ECONOMIC DETERMINANTS OF THE VARIATION IN AVERAGE CARCASS WEIGHT FOR UNITED STATES SLAUGHTER CATTLE

by

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DEDICATION

I dedicate this thesis to my family members and loved ones - for their support, motivation, and most importantly their patience.

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NOMENCLATURE

The following is a brief description of the pharmaceutical products commonly used in fed cattle production.

Therapeutic Antibiotic: An antibiotic used to treat sick cattle in feedlot production (American Meat Institute 2010).

Beta-agonist: A non-hormonal product given to steers to improve feed efficiency and average daily gain (Elanco Animal Health 2003). This product binds to muscle receptors and redirects nutrients for increased lean meat yield and reduced fat deposition (Beef Research 2013). Beta-agonists are approved for administration to steers in a commercial feedlot setting in the last 28-42 days of the finishing period (Elanco Animal Health 2003).

Dewormer (anthelmintics or parasiticides): These products are for external and internal parasite control and prevention in cattle. Administration of dewormers to cattle may be oral or through injection and pour-on methods (Strickland and Jones 2012). Cattle infected with parasites often have reduced feed intake (Strickland and Jones 2012). Dewormer products act to inhibit parasites while improving animal performance.

Growth Implant: An implant is a hormone in the form of a pellet that is inserted into the ear of cattle(FDA 2015). Once the hormone enters the animals blood stream it promotes protein deposition while reducing fat deposition (Beef Research 2013). Implants improve average daily gain and feed efficiency of cattle (FDA 2015).

Ionophore: A non-therapeutic antibiotic that is fed to cattle to alter rumen microbes. Ionophores inhibit methane producing microbes which allows beneficial microbes to produce more energy from feed (Beef Research 2013). As a result, both feed efficiency and average daily gain are improved when ionophores are fed (Beef Research 2013).

ABSTRACT

Over the past century, average carcass weights of slaughter cattle have demonstrated a substantial upward trend, as well as year-to-year volatility. Since the mid-1970s however, increasing average carcass weights have coincided with high levels of beef production but with diminishing beef cow herds. Increased beef production with fewer cow numbers is likely explained by technological advancements throughout the beef industry. Annual variability in average carcass weight, on the other hand, is hypothesized to arise because of the dynamics of fed cattle production arising from changes in input and output prices. To identify the economic factors responsible for the variation in average carcass weight theoretical and empirical models are developed. Based on the theoretical model, cattle feeders choose the levels of corn and labor that yield optimal carcass weights by equating each factor's value marginal product to the marginal cost. Theoretical predictions are then tested using 85 years of aggregate annual data in a distributed lag model. Overall, we find coefficient estimates on the input and output prices consistent in sign with our theoretical predictions. Of importance is the finding that the manufacturing wage accounts for an estimated 61 percent of the total input and output price induced variation in average carcass weight. A trend for technological change in the beef industry accounts for a yearly increase in average carcass weight of 3.6 pounds.

CHAPTER ONE

INTRODUCTION

The United States is the world leader in beef production, producing 19 percent of the world supply of beef in 2014 (USDA 2015; figure 1.1).[1] While current United States beef production remains high, the total number of cattle slaughtered recently reached its lowest level since 1968 (NASS 1921). Compensating for the reduction in cattle slaughter numbers are increasingly large average carcass (dressed) weights of slaughter cattle. Figure 1.2 indicates average carcass weights trend upward over the past century, rising 49 percent since 1921 (NASS 1921).

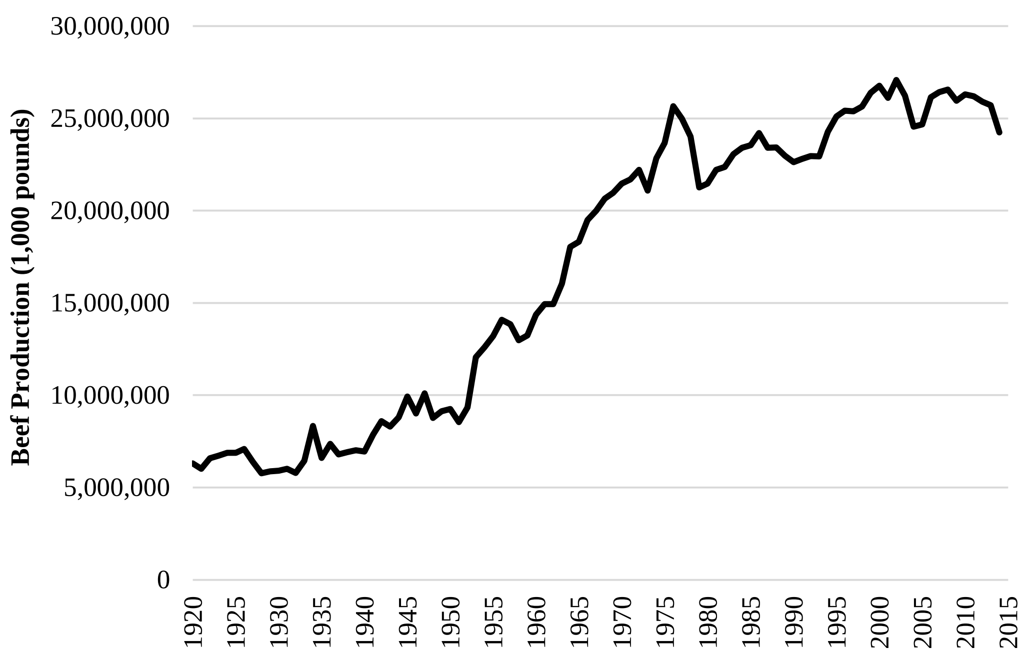

Figure 1.1: United States Beef Production, 1920-2014

[1] In 2014, the United States produced 11,076 lb of beef and the world produced 59,746 lb (USDA 2015).

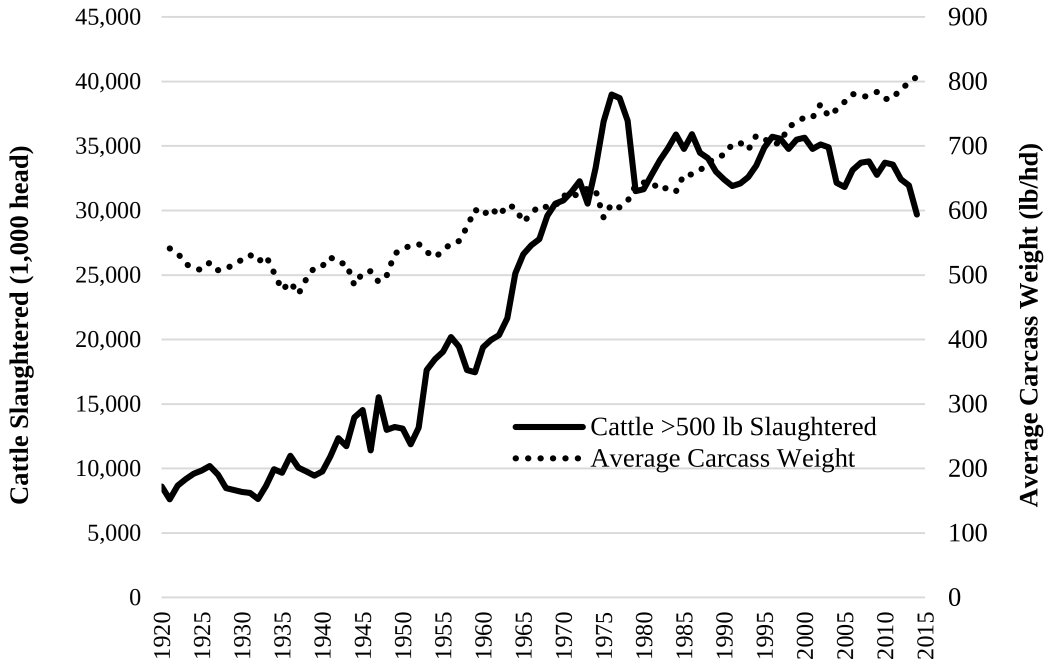

Figure 1.2: Average Annual Average Carcass Weight and Slaughter Numbers for Federally Inspected Slaughter Cattle, 1921-2014

Past empirical work suggests that technological advancement in the industry has been the primary source of the growth in average carcass weight (Marsh 1999). These technological advancements include the areas of animal health, nutrition, and genetic technologies (Brester and Marsh 1983; Elam and Preston 2004). Coinciding with increasing average carcass weights is the increasing United States population and the rising income of United States consumers (figure 1.3; U.S. Census Bureau 1930). Mintert, Schroeder and Marsh (2002) have shown that beef demand is highly responsive to increasing consumer incomes. Further, slaughter cattle demand increases with increasing beef demand (Schultz and Marsh 1985), which could lead to higher average carcass weights.

