioreactor line can be described as follows. The cell culture medium will need to be prepared, so this model includes a 1,000L vitamin preparation tank, a 2,000L preparation tank for the smaller bioreactors, and a 30,000L preparation tank for the large bioreactors. The individual ingredients will be combined with the basal media and water in the smaller preparation tanks and diluted to the proper ratio in the larger tank. To minimize downtime between batches, this model also includes two 30,000L media storage tanks at the beginning of the line. After it is mixed, the medium will be fed through a series of seed bioreactors with volumes of 200L, 1,000L, and 5,000L. Seed bioreactors are used to gradually increase the batch size before it reaches the final bioreactor to minimize time spent in the final bioreactor and have a constant output of cell-based meat. The cells will then move to a 20,000L final-stage bioreactor where the harvesting will take place. There will be two 30,000L harvest tanks at the end of the production line where the meat can begin the scaffolding process.

The manufacturing plant will have to abide by the rules and regulations provided by the agencies that oversee production (e.g., the Food and Drug Administration, Occupational Health and Safety Administration). The plant will have water mixed with active ingredients of the cell-culture medium that will go through a series of deactivation steps before it can be disposed of in a sewer system. In addition to media deactivation for environmental concerns, the plant will also need cleaning in place (CIP) units to meet sanitary standards likely to be required by regulatory agencies and reduce cross-contamination. This will follow suit to common standards in the pharmaceutical industry. Finally, the bioreactor line will need two 20,000L cell waste inactivation tanks and three CIP units equipped with two tanks each.

The media preparation and post-harvest equipment can support a second line of bioreactors with staggered production, hence the extra media preparation tanks and harvest tanks.

To meet the goal of 4 bioreactor lines, this equipment spec has been doubled to use two media preparation lines, four bioreactor lines, and two harvest and deactivation lines. A quote for the cost of equipment was obtained from an industry leader in food-grade processing equipment. The total cost was estimated to be $60,000,000 with all equipment and setup included. Depending on equipment specifications, input prices, and post-order changes, the manufacturer warns consumers the total cost could increase or decrease by up to 30%. The bioreactors are amortized over a 10-year useful life and a 10% cost of capital assuming no salvage value, resulting in an annual fixed payment of $9.76 million. At the previously stated annual output of 548,400 kg, this will cost $17.81/kg.

Labor Cost

The final major cost of cell-based meat production is labor. This industry will use pharmaceutical-grade equipment, which will require a highly qualified team of operations engineers, microbiologists, product development scientists, managers and administrators, accountants, computer and communications technologists, board of directors, input procurement specialists, janitorial staff, packaging and shipping specialists, safety specialists, and legal and human resources staff. The production facility is expected to run 24 hours a day year-round and will require one laborer, lower-level operations staff supervised by an operations engineer, per bioreactor as well as a full labor force during business hours. Using average salaries from the Bureau of Labor Statistics, BLS, and assuming all employees are full time, these employees will earn an average annual salary of $75,868 (BLS, 2020). In addition to each average salary, benefits, including healthcare insurance, sick leave, retirement contributions, and vacation time, have been estimated at 30% of each total salary, bringing the total amount paid per employee to just under $103,000. Estimates are based on pharmaceutical industry averages for each of the specific positions above ranging from a low of $32,000 to a high of $245,000. Positions, salaries, and number of employees are described in Table I-3. On average, for an annual output of 548,400 kg of meat protein, labor will cost $17.65/kg of output which is 28% of the total cost.

Minor Costs

Transportation Cost

In the San Francisco area, transportation was estimated to the nearest large retail distribution center from the warehouse district using Google Maps. The product is transported in a refrigerated semi-trailer. Refrigerated trucking rates are assumed at $2.49/km, and the nearest big-box distribution center is approximately 322 km from San Francisco. This firm will fill 36 trailers each year with annual production of 548,400 kg and an average trailer weight of 18,140 kg, filling trailers close to full capacity. This will result in an annual 11,587 km traveled with a total cost of $28,800 or $0.05/kg of cell-based meat.

Electricity Cost

Risner et al. (2021) found that electrical costs are negligible when compared to the total cost of production. Production will use more electricity than a typical industrial plant. Due to limited information, electricity costs were budgeted at four times the industrial average use in California. The industrial average electricity use in California is 26,981 kWh at $0.16/kWh (EIA, 2021). Given that this firm will operate 24 hours a day, year-round, the firm is expected to use 1,200,000 kWh each year at a price of $0.16/kWh, resulting in an annual cost of electricity equal to $197,520, or $0.36/kg. Backup electricity costs are not included should power be lost during production.

Packaging Cost

Similar protein substitutes, i.e. plant based meat, have been packaged in the form of ground meat in vacuum-sealed bags in 0.45 kg allotments, or 20x25 centimeter bags. According to bulk industry pricing for 20x25cm (estimated with imperial 8x10 inch bags at 1 pound each) vacuum sealable bags will range from 15 to 18 cents per unit. Assuming optimistic conditions, this will result in an annual cost of $181,383 for an annual production of $548,400 kg. This cost was estimated as $0.33/kg.

Water Cost

Similar to other food-processing industries, a major concern of the cell-based meat industry is its expected annual use of clean water. Using a 50% harvesting scenario and a production cycle of 51 days on all 16 bioreactors, this firm was calculated to use 226,619 liters of water weekly, or 11.78 million liters per year (Specht, 2020). This was estimated using the total cost for California using a four-inch water meter and converted the number to hundreds of cubic feet, or CCF (Calwater, 2020). This includes wastewater cost and assumes this is the method the firm will use to dispose of the media after it has been deactivated. Whenever cell-based meat is regulated in the United States, this could likely change. Water will cost $33,439.95 each year, or $0.06/kg.

Cold Storage Cost

The final product will be composed cells similar to traditional animal tissue; therefore, it needs to stay refrigerated in a cold storage facility prior to shipping to preserve the product for the consumer. It is assumed this product is kept refrigerated upon packaging and is kept at that temperature until consumption. For an annual output of 548,400 kg, 36 refrigerated trailers are filled each year, or approximately 18,140 kilograms of output every 10 days. According to an industry leader in cold-storage construction, this will require 457.2 square meters of cold storage at the firm at a construction cost equal to $722/square meter. This equates to a fixed cost of $330,000, or $0.10/kg. This quote was estimated to meet staggered batch requirements to keep up with production. Given the large fixed-cost requirement of this construction, it was amortized over ten years assuming no salvage value and a ten percent cost of capital.

Building Lease, Information Technology, and Insurance Cost

For this analysis it was assumed that it was more economical to rent a warehouse and equip it with all the equipment and machinery, including the four bioreactor lines and cold storage facility necessary for the desired scale of operation. To this end, a 2,787 square meter warehouse and corresponding property was rented at a price $129 per square meter per year under a 20-year lease arrangement, which according to Zillow.com was the going rate for this type of property in the warehouse district in San Francisco, California in January of 2022.

It was assumed that 100 computer information and technology stations are required to operate the plant at a cost of $2000 each. This cost includes purchase price for computers, monitors, printers, phones, photocopiers, software, and internet access per station.

It was also assumed that in order to safeguard the cell-based meat firm's investment from unforeseeable losses, the firm needs to have a policy insuring $80 million in assets annually. The price for such a policy is $1000 per million dollars insured, or $80,000 per year.

Stem Cell Cost

Current technology takes cells from live animals to create the initial cell culture. These cells have to be replenished. The goal for future sustainability is to be completely animal free, and thus, stem cell free (Kadim et al., 2015). The Essential 8 Basal Media is optimized for human growth components and is a serum-free media, meaning fetal bovine serum is not needed for production, while instead using insulin and transferrin (Specht, 2020). Similarly, the goal is to develop a stem cell line that is independent of live animals. No cost for maintaining this line is included since it is hoped that the cost will be negligible.

Sensitivity Analysis

Sensitivity analysis was conducted to gain an understanding of how production costs ($/year) and final expected costs of cell-based meat ($/kg) can be expected to vary for incremental *ceteris paribus* changes in assumptions about total production (kg/year) and costs for key inputs such as medium costs, bioreactor costs, and labor costs.

Down Time

The base assumption that the firm will operate 24 hours per day year-round is designed to place a lower bound on total production costs. However, this assumption is not feasible in the real world because reductions in total production are expected to occur as a result of necessary annual machinery repair and maintenance. Reductions in production can also be due to exogenous events such as malfunction, disruptions of timing of harvesting, disruptions in supply chain, and unforeseen circumstances that food manufacturers tend to incur over the course of time. Calculations suggest the total cost per kilogram is expected to increase by $0.15 for every day without production. In other words, each day without production reduces the overall output by approximately 1,500 kilograms.

The three major costs for a cell-based meat production firm are the cell-culture media, bioreactors, and labor. The remainder of the sensitivity analysis is focused on these three costs plus the cost of transportation because so many outside factors can impact transportation.