Over time considerable year-to-year variation in average carcass weights has been

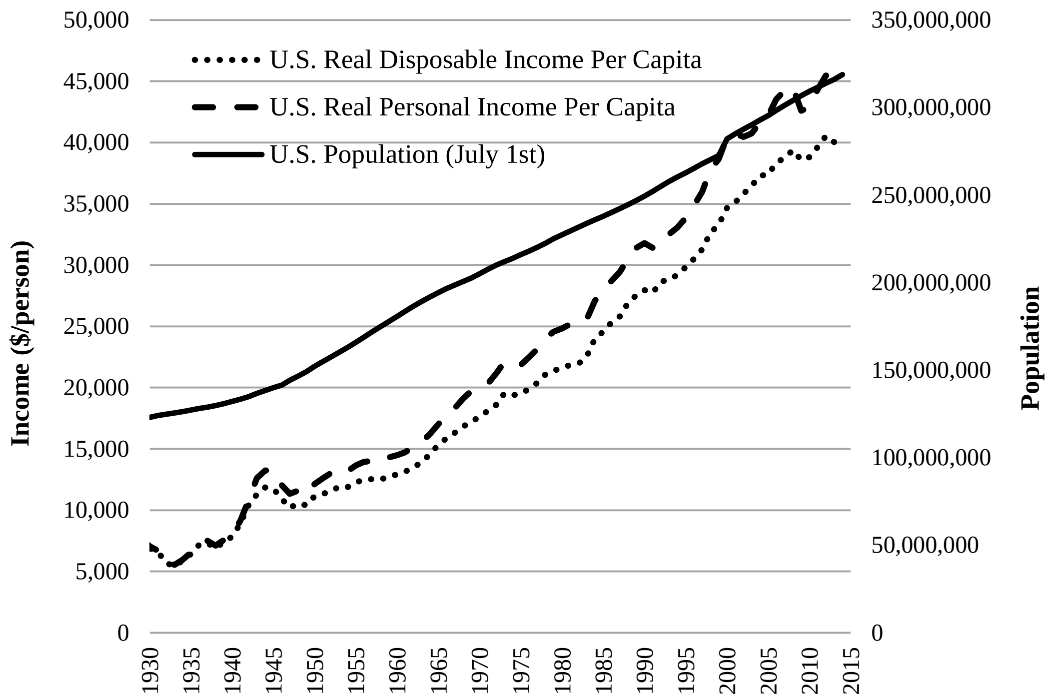

Figure 1.3: United States Population, and United States Real Disposable and Personal Income Per Capita ($ 2014), 1930-2014

observed (figure 1.4; (NASS 1921). Changing market prices and other production factors are likely a major cause of the yearly fluctuation in average carcass weights. Work by Feuz (1998) and others indicate, at constant fed prices, variation in feedlot revenue is primarily determined by carcass weights in comparison to quality and yield grade measures. These findings highlight the importance of identifying economic factors contributing to carcass weight fluctuations. Figure 1.5 shows the time series for the primary input prices (corn and feeder cattle) and output price (slaughter cattle) for fed cattle production. Market prices for fed cattle production are highly variable over time.

The present study extends the work of Langemeier & Thompson (1967), Kulshreshtha & Wilson (1972), and Marsh (1999) by examining the impact of economic

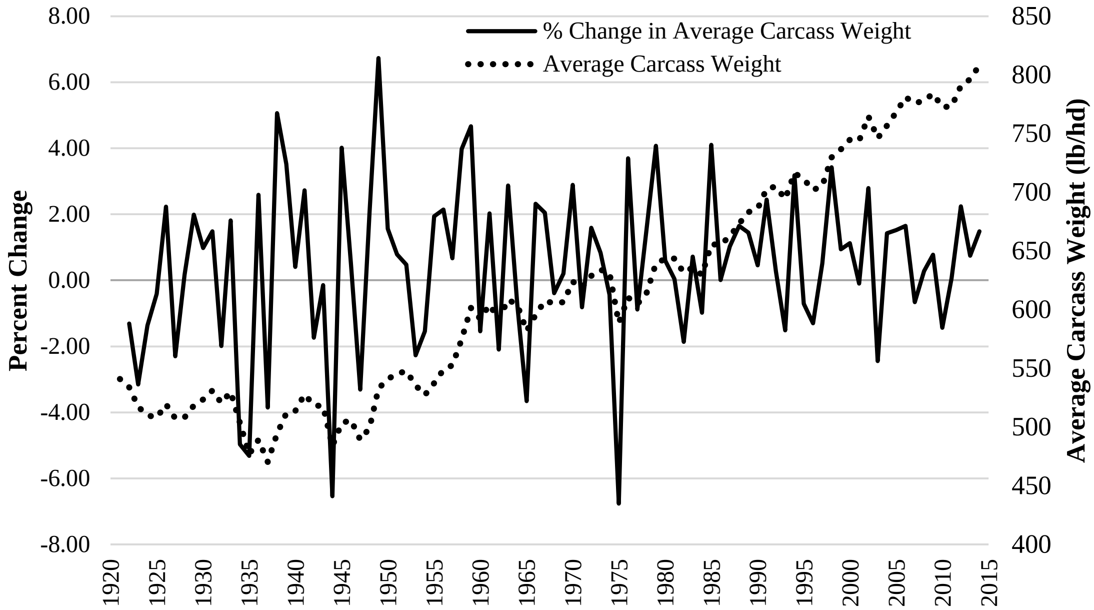

Figure 1.4: Percentage Change in Average Annual Carcass Weight Over the Previous Year, 1921-2014.

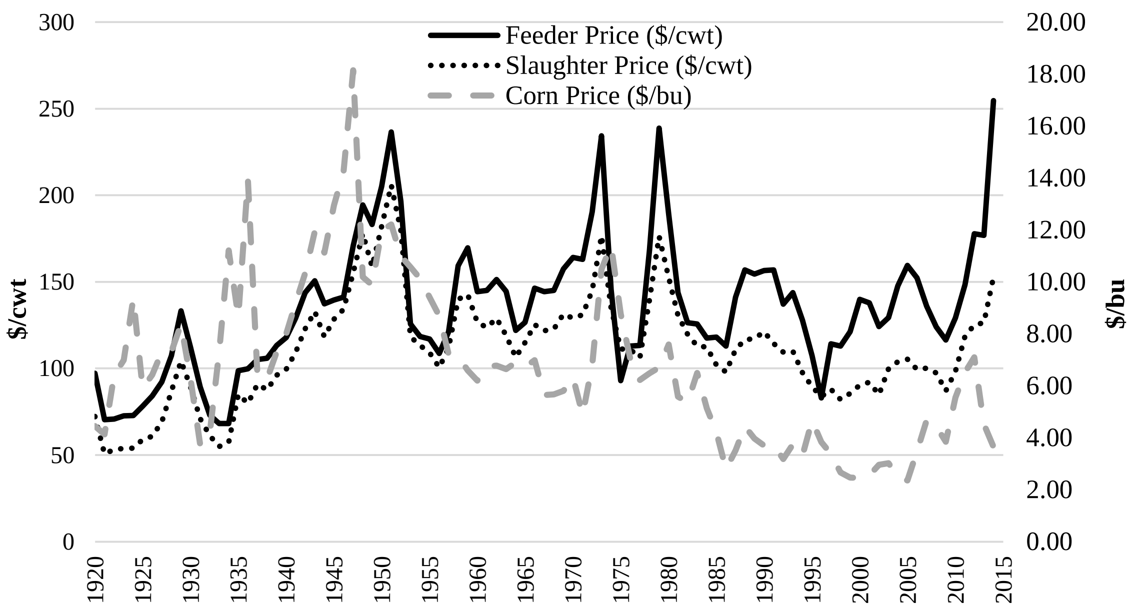

Figure 1.5: Real Input and Output Prices for United States Slaughter Cattle Production ($ 2014), 1920-2014

prices and production variables on average carcass weight. In addition to the corn and slaughter cattle prices included in past studies, the labor wage, and other controls are tested as explanatory variables. This study also attempts to clarify the direction of the effects between the slaughter price, corn price, and average carcass weight found in Marsh (1999). Using quarterly data Marsh (1999) found a negative coefficient on the fed price to corn price ratio when estimating average carcass weight. Normally economic theory predicts this sign would be positive because rising input costs reduce output and rising output prices increase output. An exception to this has been noted in studies estimating fed beef supply, whereby the short-run price elasticity of supply is negative and the long-run price elasticity of supply is positive.[2]

Another motivation is to examine the effect of changing technologies on average carcass weight as the commercial cattle feeding industry has evolved with time. Other studies assess the impact of technological advancements in cattle feeding by identifying the trend effect in average carcass weights. These studies are limited however in their period of observation, spanning only twenty years (Kulshreshtha and Wilson 1972; Marsh 1999).

The objective of this thesis is to develop theoretical and econometric models that will provide insight into the factors that affect average carcass weight, with the goal of identifying the short- and long-run impact of price, and technology on the average carcass weight of commercially slaughtered cattle. In particular, the following variables are

[2] A negative price elasticity of supply in the short-run is referred to as backward bending supply and has been noted in studies estimating slaughter cattle supply (Reutlinger 1966; Langemeier and Thompson 1967; Myers, Havlicek and Henderson 1970; Tryfos 1974; Marsh 1994).

hypothesized to be important in determining average carcass weights: corn prices, manufacturing wages, and slaughter cattle prices. We also include a time trend to account for changes in technology and a dummy for the 1975 beef grading change. In the theoretical model we assume cattle feeders are profit maximizers who choose the optimal amount of the inputs corn and labor. Profits are maximized if the value of the marginal product of the input, corn or labor is equal to the cost of an additional unit of the input, corn or labor.

Annual U.S. time series data spanning the years 1930-2014 are used in the final analysis. The average carcass weight data series represents the weighted average of steers, heifers, cows, and bulls. Because of the existence of biological and market constraints (Marsh 1994), a distributed lag model is specified to allow for partial adjustment towards a target average carcass weight. Contemporaneous and lagged price variables are included to account for the role of producers' price expectations in production decisions. Results indicate that in addition to fed cattle and corn prices, the manufacturing wage contributes to changing average carcass weights. In particular, rising labor costs account for 35 pounds of variation in average carcass weight about its mean. A moderate partial adjustment in average carcass weight is noted (λ=0.62), allowing for the calculation of short-run and long-run price effects. As expected, technological change (measured through a time trend), accounted for a large proportion of the growth in average carcass weights over time.

CHAPTER TWO

BACKGROUND

Commercial Feedlot Production

This chapter presents a discussion of commercial cattle feeding in the United States beginning with the origination and current structure of the industry. Specifics of fed cattle production are also reviewed including marketing and grading.

Development of the Commercial Feedlot Industry

Cattle feeding originated in the Midwest region of the United States starting in the late 1800s to early 1900s (Conner, Dietrich and Williams 2000). The early cattle feeders in this region were corn farmers who also owned cattle. Cattle were pasture fed up until slaughter, with corn used as a supplemental feed. Most cattle were older (3-5 years old) at marketing (Ball 1992), because cattle were grass-finished and had to be trailed to market.[3] In Texas, the development of the cattle feeding industry was prompted by the presence of cottonseed mills. These mills produced meal and hulls as byproducts which were good feed sources for cattle (Ball 1992). As a result, mill operators owned many of the early Texas feedlots (Ball 1992).

Development of the United States cattle feeding industry was encouraged by the increased availability of grain following World War II (Klopfenstein et al. 2008). The

[3] Cattle that are grass finished typically gain weight at a slower rate than cattle that are grain-finished because grasses have a lower energy content than grains. Prior to motorized transportation, cattle were walked to market sometimes over long distances. Typically older cattle had a better chance of surviving the hardships of the journey to market (Conner, Dietrich and Williams 2000).

war brought about improved technologies and greater mechanization, leading to increased productivity on farms (Dimitri et al. 2005). For instance, corn yields were 29.90 bu/acre in 1930 and 38.20 bu/acre by 1950 (Economic Research Service 2015). Improvements in corn yield was mainly due to advances in crop fertilizer, irrigation, and hybrid grains, as well as efforts to conserve soil moisture (Carlson 1987). After the war ended, demand for crops declined but supplies still remained high, resulting in low prices of corn, wheat, cotton, rice, peanuts, and tobacco (Cain and Lovejoy 2004). To reduce production of these crops the government enacted the Soil Bank Program, where producers could opt to retire cropland from production. Rather than reduce corn production, some farmers found it more profitable to feed the corn to cattle (Klopfenstein et al. 2008). Corn was a cheap input that reduced the requirement for pasture. Due to its high energy value, corn improved cattle rates of weight gain, shortening the length of the feeding period. With a shortened feeding period, farmer-feeders were able to market cattle at younger ages. The combination of corn feeding and the younger age of cattle at marketing led to an improvement in the overall quality of beef produced in the U.S.[4]

As a major producer of corn, Iowa was historically the largest cattle feeding state. Most feedlots in Iowa were small, with less than 1,000 head capacity (Conner et al. 2000). With the development of truck transportation larger feedlots began to form in other parts of the country, particularly where irrigated corn was produced and where the weather was more conducive to feeding cattle (Corah 2008). As early as 1937, there was a 10,000 head feed yard near Brownfield, Texas (Ball 1992). California also had a

[4] According to the USDA grading system, higher quality grades (Prime, Choice, Select, and Standard) of beef are characterized as younger cattle (< 42 months of age) with an abundant degree of marbling. Intramuscular fat deposition or marbling increases when high energy feeds, such as corn, are fed to cattle.

number of 10,000 head feed yards by the 1950s (Conner et al. 2000). In 1968 the first 100,000 head feed yard was being operated in Greeley, Colorado (Corah 2008).

Throughout the 1940s and 1950s cattle on feed was highest in the states of Iowa, Illinois, and Nebraska (figure 2.1; NASS 1942). In the 1960s, California's cattle feeding industry rapidly increased and surpassed Iowa in cattle-on-feed numbers. By the 1970s large-scale commercial feedlots became commonplace, particularly in the Southern Plains region (Reimund, Martin and Moore 1981).

Texas overcame Iowa as the number one cattle feeding state in 1976 (Corah 2008). As of January 1, 1973 there were 2.25 million head of cattle-on-feed in Texas, up from 132 thousand head in 1955 (figure 2.1; NASS 1942). The dramatic increase in the Southern Plains feedlot industry from 1955-1973 was largely attributed to the availability of feed, weather, and low population densities (Reimund et al. 1981).[5] Custom cattle feeding contracts were also important in providing capital to Southern Plains feedlot owners. Greater access to capital allowed owners to operate larger facilities year round (Reimund et al. 1981). In comparison, farmer feeders in the Corn Belt ran smaller seasonal operations, typically feeding their own cattle. After the 1980s Texas, Nebraska, and Kansas fed the most cattle. The highest monthly cattle on feed inventory for the United States was 14.4 million head in 1973 (NASS 1942).

The rapid increase in commercial cattle feeding was aided by rising beef demand (Reimund et al. 1981). Originally pork consumption in the U.S. was greater than beef consumption. Following World War II, the share of beef in consumer's diets became

[5] Large-scale feedlots do not usually localize in urban, highly populated areas.

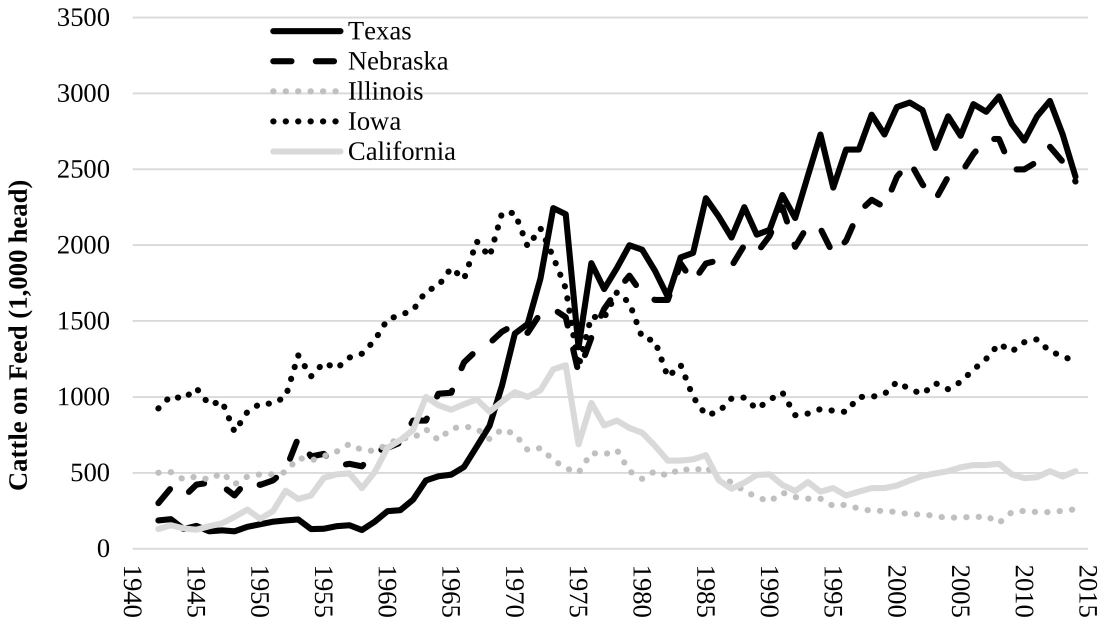

Figure 2.1: Texas, Nebraska, Illinois, Iowa, and California January 1 Cattle on Feed, 1942-2014.