Cost of Medium

Sensitivity analysis was completed on the cost of the cell-culture medium by the Good Food Institute (Specht, 2020). That report suggests that hormone substitutes and bulk components are needed to decrease the cost of the medium from $3.74/L to $0.24/L. The original analysis used *Scenario D* which assumes the cheapest production method possible while still using the Essential 8 basal media. The sensitivity analysis assumes the basal media is recreated from bulk components and uses substitutes for the main cost drivers, resulting in a cost of $0.24/L (Specht, 2020). Note, other than purchasing ingredients in bulk and producing the medium in the facility, there currently exists no ability to improve media production. Technical improvements in the mixing equipment leading to increases in the efficiency of mixing the ingredients of the medium could also reduce medium costs and total costs of production in the future.

Bioreactor Cost

This analysis suggests that small reductions in the purchase cost of the bioreactors tend to have a significant reduction in overall cost and positive impact on the cost of the final product. It is noteworthy to point out that current industry producers have stated that total capital expenditures can be reduced by repurposing old pharmaceutical production equipment for a fraction of the cost of new equipment. Also, if the demand for bioreactors increases as a result of growth in this market, engineers would seek at ways to reduce the overall cost of building bioreactors, such as producing them at greater scale, using alternative materials, or improving the biological process for growing cells. Over time, this could lead to a significant reduction in estimated production cost given that it is one of the highest costs of production.

Labor Cost

Traditional packing plants, plant-based meat production firms, and many other food and beverage manufacturers have been able to reach their current production costs through the adoption of automated labor-reducing technology. In 2001, a survey among food manufacturers found that 94% of the respondents had a mostly automated processing system, and 82% had an automated packaging system (Ilyukhin et al., 2001). In the sensitivity analysis, it is assumed that automation cuts the lower-level operations team by 25 employees, therefore further automating the production process. While automation can help reduce labor costs, the automation equipment itself can also be expensive.

Cost Under Alternative Scenarios

What would the final cost be under Specht's (2020) lowest cost and under alternative reductions in costs for the bioreactors and labor? With Specht's final scenario and lowest cost scenario, it costs $44.09 to produce one kilogram of cell-based meat, dropping the cost of the medium to $1.28/kg. This cost still assumes the same operating and fixed costs in the original analysis. Note that reducing these costs also reduces the interest paid on operating capital. The other two major costs, labor and bioreactors, are also ways to reduce the overall cost. Assuming Specht's lowest cost scenario for the medium and reducing the cost of both the bioreactors and labor by 25%, 50%, and 75% will result in a total cost of $35.09/kg, $26.10/kg, and $17.10/kg. With Specht's lowest cost and driving bioreactor and labor cost to zero, the total cost is still $8.10/kg. Reducing only one of the three major costs will not make a sufficient difference on its own, so it is going to take all three to significantly reduce the cost of production. Even then it will sell at a premium to beef, pork, and chicken.

Conclusion

Using information gathered from published reports and industry leaders, this analysis suggests that cell-based meat produced in a large-scale plant can be produced at a cost of $63/kg if technology can be developed to produce the hormones at low cost. In practical terms, for this large-scale production, a kilogram of cell-based hamburger meat would cost well over 100 dollars at the supermarket.

The three largest costs of production are the cell-culture media, bioreactors, and labor, resulting in a cost of over $55/kg for just those three categories. The cell-based meat industry requires innovation in reducing the cost of the media before it can reach the costs estimated here. Cell-based meat has not been approved for consumption in most countries, and when it does get approved, it will be much more expensive than other meat and protein products.

Increased mechanization could reduce labor costs. Using used equipment from the pharmaceutical industry could reduce costs in startups but has a limited supply. A new lower-cost cell culture medium could greatly reduce costs.

It is not likely that many consumers are willing to pay $100 for a kilogram of lean meat at the supermarket. However, history has shown that as technologies improve, the cost of production can decrease to a point that encourages large-scale production. It is projected that producing at large-scale and if projected innovations in media materialize, the cost of producing cell-based meat can drop from over $400,000/kg to just $63/kg. If such a cost is reached, cell-based meat could conceivably compete as a niche product that can command a premium price (such as high value seafoods or perhaps a rare exotic species). Results show that this industry will need to focus on reducing capital and labor costs as well as the media cost if it wants to compete on price with meats such as beef, pork, and chicken.

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Table I-1. Expected Operating and Fixed Costs Associated with a Cell-Based Meat Production Plant with a Production Capacity of 548,000 kg yr-1.

Input description	Units	Quantity (unit/year)	Price ($/unit)	Cost ($/yr)	Cost ($/kg)	Share of cost (%)
Operating:						
Water[a]	kl	11,780	2.46	28,978.80	0.05	0.08
Growth medium[a]	kl	2,880	3,743.00	10,779,840	19.66	30.90
Transportation	km	11,584.80	2.49	28,800	0.05	0.08
Electricity	kwh	1,200,000	0.16	197,520	0.36	0.57
Packaging	kg	548,400.45	0.33	181,383.45	0.33	0.52
Labor and benefits[b]	employees	94	102,997	9,681,718	17.65	27.75
Bioreactor Maintenance	% of total cost	-	5	3,000,000	5.47	8.60
Total operating costs minus interest	$	-	-	23,898,240.25	43.58	-
Interest on operating capital	total $ at risk	23,898,240	0.06	716,947	1.31	2.05
Total operating costs	$	-	-	24,615,187.46	44.89	70.55
Fixed:						
Building and property lease	m2	2,787	129.12	359,857	0.66	1.03
Bioreactors/processing equipment[c]	kl	80	-	9,764,723.69	17.81	27.99
Cold storage construction[d]	m2	457.20	721.79	53,705.98	0.10	0.15
Computer/information infrastructure	computers	100	2,000	16,274	0.03	0.05
Insurance	coverage ($M)	80	1,000	80,000	0.15	0.23
Total fixed costs	$	-	-	9,944,703.67	18.74	29.45
Total variable plus fixed costs	$	-	-	34,559,891.13	63.62	100
Breakeven price of cell-based meat	$/kg	-	-	-	63.62	-

[a] Assumes a 50% harvesting scenario with 10 harvests in each 51-day production cycle.

[b] Labor and benefits assume a 0.3 multiplier to estimate benefits.

[c] Equipment cost includes four 20kl bioreactors at the final stage and a series of smaller bioreactors, transfer piping, seed tanks, deactivation tanks, shipping, and installation costs.

[d] Cold storage is estimated to be 457.2 square meters to accommodate a weekly output of 10,546 kg.

Table I-2. Total Medium Cost Using the Essential 8 Basal Medium.

Components	Base Case	Scenario A	Scenario B	Scenario C	Scenario D
Basal medium[a]	\$62,400	\$62,400	\$62,400	\$62,400	\$62,400
Vitamin C or Precursor	\$10,035	\$10,035	\$10,035	\$10,035	\$10,035
NaHCO3	\$2.39	\$2.39	\$2.39	\$2.39	\$2.39
Sodium Selenite	\$0.03	\$0.03	\$0.03	\$0.03	\$0.03
Insulin	\$131,920	\$13,192	\$131,920	\$13,192	\$1,552
Transferrin	\$85,600	\$8,560	\$85,600	\$8,560	\$856.00
FGF-2	\$4,010,000	\$401,000	\$800.00	\$80.00	\$8.00
TGF- β	\$3,236,000	\$323,600	\$16.00	\$1.60	\$0.16
Total cost per 20,000 L	\$7,535,958	\$818,790	\$290,774	\$94,271	\$74,854
Cost per liter	\$376.80	\$40.94	\$14.54	\$4.71	\$3.74

[a] The 52 ingredient basal medium comprises the bulk of the culture medium and supplies most of the nutrients (Parkinson, 2020).

Source: Specht (2020)

Notes: Specht's scenarios E, F, and G consider possible reductions in the cost of the basal medium with the lowest cost scenario having a cost per liter of \$0.24. Scenario D is used in this study to show large-scale media production with technological advance in the growth hormones.

Table I-3. Employee Positions and Average Salaries

Position	Employees	Base Salary[a]	Position Total	Benefits Paid
Chief Executive Officer	1	$ 245,300	$ 245,300	$ 73,590
Chief Financial Officer	1	$ 245,300	$ 245,300	$ 73,590
Chief Operations Officer	1	$ 245,300	$ 245,300	$ 73,590
Operations Manager	2	$ 165,140	$ 330,280	$ 99,084
Assistant Manager	6	$ 136,280	$ 817,680	$ 245,304
Operations Engineers	5	$ 97,670	$ 488,350	$ 146,505
Operations Lower Level	30	$ 52,640	$ 1,579,200	$ 473,760
Accounting Team	5	$ 86,140	$ 430,700	$ 129,210
Packaging/Shipping Team	5	$ 36,340	$ 181,700	$ 54,510
Product Development	10	$ 98,610	$ 986,100	$ 295,830
Custodial Staff	5	$ 32,740	$ 163,700	$ 49,110
Marketing/PR Team	5	$ 74,350	$ 371,750	$ 111,525
Microbiologists/Scientists	3	$ 82,670	$ 248,010	$ 74,403
Procurement	3	$ 74,200	$ 222,600	$ 66,780
Maintenance Engineers	4	$ 55,590	$ 222,360	$ 66,708
Human Resources	4	$ 78,970	$ 315,880	$ 94,764
Information Technology	4	$ 88,320	$ 353,280	$ 105,984
Total by category	94		$ 7,447,490	$ 2,234,247
Average			$ 79,229	$ 23,769
Salary paid per employee				$ 102,998

[a] All positions and salaries come from the Bureau of Labor Statistics (BLS, 2020) industry averages for pharmaceutical manufacturing. Benefits are assumed to be 30% of the total salaries paid for each position.

CHAPTER II

IGENITY PANEL SCORES IN A COW-CALF OPERATION

Abstract

Igenity panel scores measure genetics and have proven helpful in feedlot and bull selection, but the cost of such testing has prevented widespread adoption. Little research, however, has been conducted to understand the relationships between genotypic panel scores and economically relevant cow-calf production variables such as weaning weights, cow weights, and birth weights, all of which are important determinants of cow-calf profitability. Understanding these relationships could lead to improvements in efficiency and profitability in the beef sector. Data from four ranches in South Central Oklahoma were used with mixed regression models to determine the relationships between economically relevant production variables and genetic panel scores. Marginal revenues were calculated for each panel score to show their effect on calf revenue, cow revenue, and dystocia. Some factors such as tenderness, average daily gain, residual feed intake, and marbling had negative effects on cow-calf profitability.

Introduction

Previous research found that genetic profiles help predict key cattle growth traits in bull (Vestal et al., 2013), feeder (DeVuyst et al., 2011), and live cattle selection (Holt, 2010; Thompson et al., 2014), but there has been little research on the relationship between genotypic panel scores and economically relevant cow-calf production variables. Further, traits that are desirable in feedlot cattle production, such as average daily gain, residual feed intake, marbling, and tenderness, are potentially deleterious for cow-calf operations. For example, increased cow weights may not correlate with increased cow-calf profitability (Bir et al., 2018).

The objective of this study was to find the value of genetic traits to the cow-calf sector by determining their effect on calf birth weight, weaning weight, and cow weight. Herds have shifted to a more feedlot-driven genetic composition with an emphasis on muscle, growth, and milk production in the last few decades (Bir et al., 2018; Smith, 2014). What traits, if any, produce higher weaning weights, efficient cow weights, or increase producer profitability? Does the optimal selection of Igenity panel scores for the entire beef sector differ from those that benefit cow-calf operators? Genetic traits as measured by Igenity panel scores are readily available and producers as well as the whole cattle industry can benefit from knowing more about how best to use this information.

Summary of Previous Research

Genetic testing in beef cattle started with testing for the leptin gene in the 1990's, and the tests focused on single nucleotide polymorphisms (SNPs) that were associated with fat deposition (Fitzsimmons et al., 1998; Buchanan et al., 2002). The leptin gene was able to predict intramuscular and external carcass fat and showed promise to increase feedlot profitability for cattle priced on a grid. While the leptin gene had little to no effect on days on feed and thus there was little value to sorting cattle, it was important in feeder cattle selection with differences up to $48 per head between the different SNPs (DeVuyst et al., 2007). Although genetic testing in cattle showed promise for increasing profitability, testing for the leptin gene in feedlot cattle was abandoned after a few years (Van Eenannaam and Drake, 2012). A study by Mitchell et al. (2009) finds that selecting for the leptin gene within the herd can increase calf weaning weight and cow-calf profitability. In recent years, tests for the leptin gene have been replaced by genomic marker panels. These tests use dozens of SNPs for predicting desired outcomes (Thompson, 2018).

Genomic marker panels were collected in a study of 10,209 commercially fed cattle that included carcass and cattle performance traits (Thompson et al., 2014). Using the genetic tests for management decisions and sorting cattle resulted in values of around $1 per head for each trait evaluated. Using panel scores to market cattle, however, resulted in a range of values from $1-$13 per head depending on the structure of the grid (Thompson et al., 2016). The value of these tests, however, was not enough to offset the cost of testing. In 2016, the Igenity Gold profile cost $40, but the cost has since fallen to $29 per test with the improved Igenity Beef Profile (NEOGEN, 2021). Similar to the leptin gene, selecting for cattle based on genomic marker panels is expected to yield more than using the panels for management decisions alone (Thompson et al., 2014). The expected value of selecting for a single trait was $22, and the value associated with selecting for multiple traits was $38 (Thompson et al., 2014). The value between these genetic differences is high, especially in bull testing (Vestal et al., 2013). There is a market inefficiency due to asymmetric information (Maples, 2019), which causes cow-calf producers with better feedlot genetics to not be fully rewarded. Testing for genomic panel scores has not yet been widely adopted except for breeding animals.

Results from hedonic pricing models show that cow-calf producers did not initially consider available genetic information when selecting or replacing herd bulls (Irsik et el., 2008). Rather than focusing on genetics, the price of a bull was highly dependent on breed, with preference toward Angus, older animals, and lower birth weights. Expected progeny differences (EPDs) are increasingly used in cattle selection, with Vestal et al. (2013) and Boyer et al. (2019) concluding that EPDs were significant determinants of bull prices. The calving ease direct EPD was the only trait that was a significant predictor of bull price in an 11-year study of bull sales in Tennessee (Boyer et al., 2019).

Cow-calf producers have shifted their production practices over the last few decades resulting in higher mature cow weights (Bir et al., 2018; Smith, 2014). This shift in weights was due to a push to produce for feedlot profitability rather than cow-calf profitability (Bir et al., 2018). A concern is that traits that are positive for feedlots could be negative for cow-calf producers. Previous studies did not examine the effects of Igenity panel scores at the cow-calf producer level, but they offer insight into the value of selecting for these traits at the feedlot level (DeVuyst et al., 2011; Thompson et al., 2014; Thompson et al., 2016). This research aims to overcome these gaps and combine the impacts of genetic panel scores from a cow-calf operation with previously estimated impacts on feedlot operations to evaluate the potential for misaligned economic incentives in the beef industry.

Data Collection

From 2015 through 2020, hair follicle samples were taken from cows, steers, heifers, and bulls at weaning or purchase across four ranches in Southern Oklahoma owned and operated by the Noble Research Institute (NRI). These samples were sent to NEOGEN to determine the Igenity genetic profile for each animal. The current NEOGEN Igenity Beef (NEOGEN, 2021) profile provides scores on a scale of 1-10 for 16 traits and three indexes. The scores used at the time of this study were from the Igenity Gold index, but that index is now grouped into the whole Igenity Beef Profile, so the data do not include the full 16 traits Igenity now offers. Producers use this profile to rank cattle based on operation goals. The indexes include maternal, performance, and carcass traits. The maternal index is designed for cow/calf production, and it highlights calving difficulties, inefficient milk production, cattle with poor dispositions, and cows that do not breed back. The performance index was designed with efficiency in mind and highlights lower maintenance cattle and improves gain. The carcass index was designed to help producers predict and select breeding stock that produce higher quality carcasses among their progeny. Here, 13 Igenity panel scores are used including birth weight, calving ease direct, calving ease maternal, stayability, heifer pregnancy, docility, milk, residual feed intake, average daily gain, tenderness, marbling, ribeye area, and fat thickness. Data were collected for 1,205 calves born and weaned on the NRI ranches during that timeframe. Table II-1 shows summary statistics for all calf events and panel scores. Data were collected for 1,544 cows, providing 10,156 cow weights. Cow data include mature cows, first-calf heifers, bred heifers, exposed heifers, and replacement heifers all over one year old. These weights were captured at the chute during pregnancy checks, breeding, veterinary applications, and weight checks from 2015 to 2020. Table II-2 shows the summary statistics of cow weights. Note that calf panel scores were used for the calves rather than dam panel scores. Using dam panel scores would have resulted in losing about half of the observations. The way the data were collected did not allow complete matching of dams and calves. The main place where this would matter is that the dam’s panel score for milk might be more closely linked to weaning weight than the calf’s score.