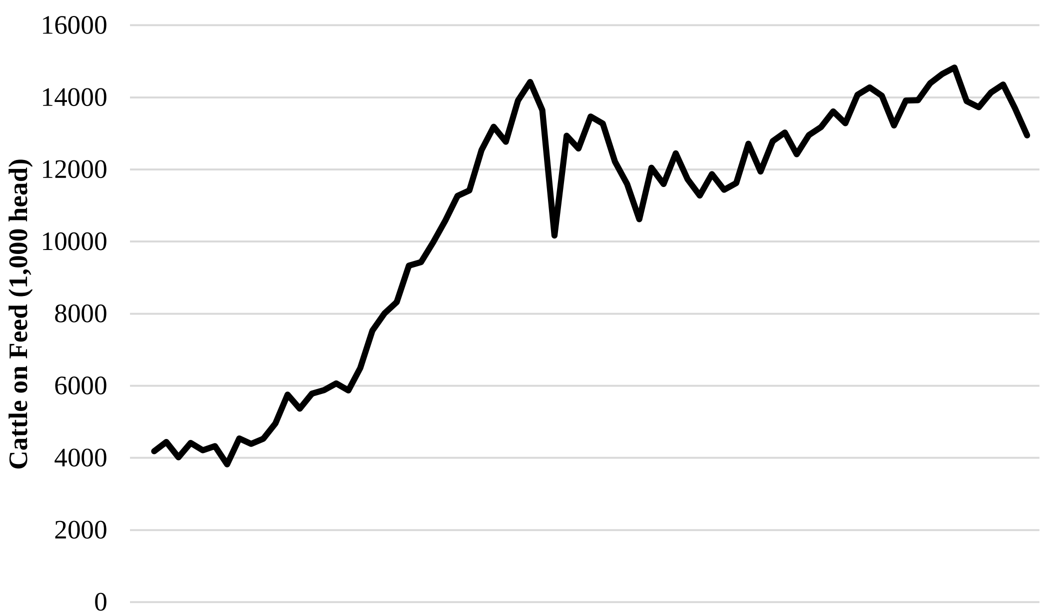

Figure 2.2: United States January 1 Cattle on Feed, 1942-2014.

greater than pork (figure 2.3; ERS 1910a). Per capita beef consumption went from 38.6 pounds in 1930 to 94.1 pounds in 1976 (ERS 1910b). The notable increase in both beef demand and consumption over this period has been largely attributed to consumers preference for beef, rising incomes, an increasing population, and growth of the U.S. economy (Reimund et al. 1981; Mintert, Tonsor and Schroeder 2009). [6] Since 1976, beef consumption has trended downward and is currently at levels similar to the early 1950s (ERS 1910b). Research has suggested the recent decline in beef demand has come from preference for convenience foods, food safety recalls, and health concerns (Schroeder, Marsh and Mintert 2000).[7]

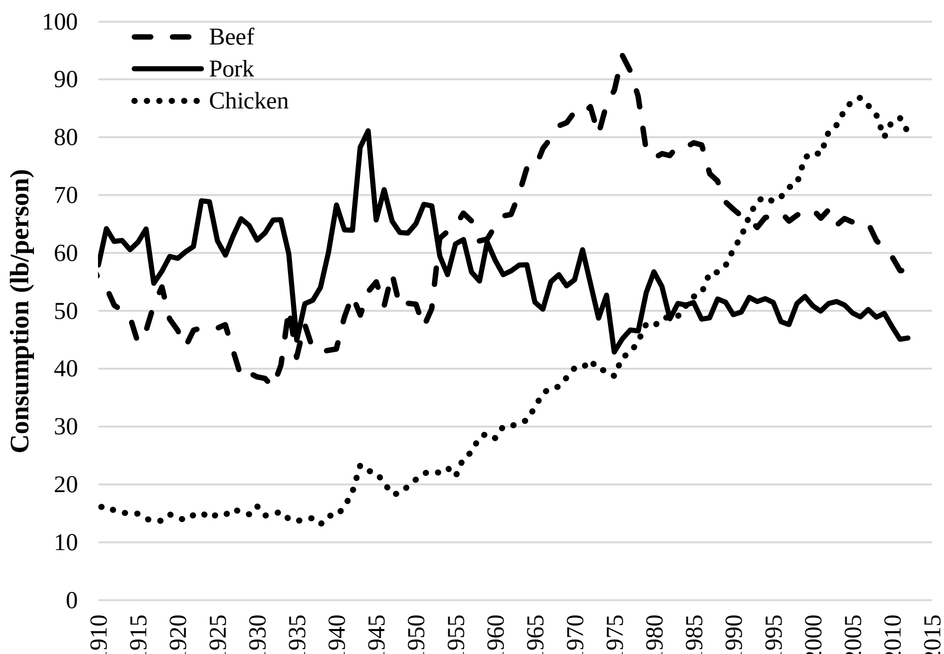

Figure 2.3: United States Per Capita Meat Consumption, 1910-2012.

[6] Beef demand is per capita beef consumption at a specific retail beef price.
[7] Preference for convenient food was proxied by the female labor force participation rate.

Current Structure of the Commercial Feedlot Industry

Today the commercial feedlot industry is concentrated primarily in the High Plains region where both feed grains and cattle are abundant. Altogether Texas, Nebraska, and Kansas are the top cattle feeding states, marketing over 65 percent of the fed cattle in the United States (Cook 2015). In 2014, the top 3 corn producing states were Iowa, Illinois, and Nebraska, producing 44% of all corn (NASS 2015).[8] Of the corn used domestically 45% or 5.317 billion bushels went to livestock feed (ERS 2015b). In terms of cattle packing facilities, most are localized geographically in the rural Great Plains region (Drabenstott, Henry and Mitchell 1999). Presently, Tyson Foods, JBS USA, and Cargill Beef hold 65 percent of the nation's slaughter capacity for cattle (Cattle Buyer's Weekly 2013).

Commercial feedlots are the net one-time capacity greater than 1,000 head. Currently, only 2.6 percent of all feedlots are commercial (Mathews 2012). Eighty to 90 percent of fed cattle marketings are from commercial feedlots, and 40% of fed cattle marketings are from commercial feedlots with a capacity of at least 32,000 head (Mathews 2012). Cattle ownership in feedlots varies between owners, investors, and customers. Often large commercial feedlots are associated with custom feeding and small commercial feedlots, retained ownership.[9]

Economies of Size in Commercial Feedlot Production

Typically commercial feedlots have large capital requirements, particularly for

[8] In 2014 Iowa produced 2.367, Illinois 2.350, and Nebraska 1.602 billion bushels of corn (NASS 2015).
[9] Custom feeding is an arrangement where a producer pays a feedlot to feed and care for their animals. The feedlot charges a yardage fee per animal per day. In contrast, a feedlot may choose to feed and take care of owner cattle.

cattle, equipment, and facilities (Reimund et al. 1981; MacDonald and McBride 2009). As a result, economies of size have arisen due to mechanical, biological, and organizational advancements (Reimund et al. 1981). Size economies are shown by the difference in capital costs per animal for feedlots of varying capacities, $468/head for 1,000 head yards and $243/head for 20,000 head yards (Duncan et al. 1997).