Data represent four different cow/calf herds located on four different ranches. The ranches are: Oswalt Road Ranch (OR) located near the community of Oswalt, OK (33°59'24.5"N 97°15'16.1"W), D. Joyce Coffey Ranch (CR) located near the community of Marietta, OK (33°56'03.5"N 97°13'38.6"W), Pasture Research and Demonstration Farm (PRDF) located near the community of Ardmore, OK (34°13'06.6"N 97°12'14.4"W), and the Red River Research and Demonstration Farm (RRF) located near the community of Burneyville, OK (33°52'56.5"N 97°16'03.5"W). CR and OR are comprised of native prairie grass and PRDF and RRF have introduced bermudagrass pasture. Hay and protein cubes were used to supplement feed in the winter months. Angus cows were artificially inseminated following the CoSynch 7 synchronization program. Those cattle were artificially inseminated with Angus semen with Charolais bulls turned out within 24 hours upon insemination. Angus cows sired by Hereford bulls followed a natural 60-d breeding program. Multiple analyses were conducted for weaning weight, birth weight, and cow weight including Pearson correlation coefficients and mixed model regressions to determine genetic correlations with weight, sex, and age.

Igenity panel scores predict future progeny performance in comparison to the progeny of other animals (Igenity, 2020). The panels include two to over 100 SNPs (DeVusyt et al., 2011), but the exact number is proprietary. Higher Igenity panel scores are not always better but indicate the animal has a higher genetic potential for that trait. Table II-3 provides a description and the desired outcome for each trait. Igenity provides tables for the genetic effects of each score that allow producers to convert their panels into molecular breeding values (MBV's), so they can see their potential benefit when it comes to calf crop revenue, cull cow revenue, herd longevity, and lowered dystocia rates. These molecular breeding values are in the units of the desired trait (i.e. the MBV's for the birth weight panel score are in pounds). The molecular breeding values in their indices follow a linear pattern, so that provides justification for including the panel scores linearly in the regression equations. Lastly, producers can put individual selection pressure on individual traits in their index and receive feedback on traits that are desirable in their herd (Igenity, 2020). This is why it is so important for producers to understand their desired results and the outcomes associated with different genetic values.

Econometric Models

The first step in the analysis was to calculate Pearson bivariate correlation coefficients between Igenity genetic panel scores, weaning weight, and cow weight. Next, genetic panel scores were used in combination with age, time of year, and sex to determine their relationship with weaning weight, birth weight, and cow weight using the MIXED Procedure in SAS (SAS Institute Inc., 2013). Rebreeding success was not considered due to an inadequate number of observations being available (approximately 300 had sufficient information). Note that estimated equations are reduced form models. Reduced form models do not include other dependent variables as explanatory variables (Marsh and Brewster, 1989). For example, birth weight is a known predictor of weaning weight, however, the inclusion of birth weight changes the structural properties of the weaning weight equation. Weaning weight and birth weight equations use the genetic markers from the calf while the cow weight equation uses genetic markers from the cow.

The weaning weight relationship was modeled as

$$(1)\qquad WeanWeight_{it} = \beta_0^{WW} + \sum_{n=1}^{13} \beta_n^{WW} IBP_{itn} + \beta_{14}^{WW} Age_{it} + \beta_{15}^{WW} Age_{it}^2 + \beta_{16}^{WW} Female_{it} + \tau_t^{WW} + \varepsilon_{it}^{WW}$$

where $WeanWeight_{it}$ is calf weaning weight WW in pounds for the *i*th animal in the *t*th year, Age_{it} is the calf's age at weaning, Age_{it}^2 is the calf's age squared, IBP_{itn} is the Igenity genetic panel score for the *n*th panel, $Female_{it}$ is a class variable that takes a value of one for females and zero for males, and year random effect τ_t^{WW} and error term ε_{it}^{WW} for the weaning weight equation are assumed to be independent and normally distributed with a mean of zero.

An equation for calf birth weight was also estimated as

$$(2)\qquad BirthWeight_{it} = \beta_0^{BW} + \sum_{n=1}^{13} \beta_n^{BW} IBP_{itn} + \beta_{14}^{WW} Female_{it} + \tau_t^{BW} + \varepsilon_{it}^{BW}$$

where $BirthWeight_{it}$ is calf birth weight BW in pounds. Year random effect τ_t^{BW} and error term ε_{it}^{BW} are assumed to be independent and normally distributed with a mean of zero. The Igenity genetic panel scores represent the genetics of the calf and not the dam.

The genetic relationship between cow weight and the panel scores is represented as

$$(3)\qquad CowWeight_{it} = \beta_0^{CW} + \sum_{n=1}^{13} \beta_n^{CW} IBP_{itn} + \sum_{j=1}^{14} \beta_j^{CW} Age_{itj} + \sum_{k=1}^{4} \beta_k^{CW} Q_{itk} + \mu_i^{CW} + \tau_t^{CW} + \varepsilon_{it}^{CW}$$

where $CowWeight_{it}$ is the chute-recorded weight CW in pounds, Age_{it} is a class variable denoting cows at the *j*th age, Q_{itk} is a class variable to denote the *k*th quarter in which the cow was weighed, and individual cow random-effect μ_i^{CW}, year random-effect τ_t^{CW}, and error term ε_{it}^{CW} are all assumed to be independent and normally distributed with a mean of zero.

Economic Analysis

A first order Taylor series approximation was used to find the marginal revenue (or cost) associated with each panel score (Mitchell, 1990). The approach begins with producer profit for a single, representative cow. Partial derivatives of the profit function were used to determine the effect on profit of changing the genetic panel scores for both the calves and cows. The components of the first derivative include calf crop revenue, cull cow revenue, dystocia, variable cost, and feed cost. Summing the effects together provides an estimate of the marginal return of an additional unit of each panel score was calculated.

To determine the profit maximizing combination of genetic panel scores, the following equation was used to model calf crop revenue, cull cow revenue, and relevant costs associated with a cow-calf operation. Cow-calf producer profit can be represented as

$$\pi = [(WW_H \times P_H \times 0.5 \times (1 - RPL) + WW_S \times P_S \times 0.5) \times (1 - \%Open) + (P_C \times \%Culled \times CW) - VariableCost - FeedCost(CW)] \times SD \quad (4)$$

where:

$$RPL = 2 \times \frac{\%Culled}{1 - \%Open}$$

$$\%Culled = \%Open + \%Others$$

$$\%Open = \%Base + \%Dystocia$$

$$\%Dystocia = BW \times Rate$$

$$FeedCost(CW) = P_F \times CW^{0.75}$$

$$SD = a \times CW^{-0.75}$$

where π is profit for the representative cow where WW_H is heifer weaning weight in pounds, P_H is heifer price per hundredweight, RPL represents heifers retained for replacement, WW_S is steer weaning weight in pounds, P_S is steer price per hundredweight, $\%Open$ is the percent of the cow herd that did not produce a calf, which could be due to not rebreeding, being culled for other medical issues, or having issues with dystocia, P_C is cull cow price of lean cows, $\%Culled$ is the portion of the cow herd that was culled, CW is cow weight in pounds, $VariableCost$ includes veterinary/health costs and the costs associated with replacing a cull cow with a replacement, SD is stocking density per acres needed to support a single representative cow (so *SD* is one for the representative cow), $FeedCost(CW)$ is the total feed cost per pound of metabolic weight P_F, $\%Others$ is the percent of cows culled after producing a calf, $\%Base$ is the percent of cows culled related to age and failing to breed, $\%Dystocia$ is the percent of calves lost and cows culled due to calving issues and assumes a linear relationship with birth weight BW in pounds, $Rate$ is the linear multiplier used to determine dystocia (*Rate* is 0.000125 for the representative cow), and *a* is a constant. It is assumed the net energy for cow maintenance is a function of metabolic weight, $CW^{0.75}$ (NRC, 1984). Prices were calculated using LMIC (2021) data and assume an October 1 sale date as weaning in the data ranged from late August to late October, with most calves weaning in October. Some weeks did not have a sale due to weather and other issues, so the nearest price within two weeks of October 1 was taken in that case.

The first step in calculating these marginal revenues was to derive marginal revenue for an additional pound of calf weaning weight. Note that price is not appropriate as the price per pound decreases as cattle increase in weight. In the cattle trade the effect of weight on price is reflected in a price slide. This equation can be described as

$$(5) \qquad MR = \frac{\partial Revenue}{\partial WW} = Slide * WW + Price$$

where MR is the marginal revenue of an extra pound of gain, $slide$ is the price slide associated with a higher weaning weight $\left(\frac{\partial P}{\partial WW}\right)$, WW is calf weaning weight, and $Price$ is calf price per pound. The marginal revenue is calculated for both heifers and steers using their respective prices.

The first order partial derivative was taken from profit function with respect to IBP_i for the *i*th calf panel score $\left(\frac{\partial \pi}{\partial IBP_{Calves_i}}\right)$ to find the marginal values associated with each calf panel score. The marginal returns associated with each calf panel score has two components: effect on sales through weaning weight and effect on dystocia through birth weight. This is represented as

$$\text{(6)} \qquad \frac{\partial \pi}{\partial IBP_{Calves_i}} = \left(\frac{\partial \pi}{\partial WW} \times \frac{\partial WW}{\partial IBP_i} \times MR\right) + \left(\frac{\partial \pi}{\partial DYS} \times \frac{\partial DYS}{\partial BW} \times \frac{\partial BW}{\partial IBP_i} \times P_A\right)$$

where $\left(\frac{\partial \pi}{\partial WW} \times \frac{\partial WW}{\partial IBP_i} \times MR\right)$ is the marginal return associated with an additional unit of Igenity panel score *i* for calf crop revenue and $\left(\frac{\partial \pi}{\partial DYS} \times \frac{\partial DYS}{\partial BW} \times \frac{\partial BW}{\partial IBP_i} \times P_A\right)$ is the marginal return associated with an additional unit of each Igenity panel score for dystocia cost where P_A is the price of the heifer, steer, or cow. Since stocking density is one, it does not appear in the equation.

The first order partial derivative was taken from profit function with respect to IBP_i for the *i*th cow panel score $\left(\frac{\partial \pi}{\partial IBP_{Cows_i}}\right)$ to find the marginal return associated with each cow panel score. The components of marginal returns associated with each cow panel score are cull cow revenue, feed cost, and stocking density. This is represented as

$$\text{(7)} \qquad \frac{\partial \pi}{\partial IBP_{Cows_i}} = \left(\frac{\partial \pi}{\partial CW} \times \frac{\partial CW}{\partial IB_{\ \ i}} \times P_C\right) + \left(\frac{\partial \pi}{\partial Feedcost} \times \frac{\partial Feedcost}{\partial CW} \times \frac{\partial CW}{\partial IBP_i} \times P_F\right) +$$

$$\left(\frac{\partial \pi}{\partial SD} \times \frac{\partial SD}{\partial CW} \times \frac{\partial CW}{\partial IBP_i} \times P_C\right) \times \pi$$

where $\left(\frac{\partial\pi}{\partial CW}\times\frac{\partial CW}{\partial IB\ _{i}}\times P_C\right)$ is the marginal return of an additional unit of Igenity panel score i for cull cow revenue, $\left(\frac{\partial\pi}{\partial Feedcost}\times\frac{\partial Feedcost}{\partial CW}\times\frac{\partial CW}{\partial IBP_i}\times P_F\right)$ is the marginal cost associated with an additional unit of each Igenity panel score for feed cost, and $\left(\frac{\partial\pi}{\partial SD}\times\frac{\partial SD}{\partial CW}\times\frac{\partial CW}{\partial IBP_i}\times P_C\right)$ is marginal return (cost) associated with an additional unit of each Igenity panel score for a change in stocking density. Assuming that stocking density is equal to one for cull cow revenue and feed cost, an increase in cow weight will impose costs to the producer in the form of a reduced stocking density.

Since calf and cow Igenity panel scores originate from the same herd, it is assumed that there is equilibrium within the herd genetics. This allows for the calf and cow panel scores to be directly evaluated against each other. As such, equations (6) and (7) are summed to determine the marginal return of each calf and cow panel score for each additional unit of the panels for the whole cow-calf operation. This is represented as

$$(8)\qquad \frac{\partial\pi}{\partial IBP_i}=\frac{\partial\pi}{\partial IBP_{Calves_i}}+\frac{\partial\pi}{\partial IBP_{Cows_i}}.$$

When expanded, equation (8) can be represented as

$$\begin{aligned}(9)\qquad \frac{\partial\pi}{\partial IBP_i}=&\Big(\big[\left(\beta_i^{WW}\times MR_H\times(1-RPL)\times 0.5\right)+\left(\beta_i^{WW}\times MR_S\times 0.5\right)\big]\times(1-\\&\%Open)+\left(\beta_i^{CW}\times P_C\times\%Culled\right)+\big[-\left((WW_H\times P_H\times 1.5)+(WW_S\times P_S\times 0.5)\right)+\\&(CW\times P_C)-VariableCost\big]\times\beta_i^{BW}\times Rate+\left(\beta_i^{CW}\times 0.75\times P_F\times CW^{-0.25}\right)\Big)\times\\&SD+\left(-0.75\times\beta_i^{CW}\times a\times CW^{-1.75}\times CW\times P_C\times\%Culled\right)\end{aligned}$$

where $\beta_i^{WW}$is the marginal value for Igenity panel score i for the weaning weight equation WW, MR_H is the marginal revenue of an extra pound of weaning weight for heifers, MR_S is the marginal revenue of an extra pound of weaning weight for steers, β_i^{BW}, is the marginal value for the birth weight equation BW, and β_i^{CW} is the marginal value for the cow weight equation CW.

Holding dystocia and stocking density constant, the marginal effect of the calf Igenity panel scores on calf crop revenue is represented as

(10) $\frac{\partial\pi}{\partial WW} \times \frac{\partial WW}{\partial IBP_i} \times MR = \left[\left(\frac{\partial(WW_H \times P_H)}{\partial IBP} \times (1 - RPL) \times 0.5\right) + \left(\frac{\partial(WW_S \times P_S)}{\partial IBP} \times 0.5\right)\right] \times (1 - \%Open)$.

Holding dystocia and stocking density constant, the marginal effect of the cow Igenity panel scores on cull cow revenue is represented as

(11) $\frac{\partial\pi}{\partial CW} \times \frac{\partial CW}{\partial IBP} = \left(\beta_i^{CW} \times P_C \times \%Culled\right) - (\beta_i^{CW} \times FeedCost_C)$

where cow price is expressed in dollars per pound. Cull cow values differ between marketing categories rather than weight, so a price slide is not used (Peel and Doye, 2017).

Higher birth weights are usually associated with lower calving ease, a higher rate of dystocia, and higher weaning weights (Berger et al., 1992). The effect of the calf Igenity panel scores on profit through dystocia created by changes in birth weight is represented as

(12) $\frac{\partial\pi}{\partial DYS} \times \frac{\partial DYS}{\partial BW} \times \frac{\partial BW}{\partial IBP} = \left[-\left((WW_H \times P_H \times 1.5) + (WW_S \times P_S \times 0.5)\right) + (CW \times P_C) - VariableCost\right] \times \beta_i^{BW} \times Rate \times SD.$

Increased dystocia affects all revenue streams because it results in a larger percent of heifers retained for replacement, fewer steers and heifers sold due to death loss, but it increases cull cow revenue due to an increase in cows culled. It also imposes an extra feed cost associated with retaining another heifer, potentially lower weaning weights, and a loss in productivity from culling an extra cow. The Noble Research Institute herds have a low rate of dystocia due to the herd being selected for maternal traits, so the rate of dystocia for an 85-pound calf is assumed to be 1.11%.

Feed cost is expected to change with cow weight and a change in the cow Igenity panel scores. This equation is represented as

$$(13) \qquad \frac{\partial \pi}{\partial Feedcost} \times \frac{\partial Feedcost}{\partial CW} \times \frac{\partial CW}{\partial IBP} = \left(\beta_i^{CW} \times 0.75 \times P_F \times CW^{-0.25}\right).$$

Feed costs were calculated for our representative cow using the CowCulator software (Lalman, 2020). This research assumes a current rental rate of bermudagrass at \$22/acre, a 75% utilization rate of introduced bermudagrass, and a stocking density of four acres per representative cow. Hay consumption is assumed to have an 80% utilization rate and a price of \$75/ton (Doye and Lalman, 2011). 20% cubes are used and are composed of 65% wheat midds, 30% cottonseed, and 3% molasses (Bir, 2018). Cube prices are obtained from relevant products at Tractor Supply Co. (2022). Total feed cost was calculated by multiply pounds of forage, hay, and cubes used by their utilization rates and price and dividing the result by cow metabolic weight to obtain feed cost per metabolic pound.

Stocking density will also vary by cow weight. As cows get larger, the stocking density will decrease. This will be a necessary adjustment to the marginal returns associated with each cow panel score. This equation is modeled as

$$(14) \qquad \frac{\partial \pi}{\partial SD} \times \frac{\partial SD}{\partial CW} \times \frac{\partial CW}{\partial IBP} = -0.75 \times \beta_i^{CW} \times a \times CW^{-1.75} \times CW \times P_C \times \%Culled.$$

Results and Discussion

Pearson bivariate correlation coefficients were estimated for the Igenity panel scores, cows, and calves to determine the differences between them and highlight the extreme similarities between the two. Tables II-4, II-5, and II-6 show these correlation coefficients for the Igenity panel scores

– calves, Igenity panel scores – cows, and weight, respectively. Since the panel scores are grouped into indexes for different types of performance, multicollinearity can be expected to be an issue for scores that use similar SNP (DeVuyst et al., 2011).