Large-scale commercial feedlots operate year round, have small land bases, and purchase the majority of their feed. As a result, commercial feedlots possess high capacity storage facilities, advanced mills, and specialized feeding and manure handling equipment (Reimund et al. 1981; MacDonald and McBride 2009). Increased mechanization has been important for reducing the labor requirement for feedlots and increasing the number of cattle that can be fed. Feedlots have also become more specialized in certain aspects of feedlot production (Reimund et al. 1981; MacDonald and McBride 2009) by hiring managers, veterinarians, Ph.D. nutritionists, cattle buyers, accountants, and futures and options traders.

In commercial feedlot production, biological technologies are used to promote weight gain, feed efficiency, carcass quality, and health. [10] Most of these technologies are pharmaceutical products that fall under the categories of implants, ionophores, dewormers, antibiotics, vaccines, and beta-agonists.[11] Feedlot adoption rates for many of these technologies are over 80%, resulting from their efficacy and input cost savings (Lawrence and Ibarburu 2007). Technologies that improve cattle feed efficiency reduce

[10] Feed-efficiency represents the relative proportion of dry matter consumed on a daily basis by an animal that is converted to average daily weight gain.

[11] See Nomenclature on pg. ix for a description of these pharmaceutical products.

the amount of feed required to produce an additional pound of weight. Technologies improving carcass quality reduce fat yield and or improve marbling and tenderness of carcasses. In comparison, technologies that improve animal health (e.g. vaccines) reduce the spread of disease and death loss, allowing for greater concentration of cattle in pens (Reimund et al. 1981). Researchers have estimated feedlot cost savings from using these products range between $5.9/head and $68/head (Lawrence and Ibarburu 2007).

Fed Cattle Production

Commercial feedlots specialize in producing highly marbled beef for human consumption. In particular, feedlots produce fed beef from cattle that are finished on a grain-based diet in a confinement setting.[12] This contrasts with unfed beef (such as culled cows), cattle not finished on a grain-based diet that are primarily used for hamburger. Typically, feeder steers and heifers represent the majority of fed cattle in the United States (NASS 1921-2014). Feeder cattle are further classified into calf-feds and yearlings. Calf-feds are heavier calves produced by cow calf producers. Yearlings are the lighter calves that move from the cow-calf system into backgrounding yards. Backgrounding yards specialize in growing calves on a forage based-diet, which later enter feedlots for finishing.

Feeder cattle may be purchased directly from cow-calf producers, or indirectly through cattle buyers and auctions. Once purchased, feeder cattle are placed into feedlots in group pens by ownership. During finishing, cattle are fed a ration consisting mainly of

[12] The term finished refers to cattle that are fed until they reach a marketable slaughter weight. Confinement refers to cattle that are fed in pens.

corn or some other grain twice daily.[13] Each animal will consume 1.5-2 tons of feed during the finishing period (CME Group 2014). The finishing period typically ranges from 4-6 months for a calf-fed and 6-8 months for a yearling. At the end of the feeding period the fed animal's live weight is usually between 1200-1400 pounds (CME Group 2014), which produces approximately a 750-900 pound carcass.[14]

Live weight refers to the weight of the animal prior to slaughter, while carcass weight measures the weight of the animal post-slaughter after the head, hide, and offal have been removed. Both the live weight and carcass weight of an animal are related through the dressing percentage. [15] The dressing percentage refers to the proportion of pre-slaughter live weight that is carcass weight. As days on feed increase the dressing percentage increases (MacDonald et al. 2007). [16] This implies, as days on feed increase for an animal, each additional pound of live weight gain leads to an even greater proportional increase in carcass weight gain. Average daily gain of an animal decreases as it nears slaughter, however relative to live weight gain, carcass weight gain declines at a slower rate (MacDonald et al. 2007).

Fed Cattle Marketing

Cattle feeders have the option of pricing cattle based on weight, live or carcass, as

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[13] The USDA reports 95% of feed grain usage is corn, this would include poultry, pork, and beef sectors (Capehart 2015). Other grains commonly fed to cattle include barley and sorghum. Cattle rations typically include a roughage source (e.g. silage, straw, hay) in addition to grain and supplement, although the grain makes up the greatest proportion of the ration.

[14] In September of 2015, NASS reported in the *Livestock Slaughter* report that the monthly average carcass weight of steers was 920 pounds, the largest weight recorded to data.

[15] Carcass weight is calculated as the live weight multiplied by the dressing percentage, commonly 63%. For example, 1200 lb live weight × 0.63 = 756 lb carcass weight. A common dressing percentage for fed cattle is 63 percent.

[16] Days on feed is defined as the total days from cattle placement into the feedlot until slaughter.

well as carcass value, grid and formula (Radunz 2010). Historically, all fed cattle pricing was based on live weight. Live weight pricing relies on the pre-slaughter weight of an animal. An entire pen is sold at one time with live weight pricing and the sale occurs at an auction market or at the feedlot (Radunz 2010). Buyers visually inspect the pen of cattle before offering a sale price. The live weight sale price is based on the current wholesale Choice carcass price adjusted for the expected quality and dressing percentage of the pen (Hogan et al. 2009; Radunz 2010). [17] In comparison, payment for carcass weight pricing is based on the animals hot carcass weight at slaughter. Similar to live weight pricing, all cattle in a pen receive the same carcass weight price. The carcass weight price is also established based on the current wholesale Choice carcass price along with other quality considerations (Hogan et al. 2009). Unlike live weight pricing however, the buyer does not need to guess the dressing percentage of the cattle marketed when carcass weight pricing (Radunz 2010). In 2012, approximately 60 percent of cattle were marketed on a carcass weight basis, while 40 percent were marketed on a live weight basis (Herrington and Tonsor 2012).

Marketing of cattle based on carcass merit, quality and yield grade in addition to carcass weight is possible through formula and grids. Formula pricing uses an external reference price (Ward, Schroeder and Feuz 1999), such as the live cattle futures price. Grid pricing is at the individual animal level and requires a base price in the formula. Premiums and discounts are then applied to the base price depending on how a carcass grades (quality and yield) at slaughter (Radunz 2010). Discounts are also given out for

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[17] Choice refers to a carcass quality grade category characterized by younger cattle with moderate to small degree of marbling.

various other specifications such as heavy carcasses, dairy breeds, and dark cutters (e.g. bruised carcasses) (Radunz 2010).[18]

Often the distinction is made between the cash (cash and grid) and non-cash (formula, forward contracting) trade in fed cattle marketing. Over time the cash market has diminished significantly. In 2013, the percentage breakdown of marketing types was: 23.1 percent cash, 6.3 percent negotiated grid, 59.8 percent formula, and 10.8 percent forward contract (Kay 2015). Price discovery is the primary concern with the decline in cash market trade (Koontz 2015). As more cattle are marketed under non-cash trade, fewer transactions in the cash market determine the base price for formulas (Schroeder et al. 1997). Another concern with non-cash trade is the availability of information, particularly on transaction volumes and prices. The USDA implemented the Livestock Mandatory Reporting Act in 2001 in response to producer concerns. The Act requires packers with greater than 125,000 head annual capacity to disclose pricing information (Grunewald, Schroeder and Ward 2004). Pricing information has to be disclosed daily to the USDA on all cattle purchases and beef sales (Grunewald et al. 2004).

Beef Cattle Grading

Beef carcass grading by the USDA is a non-mandatory service that is paid for by producers and retailers (Food Safety and Inspection Service 2014). The grading standards

[18] The term dark cutter, refers to beef that is dark in color rather than bright red. If an animal undergoes stress prior to slaughter, glycogen stores are depleted. Depleted glycogen levels inhibit glycolysis which produces lactic acid as a byproduct. Lactic acid is responsible for keeping beef the bright red color. See the following link by J. Savell for more details http://meat.tamu.edu/2013/01/22/dark-cutting-beef/.

were initially developed in 1916 and became official U.S. standards in 1926 (USDA 1997). USDA beef grading encompasses grades for quality as well as yield. Carcasses can be graded separately or together with respect to yield and quality grade. To market beef by a particular grade or USDA certified program, grading is required. It is common for Standard and Commercial grades of beef to be sold at retail or as brands that are ungraded (FSIS 2014). Beef consumed as hamburger and in processed products is rarely graded (FSIS 2014). Ungraded carcasses are classified as "no-roll," a term originating from the tool used to apply carcass grades (Burson 2005).

The first component of USDA carcass grading is quality grade. Quality grade is supposed to represent palatability, tastefulness, flavor, and juiciness of meat (FSIS 2014). Beef carcasses may fall into eight different quality grades depending on their degree of marbling and maturity (figure 2.4; FSIS 2014). Marbling or intramuscular fat signifies the degree of carcass fat, a measurement of the ribeye at the 12^{th} rib (USDA 1997). Maturity is based on physiological age of the animal and can be determined through ossification of the vertebrae.[19] Quality grade indicates differences (though not, perfectly) in expected eating quality (Knight 2007) and, therefore, is also representative of carcass value.

Referring to the 1997 USDA Standards for Grades of beef, Prime is the top quality grade and represents carcasses with slightly abundant to abundant marbling scores. Carcasses grading Choice have small to moderate degrees of marbling, while carcasses grading Select have only a slight degree of marbling. Standard is the leanest quality grade category, where the degree of marbling ranges from traces to practically

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[19] Approximate age (maturity) categories are A- 9 to 30 months; B- 30 to 42 months; C- 42 to 72 months; D- 72 to 96 months; E- > 96 months (Holland and Loveday 2012).

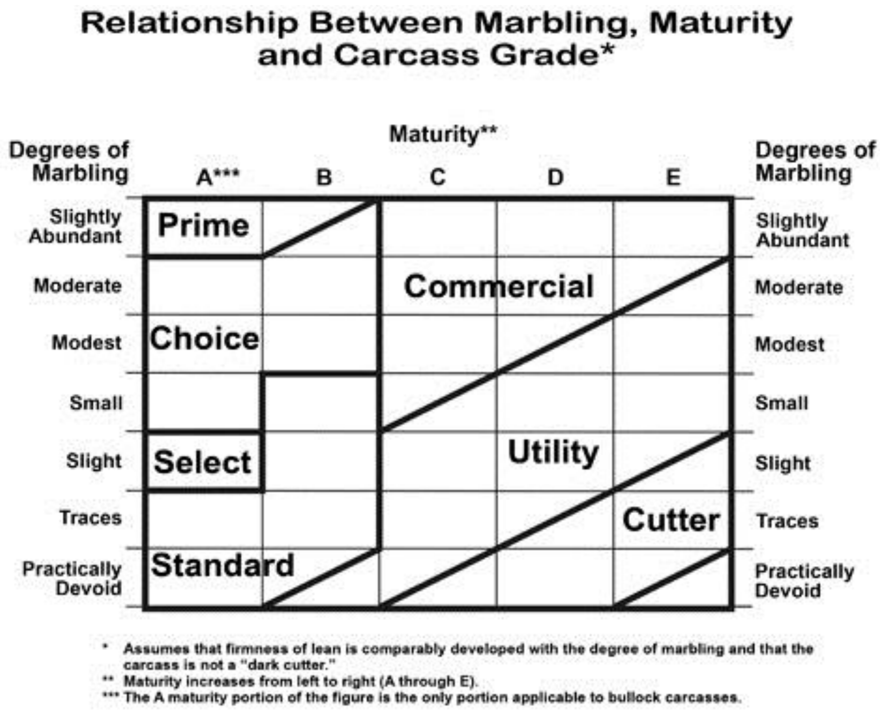

Figure 2.4: Relationship between Marbling, Maturity and Carcass Grade (USDA 1997, p.9).

devoid. Prime, Choice, Select, and Standard grades encompass younger cattle of A and B maturity, although Select carcasses are restricted to A maturity only. Commercial, Utility, Cutter, and Canner grades are comprised of older cattle with C through E maturity. In 2014 the AMS reported that of all cattle slaughtered, 4.1 percent graded Prime, 64.6 percent Choice, 24.9 percent Select, and zero percent were graded Standard. The remaining 6.4 percent of cattle went ungraded and represented the four lower grades of beef (Commercial, Utility, Cutter, and Canner) (Agricultural Marketing Service 2015).

Yield grade (YG) or cutability reflects the percentage of closely trimmed, boneless, retail cuts from primals of the chuck, rib, loin, and round (USDA 1997).[20]

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[20] A beef carcass is first cut into primals during the butchering process.

Assignment of yield grade is formula based. The formula incorporates measures of hot carcass weight, 12th rib external fat thickness, percent kidney, heart, and pelvic fat, and ribeye area (USDA 1997). Yield grade consists of five categories, labeled 1 to 5 (FSIS 2014). A carcass with a yield grade of 1 consists of a greater amount of retail beef than a carcass of a yield grade of 5. To packers and cattle feeders yield grade represents the amount of saleable meat that can be obtained from a carcass (Holland and Loveday 2012). In 2014, only 26.2 percent of cattle slaughtered were yield graded (Agricultural Marketing Service 2015). Of those, 7.7 percent graded yield grade 1 (YG1), 35.9 percent YG2, 45.4 percent YG3, 9.8 percent YG4, and 1.3 percent YG5.

Over time there have been many modifications to beef grading standards. The most significant grading revisions were made in 1950, 1965, and 1975 (USDA 1997). The most recent grading change was in 1997. In 1950, a decision was made to reduce the minimum amount of marbling required for each quality grade category (USDA 1997). At the time, the quality grades were Prime, Choice, Good, and Standard. As a result of the change, the Prime grade was reformulated to include the Choice grade, the Good grade was renamed Choice, and the Commercial grade was split by maturity (young and old). By 1965 cutability grades were introduced, although their use was not mandatory (USDA 1997). Minimum marbling requirements were also reduced in 1965 for mature animals in Prime, Choice, Good, and Standard categories. Figure 2.5 shows the quality grade standards for 1965.

The grading change of 1975 resulted in four major changes, summarized below (Harris, Cross and Savell 1996; USDA 1997). Compare Figure 2.4 and 2.5 to visually see the changes in USDA quality grades arising from the 1975 change.

(1) Maturity was no longer used in defining the quality grade of steer, heifer, cow, and bullock beef in the A maturity category. This change was in response to research that had indicated the consumers dining experience was not affected by this factor. [21] Instead the minimum marbling requirements for Prime, Choice, Good, and Standard grades became the same across all A maturity animals and corresponded to the original minimum marbling requirement of the pre-1975 grading categories.

(2) There was a one-half of a percentage point increase in the minimum marbling requirement for A maturity cattle to grade Good.

(3) For the maturity B carcasses in Prime, Choice, and Standard grades the rate of increase of marbling with increasing maturity remained the same as before, but the minimum degree of marbling required for B maturity carcasses was lowered to match the marbling level for A maturity carcasses.

(4) Conformation was no longer required in grading cattle for quality. Conformation was a form of visual inspection of the muscling and thickness of an animal.

Instead all carcasses were required to have yield and quality grade designations. The objective of the 1975 grading change was to create leaner quality grade boundaries to benefit both consumers and producers (Rhodes 1975). Cattle feeders could meet the marbling requirements by reducing days on feed to finishing (Rhodes 1975). Consumers

[21] Bullock- represents a young bull of A maturity.

would have more access to lean palatable meat. The other objective was to introduce yield grade, a direct measure of carcass value. Nelson (1977) examined the effects of the grading change and found the proportion of carcasses grading Choice increased and the proportion of carcasses grading Good decreased. The grading changes however, were not found to affect overall beef demand (Nelson 1977).

To encourage grading of leaner carcasses the USDA renamed the Good grade Select in 1987 (USDA 1997). At the time there had been a consumer movement towards healthier, leaner beef, yet few carcasses were being graded in the Good category. By 1989, another change occurred where the dual grading requirement for quality and yield grade was removed (USDA 1997). Finally in 1997 the Choice and Select categories were narrowed. The Select category was restricted to A maturity carcasses. In addition, there was an increase in the minimum percentage of marbling required for carcasses to grade Choice (USDA 1997).

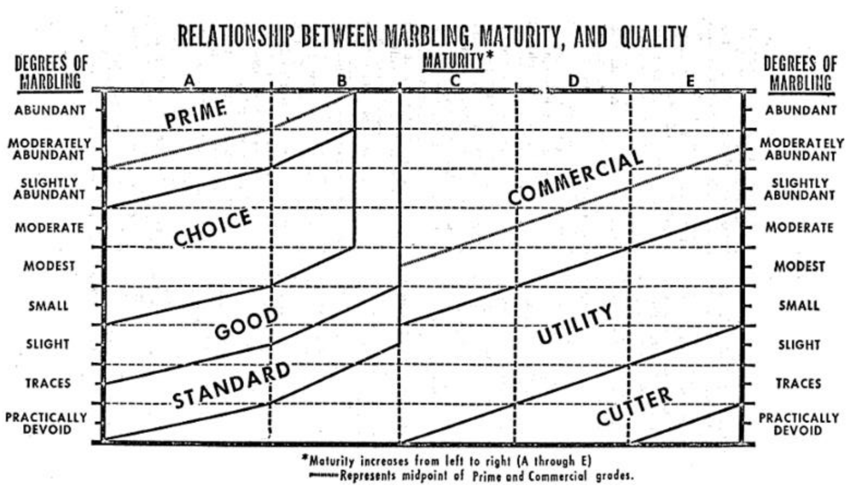

Figure 2.5: Relationship between Marbling, Maturity, and Carcass Quality Grade – 1965 (U.S. Division of the Federal Register 1971, p.26)

CHAPTER THREE

LITERATURE REVIEW

This chapter reviews literature on the economics of fed cattle production. The review is broken into three parts. Part one examines factors contributing to cattle feeding profitability, including average carcass weights. Part two reviews empirical models of average carcass weight. The final section discusses determinants of cattle average carcass weights.