Similar to the findings of DeVuyst et al., only a couple pairs of panel scores had high correlation. The two with the highest value are the Igenity Birth Weight Score and the Igenity Calving Ease Direct Score with a value of -0.82 in Table II-4 and -0.80 in Table II-5. The Igenity Calving Ease Direct Score was omitted from the regression models to reduce multicollinearity. The correlations between panel scores and the phenotypic variables, weaning weight, birth weight, and cow weight all show there is more variation unexplained than explained by the panels. The highest of the values between the selected weights and the panel scores is the Igenity Marbling Score with a correlation coefficient of -0.41 for birth weight. That relationship is likely due to the high marbling Angus bulls being selected for maternal traits and thus low birth weights, while the Hereford and Charolais bulls would have less marbling and were selected for terminal performance with less consideration of calving ease. The correlation between cow weight and genetic panel scores are the lowest due to greater variation due to other factors such as age.

Regression analysis was performed to analyze the relationship of the genetic panel scores with their respective weights to control for other factors such as age and sex. Table II-7 shows the estimated effect of each genetic panel score along with the phenotypic variables of age, sex, and a quadratic transformation of age. Multicollinearity between the models has been limited through the removal of highly correlated variables. Outliers in the data were found by using Cook's Distance (Cook, 1977). Values over 0.01 were identified as potential outliers. Most outliers in terms of weight were attributed to Hereford and Charolais breeds rather than predominately Angus breeds. As a result, these outliers were retained for genetic diversity by breed.

The relationship between cow weight and the cow panel scores is largely insignificant except for birth weight ($p<0.05$), residual feed intake ($p<0.01$), and tenderness scores ($p<0.01$). The birth weight score had a positive effect on all three weights. Age at weaning and the quadratic transformation of age at weaning were both significant predictors ($p<0.01$) of weaning weight. The quadratic term for age has a negative relationship with weaning weight and shows that weaning weight increases with age at a decreasing rate. Female calves were also significant and negative for both birth weight and weaning weight ($p<0.01$).

Calf Igenity panel scores that were significant predictors of birth weight[1] include average daily gain, birth weight, marbling, milk, residual feed intake, ribeye area, and tenderness. Average daily gain, marbling, residual feed intake, and tenderness calf panels had negative relationships with birth weight. These panel scores are related to feedlot and carcass performance, and they were hypothesized to have little to no relationship with birth weight. Calving ease was an insignificant predictor of birth weight, which means that it added no information beyond what was already included in the birth weight panel score. Positive relationships include birth weight score, ribeye area, and milk. As expected, when the birth weight score increases, birth weight also increases. This score was designed to predict an increase in birth weight for a higher score. Ribeye area, a predictor for ribeye area at the 12th rib, may also be a good predictor of weight (Igenity, 2020).

Calf Igenity scores that were significant predictors of weaning weight include average daily gain, birth weight, docility, marbling, residual feed intake, ribeye area, stayability, and tenderness. Calf panels for average daily gain, docility, marbling, residual feed intake, stayability, and tenderness all have negative relationships with weaning weight. The birth weight score and

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[1] Multiple comparisons are a potential concern in this analysis. Bonferroni corrected *p*-values (Napierala, 2012) are the most conservative test in this case and can be obtained by dividing the critical value by twelve, which would make the critical value 0.004. Using the Bonferroni correction does not change the significance of most of the panel scores in the birth weight and weaning weight equations including average daily gain, marbling, residual feed intake, ribeye area, and tenderness (Napierala, 2012).

ribeye area had positive relationships with weaning weight. The negative coefficient on average daily gain was unexpected. Average daily gain was hypothesized to have a positive relationship with weaning weight because a higher genetic potential for gain should yield a higher weaning weight. The birth weight score was positive reinforcing the idea that higher birth weights lead to higher weaning weights.

Marginal returns (costs) associated with each trait were estimated across all facets of cow-calf production, including calf revenue, cull cow revenue, and associated costs of production. Table II-8 shows the marginal returns associated with each aspect of production. Every trait except for birth weight, calving ease direct, and ribeye area had a negative marginal revenue. The highest negative marginal values were associated with residual feed intake, -$7.82, marbling, -$6.32, average daily gain, -$5.23, and tenderness, -$5.12. Residual feed intake was hypothesized to have a negative impact on revenue as an animal with a higher score is expected to produce progeny that consume more feed for the same daily gain (Igenity, 2020). However, it was unexpected for average daily gain to have a negative impact on revenue. A higher score was expected to be associated with a higher rate of gain over the same time period although the MBV's are quite small with an expected 0.02-pound difference for each per-unit increase in the Igenity score (Igenity, 2020). Marbling and tenderness are both associated with the carcass index and were not expected to have much of a relationship with calf crop revenue. Not only were they negative predictors of weaning weight, but they also had a large negative effect on marginal revenue.

The highest positive values for a single unit of each trait were ribeye area, $7.17, and birth weight, $5.12. The ribeye area score has a large positive relationship with weaning weight. The birth weight score was also hypothesized to positively affect revenue because higher birth weights typically lead to higher weaning weights, although they could have an adverse effect on dystocia rates.

The marginal effect of dystocia is included in the total value of each trait, although its initial impact is quite low. As stated earlier, the rate of dystocia for an 85-pound calf is assumed to be 1.11%. This rate of dystocia, when factored into the loss of calf crop revenue, increase in cull cow revenue, and the variable costs associated with extra feed cost and lower productivity, can highlight the true effects of these genetics to cow-calf producers. Vet cost was assumed to be $42/head, and the other variable costs associated with losing a calf are assumed to be $500. The highest positive effects of the panel scores on dystocia are average daily gain, $0.24, marbling, $0.23, and residual feed intake, $0.16. The highest negative effects of the panel scores on dystocia are birth weight, -$0.45, milk, -$0.14, and ribeye area, -$0.14. These effects are not economically significant. Many producers use birth weight as a guide for sire selection, so this effect is of particular interest. At this lower rate of dystocia, an additional unit of the birth weight score still has a positive net-effect on calf crop revenue. Genetics have little to no effect on feed cost with vales ranging from -$0.20/unit for an additional unit of the birth weight score to $0.29/unit for the residual feed intake score. The animal growth measures are all negative, increasing the cost to producers as they gain extra weight.

These numbers might seem quite small for a cow-calf producer, but they could make quite a difference in sire selection. Assuming a single bull sires 25 calves a year for four years, multiple-unit changes in these calf and cow panel scores could result in thousands of dollars lost or gained. For example, a three-unit change in the average daily gain score would cost the producer $1,629, and a three-unit change in the ribeye area score would gain the producer $2,184. When scaled for a large operation, these multiple-unit changes can justify substantial differences in bull prices.

Lastly, molecular breeding values for feedlot selection were taken from Thompson (2014) and evaluated against the same traits' effect on cow-calf revenue. The only traits that were the same between the two studies were average daily gain, marbling, ribeye area, and tenderness.

The profit associated with molecular breeding values was reported in the units of each individual MBV. After adjusting for the scale difference between the MBV's and the Igenity panel scores, the resulting effects on feedlot profit were as follows: average daily gain, \$0.54, marbling, \$3.52, stayability, -\$2.81, and tenderness, \$0.19. Each trait has the exact opposite effect on feedlot profit as the corresponding trait has on cow-calf profit. The cow-calf traits also outweighed the feedlot traits in value, resulting in a largely negative impact to the whole beef sector.

Sensitivity Analysis

Since reduced-form equations were used to predict weaning, cow, and birth weights, it is necessary to explore the effects of the Igenity panel scores with additional exogenous variables in the model. Three additional equations were estimated for weaning weight that include a cubic effect for age, a class variable for primary breed, and calf birth weight. Table II-9 shows the results of each of these equations. Primary breed includes Angus, Angus cross, and unknown breeds. Angus cross calves were sired by the Charolais cleanup bulls or were part of the Hereford breeding program. Primary breed was hypothesized to take away some of the effects of the calf Igenity panel scores due to the genetic power of breed, however, that was not the case. Eight of the twelve included calf panel scores were significant at the 10% level, and sign did not change for any of the panel scores. Angus was a significant predictor of weaning weight ($p<0.01$) and resulted in a 29-pound decrease in weaning weight.

Birth weight was also a significant predictor of weaning weight ($p<0.01$). In this equation, significance was drastically reduced to five panel scores, and the sign changed for the birth weight score. This was likely due to the extra measure of birth weight in the equation although the model does not have multicollinearity. This result was unexpected. The other panel scores did not change their sign from the original weaning weight equation, although the production and carcass traits had a much smaller nominal effect on weaning weight.

The last weaning weight equation evaluated includes the cubic term for age. This model included eight significant panel scores and sign did not change. It can be concluded that the addition of other exogenous variables to the model does not impact the result of the marginal revenue calculations. Average daily gain, marbling, residual feed intake, and tenderness are all still significant negative predictors of weaning weight and will bring down cow calf revenues.

Models were also used to show the effects of just the genetics on all three weights. Table II-10 shows those effects. Significance remains similar to the original models for the panel scores in both the weaning and birth weight equations (Table II-7) including average daily gain, marbling, residual feed intake, ribeye area, and tenderness. The only unexpected result was calving ease is now a significant predictor of weaning weight. There is no exact cause for this. In the cow weight equations, there is increased significance in addition to the original cow weight prediction model. Cow Igenity panel scores that were significant predictors of cow weight now include birth weight, fat thickness, heifer pregnancy, marbling, milk, residual feed intake, and ribeye area. However, the sign on the cow panel scores still did not change.

The rate of dystocia is expected to vary between producers, so the rate of dystocia was calculated at which the added value calf birth weight score did was equal to the cost associated with dystocia. Table II-11 shows the resulting effects of the calf Igenity panel scores on dystocia. By using the same birth weight of 85 pounds calculated from the equation, it was determined where the marginal revenue of \$4.86 from the birth weight equation is equal to the marginal cost of the dystocia equation. This relationship happens at $BW \times 0.00135$ or a rate of 12% for this specified birth weight. 12% is a very high rate of dystocia, although it is not impossible. It is important to note that this rate will change with birth weight and heavier birth weights may result in higher dystocia costs.

Since feed cost uses the metabolic weight, a change in the feed cost should be added to the model. Sensitivity analysis on feed cost shows that it takes a 200-pound change in cow weight to change feed cost by just a few cents for each unit. This is likely due to the panel scores' small effect on cow weight. This change is not economically significant.

Conclusion

Thompson et al. (2014, 2016) found that Igenity scores focused on production and carcass traits had positive relationships with feedlot performance. However, these relationships could inflict more harm to cow-calf producers with average daily gain, residual feed intake, and marbling all having negative relationships with birth and weaning weights. While lower birth weights and increased calving ease are a positive for cow-calf producers, the lower weaning weights are not. The low correlations with cow weight mean that it might be possible to select cows with lower mature weights and not hurt some of the other performance characteristics. The average daily gain and ribeye area scores are significant and positive, meaning that these same traits that produce lower birth weights, significantly increase cow weight. As Bir et al. (2018) found, heavier cows can be inefficient due to higher maintenance costs resulting in less producer profit assuming no market inefficiencies in the smaller calves.

Cow-calf producer marginal revenues drop sharply for an additional unit of the residual feed intake, average daily gain, marbling, and tenderness scores. These scores have a negative net effect when compared to the average daily gain, marbling, and tenderness feedlot molecular breeding values for selection meaning that their benefit in the feedlot does not overcome their loss to cow-calf producers. It was hypothesized that there would be little to no effect in the cow-calf sector for all the panel scores, but that is not what was found. Given the significance and net negative effect of the panel scores to producers using the cattle in this study, it is concluded that producing for traits on the feedlot and carcass index is losing producers money. Sensitivity analysis supports the use of reduced-form equations and determines that the marginal costs associated with dystocia are equal to the marginal revenue of a one-unit increase in the birth weight score when the rate of dystocia is 12%.

This research should be cautioned that this is the first study of genetic panel scores and cow-calf productivity. Later research may or may not confirm these findings. While the study is from four ranches, all the cattle were managed similarly under a similar climate. They also had similar genetics although some were purchased from different breeders.

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Table II-1. Calf Summary Statistics (n=1,205)

Variable	Mean	SD	Minimum	Maximum
Birth Weight	77.41	14.43	34	134
Weaning Weight	523.38	88.85	247	805
Igenity panel score				
Average daily gain	6.28	1.50	1	10
Birth weight	4.51	1.37	1	10
Calving ease direct	6.14	1.38	2	10
Calving ease maternal	5.86	1.13	2	9
Docility	6.34	1.08	1	9
Fat thickness	6.18	1.36	1	10
Heifer pregnancy rate	7.14	1.00	4	10
Marbling	6.30	1.53	2	10
Milk	6.30	1.27	2	10
Residual feed intake	6.28	1.22	3	10
Ribeye area	4.92	1.16	2	9
Stayability	6.64	1.03	3	10
Tenderness	5.95	2.07	1	10

Table II-2. Cow Weight Summary Statistics (n=10,156)

Variable	Mean	SD	Minimum	Maximum
Cow weight	1092	237.55	453	1804
Igenity panel score				
Average daily gain	6.21	1.40	2	10
Birth weight	4.17	1.30	1	9
Calving ease direct	6.48	1.30	2	10
Calving ease maternal	5.91	1.09	2	9
Docility	6.53	1.00	3	9
Fat thickness	6.32	1.24	2	10
Heifer pregnancy rate	7.31	0.98	4	10
Marbling	6.51	1.26	2	10
Milk	6.28	1.27	2	10
Residual feed intake	6.35	1.11	3	10
Ribeye area	4.53	1.19	1	8
Stayability	6.67	0.99	3	10
Tenderness	5.87	2.07	1	10

Table II-3. Descriptions and Desired Outcomes of Igenity Panel Scores.

Trait	Description	Desired Outcome
Maternal		
Birth Weight	Variation in birth weight	Low
Calving ease direct	Percentage of unassisted births	High
Calving ease maternal	Probability a first calf heifer will calve unassisted	High
Stayability	Probability a cow remains productive in the herd until age 6	High
Heifer pregnancy rate	Heifer's chance of conceiving over a normal breeding season	High
Docility	Animal's genetic potential to be calm	High
Milk	Pounds of calf weaning weight affected by dam milk production	Medium
Performance		
Residual feed intake	Difference in anaimals' daily consumption of feed to achieve the same level of gain	Low
Average daily gain	Pounds of gain per day post-weaning	High
Carcass		
Tenderness	Genetic potential for carcass tenderness measured by the Warner-Bratzler Shear Force test	High
Marbling	Indicates the degree of marbling in the rib eye at the 12th rib	High
Ribeye area	Estimates muscling in a beef carcass, measured in square inches of the rib eye at the 12th rib	High
Fat thickness	Depth of fat in inches over the rib eye muscle at the 12th rib	High

Source: Igenity (2020)

Table II-4. Pearson Correlation Coefficients Between Igenity Panel Scores, Calves. (*n*=1,205)

Igenity Panel Score	ADG	BW	CED	CEM	DOC	FAT	HPR	MAR	MIL	RFI	REA	STA
ADG[a]	1.00											
BW[b]	-0.06*	1.00										
CED[c]	0.19*	-0.82*	1.00									
CEM[d]	0.04	-0.34*	0.38*	1.00								
DOC[e]	0.13*	-0.13*	0.15*	0.02	1.00							
FAT[f]	0.24*	-0.43*	0.46*	0.19*	0.20*	1.00						
HPR[g]	0.17*	-0.22*	0.27*	0.05*	0.12*	0.21*	1.00					
MAR[h]	0.45*	-0.47*	0.47*	0.14*	0.09*	0.51*	0.30*	1.00				
MIL[i]	0.14*	-0.23*	0.25*	0.29*	0.08*	0.19*	0.14*	0.14*	1.00			
RFI[j]	0.26*	-0.23*	0.27*	-0.06*	0.16*	0.33*	0.16*	0.38*	0.08*	1.00		
REA[k]	0.20*	0.21*	-0.12*	-0.01	0.10*	-0.19*	0.04	-0.13*	0.03	0.00	1.00	
STA[l]	0.21*	-0.27*	0.29*	0.05	0.06*	0.30*	0.21*	0.29*	0.06*	0.18*	-0.12*	1.00
TEN[m]	0.13*	-0.04	0.08*	-0.01	0.11*	0.19*	0.06*	0.21*	0.09*	0.31*	0.03	0.08*

Notes: Single asterisks denote significance at the 5% level or 1% level.

[a]Average Daily Gain, [b]Birth Weight, [c]Calving Ease Direct, [d]Calving Ease Maternal, [e]Docility, [f]Fat Thickness, [g]Heifer Pregnancy Rate, [h]Marbling, [i]Milk, [j]Residual Feed Intake, [k]Ribeye Area, [l]Stayability, [m]Tenderness

Table II-5. Pearson Correlation Coefficients Between Igenity Panel Scores, Cows (*n*=1,544)

Igenity Panel Score	ADG	BW	CED	CEM	DOC	FAT	HPR	MAR	MIL	RFI	REA	STA
ADG[a]	1.00											
BW[b]	0.18*	1.00										
CED[c]	0.00	-0.80*	1.00									
CEM[d]	0.01	-0.40*	0.48*	1.00								
DOC[e]	0.08*	-0.06*	0.05	0.02	1.00							
FAT[f]	0.12*	-0.31*	0.31*	0.15*	0.13*	1.00						
HPR[g]	0.13*	-0.13*	0.15*	0.09*	0.06*	0.14*	1.00					
MAR[h]	0.34*	-0.39*	0.39*	0.18*	0.01	0.44*	0.19*	1.00				
MIL[i]	0.05	-0.28*	0.30*	0.32*	0.10*	0.13*	0.12*	0.21*	1.00			
RFI[j]	0.19*	-0.07*	0.12*	-0.06*	0.15*	0.22*	0.04	0.25*	-0.04	1.00		
REA[k]	0.30*	0.28*	-0.14*	-0.05	0.04	-0.22*	0.07*	-0.13*	-0.00	0.03	1.00	
STA[l]	0.10*	-0.21*	0.23*	0.10*	0.07*	0.20*	0.10*	0.21*	0.09*	0.08*	-0.08*	1.00
TEN[m]	0.12*	0.07*	-0.04	-0.05*	0.03	0.11*	0.01	0.08*	0.06*	0.21*	0.03	-0.04

Notes: Single asterisks denote significance at the 5% level or 1% level.