Determinants of Feedlot Profit

Using feedlot closeout data, various studies have evaluated factors contributing to variation in feedlot profitability of cattle marketed on a live weight basis (Langemeier et al. 1992; Mintert et al. 1993; Lawrence, Wang and Loy 1999; Mark, Schroeder and Jones 2000). Overall these studies found the fed price and feeder price were most important to feedlot profitability, together explaining more than 70 percent of the variability in profits (Langemeier et al. 1992; Mintert et al. 1993; Lawrence et al. 1999). Changing corn prices resulted in the next highest source of return variability, followed by live weight measures of feed efficiency and average daily gain (Langemeier et al. 1992; Mintert et al. 1993; Mark et al. 2000). More recently, factors affecting feedlot profitability were examined in the context of grid marketing, whereby the grid base price, feeder price, and quality grade were found to be significant determinants of cattle feeding profits (McDonald and Schroeder 2003).

The rise in the use of carcass based pricing and grids has highlighted the importance of carcass weights in determining cattle feeding returns (Feuz, Fausti and Wagner 1993; Feuz 1998; Feuz 2002; Pyatt et al. 2005; Johnson and Ward 2005; Walter and Hale 2011; Tatum et al. 2012; Wilken et al. 2015). Using various marketing schemes and data on 85 pens of cattle, Feuz (1998) analyzed the variation in feedlot returns from variation in cattle carcass weights, quality and yield grade measures, while holding the fed price constant. Regardless if cattle were sold on a live or carcass weight basis in both the show list and individual pen marketing scenarios, the proportion of revenue variation explained by weight was greater than 96.7 percent.[22] Comparatively, 71-95 percent and 38-78 percent of the revenue variability in grid marketing at the pen-level and individual level, were from carcass weight. Grading Choice in the pen-level scenario and marbling score in the individual level scenario, were the next highest sources of revenue variation. These findings were similar to Johnson and Ward (2005), where 61-71 percent of the variation in animal value resulted from carcass weight and the remaining 29-39 percent was explained by the grid price. The grid price was calculated using a constant base price that was adjusted by premiums and discounts from quality, yield grade, and weight (Johnson and Ward 2005).

Pyatt (2005) identified the amount of variation in feedlot profitability that was explained by various performance and quality measures (marbling score, carcass weight, yield grade, and daily dry matter intake) when dressed price, Choice-Select spread, and feed costs increased. As dressed price of cattle increased, hot carcass weight increasingly

[22] A show list refers to the marketing of more than one pen at a time.

explained feedlot profitability compared to all other variables. If instead the Choice-Select spread widened, the marbling score became increasingly important and carcass weight, yield grade, and daily dry matter intake became decreasingly important. In scenarios with high feed costs, both hot carcass weight and marbling score of cattle were less significant than yield grade and performance measures in determining feedlot profitability (Pyatt et al. 2005).

A comparison of the returns between live weight, carcass weight, and value-based fed cattle marketing schemes, indicated return variability increased moving from live weight to value-based marketing of cattle (Feuz et al. 1993; Koontz et al. 2008). Average prices received by cattle feeders were also higher when quality was considered, such as in value-based marketing, compared to marketing methods based on weight (live or carcass) only (Feuz et al. 1993). Higher prices were offered in value-based marketing scenarios because buyers did not have to guess on dressing percentage, quality, and yield grade of cattle carcasses. Similarly, as cattle buyers possessed more information on the quality of the carcass, price discrimination was more likely. Greater price discrimination by cattle buyers increased the profit variability for cattle feeders (Feuz et al. 1993).

Empirical Models of Average Carcass Weight

Few empirical economic studies have directly estimated the variation in average carcass weights of cattle because of changing input and output prices (Langemeier and Thompson 1967; Kulshreshtha 1976; Marsh 1999). In two of these studies the entire beef sector was modeled through a system of simultaneous supply and demand equations, where the average carcass weight equation represented one of the relationships within the system (Langemeier and Thompson 1967; Kulshreshtha and Wilson 1972). Another study used iterative three-stage least squares and a log-log functional form to estimate steer, heifer, and cow average dressed weight equations (Marsh 1999). More commonly, studies in the literature estimate slaughter cattle supply using total carcass weight (Reutlinger 1966; Langemeier and Thompson 1967; Kulshreshtha 1976; Ospina and Shumway 1979) or total live weight at slaughter (Myers, Havlicek and Henderson 1970; Hayenga and Hacklander 1970; Antonovitz and Green 1990).

Dynamic Regression Models

Fed cattle production is highly dynamic because of changing input and output prices (Marsh 1994). In addition, pricing information is often not known in advance. As a result, cattle feeders must formulate price expectations based on historical, current, or projected information (Nerlove 1958; Muth 1961). Price expectations can be modeled using lags on the price variables, where expectations are a function of current or past prices. Lags on the dependent variable are also commonly incorporated into cattle supply equations, yielding difference equations. Difference equations are useful in estimating the partial adjustment process (Kmenta 1971). Partial adjustment refers to output levels requiring time to stabilize to price shocks. Partial adjustment arises because of market rigidities, technologies, and biological constraints (Kmenta 1971; Rucker, Burt and LaFrance 1984; Marsh 1994; Marsh 1999). In fed cattle production, partial adjustment of output occurs through changing slaughter weights or the number of fed cattle marketings (Marsh 1994).

One of the first studies to illustrate the use of a dynamic model in the beef sector was that by Rucker, Burt, and LaFrance (1984). They estimated beef cow inventories using a second order non-stochastic difference equation. Specifically they found feeder prices lagged one and two periods and the ratio of the fed price to corn price lagged one period explained U.S. cattle cycle behavior. Marsh (1994) also used a partial adjustment model, specifying monthly lag structures to identify both short- and long-run price effects on fed cattle supply and feeder cattle demand. Through use of quarterly data, Marsh (1999) applied the partial adjustment theory to examine the effect of trends and price volatility on average carcass weights of steers, heifers, cows, and gilts.

Determinants of Average Carcass Weight

Factors used to account for the variation in average carcass weights in the literature have been the fed price, corn price, feeder price, the number of cattle slaughtered or on feed, and a trend. Table 3.1 presents a summary of the parameter estimates for the carcass weight determinants reported in past studies. Across studies the sign, magnitude, and significance of these factors are highly inconsistent, likely arising from different study attributes. A brief discussion of the literature on each of these factors is presented below. Other variables not previously tested in average carcass weight models are discussed and include labor costs, the 1975 beef grading change, and beef demand. Determinants of slaughter cattle supply resemble determinants of slaughter weight, therefore slaughter supply studies are reviewed as well.

Table 3.1: Summary of the Previous Literature on Reported Determinants of Average Carcass Weight

STUDY	MODEL	CATTLE TYPE	TIMEFRAME	VARIABLES	PARAMETER ESTIMATE
Marsh (1999)[a]	Iterative three stage least squares[*]	Steers	Quarterly, 1980-1997	Feeder Price	0.048
				Slaughter/Corn Price Ratio	-0.025
				Cattle Slaughtered	0.004[b]
				Trend	0.008
Kulshreshtha & Wilson (1972)	Two stage least squares	Fed cattle	Yearly, 1949-1969	Slaughter/Feed Price Ratio$_t$	2.015[b]
				Beef Cattle Inventory$_t$	-0.021
				Trend	6.667
Langemeier & Thompson (1967)	Two stage least squares	Fed cattle	Yearly, 1947-1963	Corn Price$_t$	-37.3[c]
				Slaughter Price*t*	5.48[d]
				Cattle on Feed$_t$	0.013

[*]Data were estimated in log-log form. A first order difference equation was specified to allow for partial adjustment of average carcass weight.