[a]Average Daily Gain, [b]Birth Weight, [c]Calving Ease Direct, [d]Calving Ease Maternal, [e]Docility, [f]Fat Thickness, [g]Heifer Pregnancy Rate, [h]Marbling, [i]Milk, [j]Residual Feed Intake, [k]Ribeye Area, [l]Stayability, [m]Tenderness

Table II-6. Pearson Correlation Coefficients Between Weights, Igenity Panel Scores.

	Weight		
Igenity Panel Score	BW	WW	CW
Average daily gain	-0.23***	-0.16***	-0.16*
Birth weight	0.35***	0.21***	-0.12*
Calving ease direct	-0.37***	-0.19***	0.03
Calving ease maternal	-0.13***	0.00	0.04
Docility	-0.10***	-0.08***	-0.04
Fat thickness	-0.28***	-0.22***	-0.04
Heifer pregnancy rate	-0.16***	-0.13***	0.01
Marbling	-0.41***	-0.30***	-0.04
Milk	-0.05*	-0.09***	0.05*
Residual feed intake	-0.27***	-0.30***	-0.12*
Ribeye area	0.09***	0.11***	-0.21*
Stayability	-0.19***	-0.14***	0.01
Tenderness	-0.16***	-0.25***	-0.03

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.

Table II-7. Regression Results for Cow Weight, Birth Weight, and Weaning Weight Prediction Equations. (*lbs.*)

	Equation		
Variable	CW	BW	WW
Constant	1474.27***	96.31***	-288.02
*Igenity Panel Scores**			
Average daily gain	3.34	-1.42***	-4.73***
Birth weight	6.15**	2.67***	4.93***
Calving ease maternal	0.46	-0.30	2.63
Docility	-0.60	-0.23	-3.44*
Fat thickness	-3.20	0.12	-1.51
Heifer pregnancy	1.22	-0.59	-0.17
Marbling	-4.20	-1.34***	-5.76***
Milk	4.04	0.82***	1.74
Residual feed intake	-9.05***	-0.96***	-7.07***
Ribeye area	-1.83	0.81**	6.35***
Stayability	0.15	-0.48	-3.87*
Tenderness	-2.72**	-0.53***	-4.57***
Female		-6.97***	-20.45***
Age at weaning			6.96***
Age at weaning^2			-0.01***
Cow age			
Age 1	-546.64***		
Age 2	-375.88***		
Age 3	-285.14***		
Age 4	-178.08***		
Age 5	-111.61***		
Age 6	-58.41***		
Age 7	-30.50*		
Age 8	-22.80		
Age 9	-39.36*		
Age 10	-53.29**		
Age 11	-160.16***		
Age 12	-99.03***		
Age 13	-79.22***		
Quarter 1	-68.39***		
Quarter 2	-54.78***		
Quarter 3	4.92		

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Dependent variables in the three equations are Cow Weight (CW), Birth Weight (BW), and Weaning Weight (WW).

*The Igenity Gold profile provides scores 1-10 for 13 traits and 3 indexes including maternal, performance, and carcass traits. The Igenity Calving Ease Direct score was dropped due to multicollinearity issues.

Table II-8. Marginal Returns of an Additional Unit of each Panel Score. ($/unit/cow/year)

Igenity Panel Score	Calf Crop	Dystocia	Cow	Feed Cost	Cow-Calf	Feedlot	Beef Sector
Average daily gain	(5.43)	0.24	0.25	(0.11)	(5.23)	0.54	(4.69)
Birth weight	5.66	(0.45)	0.46	(0.20)	5.12		
Calving ease direct	3.02	0.05	0.03	(0.01)	3.06		
Docility	(3.95)	0.04	(0.05)	0.02	(3.90)		
Fat thickness	(1.73)	(0.02)	(0.24)	0.10	(1.70)		
Heifer pregnancy rate	(0.19)	0.10	0.09	(0.04)	(0.11)		
Marbling	(6.61)	0.23	(0.32)	0.14	(6.32)	3.52	(2.80)
Milk	1.99	(0.14)	0.30	(0.13)	1.80		
Residual feed intake	(8.11)	0.16	(0.68)	0.29	(7.82)		
Ribeye area	7.28	(0.14)	(0.14)	0.06	7.17	(2.81)	4.36
Stayability	(4.44)	0.08	0.01	(0.00)	(4.36)		
Tenderness	(5.24)	0.09	(0.20)	0.09	(5.12)	0.19	(4.93)

Notes: Values reported are indicative of a single unit change within each panel score.

Table II-9. Regression Results for Weaning Weight Sensitivity Analysis. (*lbs.*)

	Equation		
Variable	WW-PB[a]	WW-BW[b]	WW-AGE[c]
Constant	-291.26	-593.24***	737.39
*Igenity Panel Scores**			
Average daily gain	-4.46***	-2.15	-4.82***
Birth weight	4.46**	-1.73	4.98***
Calving ease maternal	3.63*	3.44**	2.76
Docility	-2.90	-2.71	-3.45*
Fat thickness	-1.34	-1.97	-1.40
Heifer pregnancy	0.24	1.22	-0.11
Marbling	-5.13***	-2.46	-5.81***
Milk	1.62	0.56	1.85
Residual feed intake	-7.19***	-4.19**	-7.11***
Ribeye area	6.56***	4.10**	6.40***
Stayability	-4.03**	-3.15*	-4.05*
Tenderness	-4.27***	-3.18***	-4.55***
Female	-21.63***	-3.57	-20.25***
Age at weaning	6.87***	7.10***	-7.67
Age at weaning^2	-0.01***	-0.01***	-0.06
Age at weaning^3	-	-	-0.0001
Angus	-28.55***	-	-
Angus cross	18.32	-	-
Birth weight	-	2.67***	-

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Weaning weight equations with the addition of: [a]Primary breed (PB), [b]Birth weight (BW), and [c]Age at weaning^3 (AGE) are added to the original weaning weight equation to test the assumption of a reduced form model *ceteris paribus*.

Table II-10. Weight Equations Using Only Panel Scores. (*lbs.*)

	Equation		
Variable	CW	BW	WW
Constant	1534.83***	93.91***	612.55
*Igenity Panel Scores**			
Average Daily Gain	-1.99	-1.12***	-2.21
Birth Weight	-21.15***	2.39***	3.85*
Calving Ease Maternal	-8.30	-0.39	4.00*
Docility	-4.33	-0.40	-2.23
Fat Thickness	-12.52*	0.15	0.31
Heifer Pregnancy	25.01***	-0.41	0.61
Marbling	-21.47***	-1.69***	-5.34**
Milk	10.68*	0.92***	-2.57
Residual Feed Intake	-17.20**	-1.13***	-9.21***
Ribeye Area	-63.16***	0.81**	6.94***
Stayability	1.91	-0.49	-1.85
Tenderness	-0.67	-0.44**	-5.19***

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level.

Table II-11. Sensitivity Analysis of Increased Dystocia on Marginal Returns.

Igenity Panel Score	Calf Crop	Dystocia	Cow	Feed Cost	Cow-Calf	Feedlot	Beef Sector
Average daily gain	(4.66)	2.58	0.25	(0.11)	(2.13)	0.54	(1.59)
Birth weight	4.86	(4.86)	0.46	(0.20)	(0.09)		
Calving ease direct	2.59	0.55	0.03	(0.01)	3.14		
Docility	(3.39)	0.41	(0.05)	0.02	(2.98)		
Fat thickness	(1.48)	(0.22)	(0.24)	0.10	(1.66)		
Heifer pregnancy rate	(0.17)	1.08	0.09	(0.04)	0.90		
Marbling	(5.68)	2.44	(0.32)	0.14	(3.18)	3.52	0.34
Milk	1.71	(1.50)	0.30	(0.13)	0.16		
Residual feed intake	(6.97)	1.75	(0.68)	0.29	(5.09)		
Ribeye area	6.26	(1.47)	(0.14)	0.06	4.82	(2.81)	2.01
Stayability	(3.81)	0.88	0.01	(0.00)	(2.94)		
Tenderness	(4.50)	0.96	(0.20)	0.09	(3.51)	0.19	(3.32)

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