[a] Estimates reported here are for steers, even though heifer and cow average carcass weight equations were estimated as well.

[b] These coefficients were insignificant.

[c] In this study, current and lagged corn prices were calculated using the ratio of the market price to the government support price for corn. The lagged corn price differed from the current corn price in that it used the average of the prices for the year's t-1, t-2, and t-3. The coefficient on the lagged corn price (-37.9) is not reported above but was significant.

[d] Both the contemporaneous and lagged fed beef price was specified. The contemporaneous price was significant and is reported above. The lagged fed beef price was not significant and is not reported above.

Slaughter Price

Cattle feeders are paid primarily on the weight of cattle at slaughter. For cattle feeders to maximize profits, slaughter weights are expected to be positively correlated with fed prices. Even so, studies estimating average carcass weight of cattle have reported both a positive (Langemeier and Thompson 1967) and negative (Marsh 1999) relationship with the slaughter price (Table 3.1). Langemeier and Thompson (1967) specified the current and lagged fed price and found only the current price to be statistically significant. They noted a one-dollar per hundredweight increase in the contemporaneous fed price resulted in a 5.48 pound increase in average carcass weight. Using a log-log OLS model and quarterly carcass weight data, Marsh (1999) reported a 10 percent increase in the fed steer to corn price ratio resulted in short- and long-run reductions of 0.25 percent and 0.52 percent in average carcass weight. Marsh suggested when the ratio of the fed price to corn price was increasing, it implied relatively cheaper corn prices. With cheaper corn prices, cattle feeders would be inclined to place lighter feeder cattle. As a result, average carcass weights of steers declined because the average daily gain of lighter cattle was not enough to offset their smaller placement weights. Similar results were noted for heifers as steers, although for cows, Marsh (1999) reported a positive coefficient on the cow to corn price ratio in the cow carcass weight equation. It was suggested that higher cow prices encouraged cattle feeders to increase profits by adding weight to culled cows at slaughter. Finally a report by Kulshreshtha and Wilson (1972) indicated the beef price to feed grain price index did not significantly explain the average carcass weights of cattle.

Numerous studies have estimated own price elasticities of slaughter cattle supply using total slaughter weight (Reutlinger 1966; Langemeier and Thompson 1967; Tryfos 1974; Ospina and Shumway 1979) and total cattle marketed or slaughtered (Kulshreshtha 1976; Nelson and Spreen 1978; Brester and Marsh 1983; Marsh 1994; Marsh 2003) as the empirical measure for supply. Slaughter cattle supply elasticities are generally reported to be inelastic in the short-run and elastic in the long-run, with respect to slaughter price (Kulshreshtha 1976; Marsh 1994). The relationship between slaughter price and quantity should be positive, although some studies have reported a negative relationship in the short-run (Reutlinger 1966; Tryfos 1974; Brester and Marsh 1983; Marsh 1994). For example, Marsh (1994) estimated a dynamic monthly fed cattle supply model and found a 10 percent increase in the fed price led to a 1.7 percent reduction in the short-run supply of slaughter cattle. Over the long run however, Marsh (1994) found a 10 percent increase in the fed price led to a 32.4 percent increase in the supply of slaughter cattle. An increase in the fed price will reduce short-run slaughter cattle supply if producers expect future prices to go higher. An expectation for higher prices in the future causes producers to delay fed cattle marketings, reducing slaughter cattle supplies (Reutlinger 1966). Some refer to this concept as reservation demand (Myers et al. 1970). In contrast, over the long-run producers have already responded to higher fed prices by purchasing feeder cattle and increasing fed cattle marketings.

Feed Costs

Cattle feeding is highly dependent on feed grain, particularly corn as a feed source. An analysis of closeout data from two Kansas feedlots and 7,292 pens of steers, suggested 63-66 percent of the variation in feedlot cost of gain was explained by corn prices (Albright, Schroeder and Langemeier 1994). Despite this information, one study did not find feed prices to significantly explain average carcass weight (Kulshreshtha and Wilson 1972). The researchers used Canadian data and specified the fed price to grain price index to proxy output and input prices. In comparison, Langemeier and Thompson (1967) and Marsh (1999) found opposing significant relationships between the corn prices and average carcass weight. Langemeier and Thompson (1967) determined that a one-dollar per bushel increase in the market corn price to government support price for corn led to a -37.3 pound reduction in average carcass weight. An increase in the corn price ($/bu), as measured by a smaller fed price to corn price ratio, increased average carcass weight in the Marsh (1999) study. It was suggested by Marsh (1999) that higher corn prices caused cattle feeders to place heavier feeder cattle. Even though heavier feeder cattle have lower rates of gain (particularly near the end of the feeding period) they are still expected to be marketed at greater carcass weights.

Slaughter cattle to corn price elasticity estimates are typically inelastic (Tryfos 1974; Kulshreshtha 1976; Ospina and Shumway 1979; Marsh 1994). The direction of the effect is expected to be negative but empirical studies have reported both positive and negative estimates in both the short- and the long-run (table 3.2). Inconsistencies in the estimates may arise from differences in the variable definitions (grain prices versus corn prices; total fed cattle marketings versus total slaughter weight) and the type of cattle (steers or all cattle) the data were collected from. For example, Marsh (1994) estimated fed cattle supply using fed cattle marketings. In the short-run he found that higher feed

Table 3.2: Short-Run and Long-Run Elasticity Estimates for the Effect of Corn or Feed Price on Cattle Supply

Author(s)	Cattle Type	Data	Location	Short-run	Long-run
Feed Grain Price					
Tryfos (1974)*	Cattle	Annual 1951-1971	Canada	0.024	N/A
Kulshreshtha (1976)*	Cattle	Quarterly 1954-1974	Eastern Canada	-0.320	-0.960
Kulshreshtha (1976)*	Cattle	Quarterly 1954-1974	Western Canada	0.092	0.228
Corn Grain Price					
Ospina & Shumway (1979)	Steer	Annual 1956-1975	US	N/A	-0.650
Marsh (1994)	Steer	Monthly January 1978- June 1991	US	0.072	-0.744

prices increased fed cattle supply, in the long-run the response reversed and cattle supply declined. One explanation was that higher corn prices in the short-run caused cattle feeders to want to limit their losses by marketing cattle immediately. In the long-run however, cattle feeders had time to adjust to higher corn prices by reducing feeder placements and ultimately fed cattle marketings.

Feeder Cattle Costs

Typically, higher feeder prices raise input costs, increasing break-evens, and causing a reduction in fed cattle supplied. Most of the literature agrees with this relationship (Marsh 1994; Marsh 2003), although one study reported the coefficient on the feeder price was not significant in the fed cattle supply equation (Nelson and Spreen 1978). Of the reports assessing determinants of average carcass weight (Langemeier and Thompson 1967; Marsh 1999; Kulshreshtha and Wilson 1972), only one study included the feeder price in the regression equation (Marsh 1999). Marsh (1999) used quarterly data to explore the relationship between the lagged feeder price (*t-1*) and average carcass weight, holding constant other variables. Results indicated a highly inelastic, positive, and statistically significant coefficient on the feeder price variable (short-run elasticity = 0.0048; Table 3.1). One explanation for the observed relationship offered by Marsh was that the higher purchase price of feeder cattle increased the opportunity cost of feedlot turnover. Instead of purchasing replacement cattle, producers decided to feed the cattle they had to larger average carcass weights.

Cattle Inventories

Previously, cattle on feed has been used to explain average carcass weights (Langemeier and Thompson 1967; Kulshreshtha and Wilson 1972). Langemeier and Thompson (1967) reported an increase in January 1 cattle on feed inventories per 1,000 head resulted in 0.013 pound increase in average carcass weight. Others found an increase in the December 1 Canadian beef cattle inventories per 1,000 head decreased average carcass weight 0.0205 pounds (Kulshreshtha and Wilson 1972). Marsh (1999) included the number of cattle slaughtered in his average carcass weight equations. The coefficient was insignificant in steer and heifer equations. In the cow equation the coefficient was significant, with a 10% increase in number of cattle slaughtered reducing cow average carcass weights 0.54%.

Feedlot Technologies

Technological advancements in commercial feedlot production have increased the amount and quality of beef produced, while reducing input costs (Elam and Preston 2004; Lawrence and Ibarburu 2007). Elam and Preston (2004) estimated that beef production rose 80% over the period 1955-2005 because of the combined effect of advancements in pharmaceuticals, genetics, nutrition, and grain production. They measured beef production as the quotient of total pounds of beef produced and the January 1 cattle inventory. Lawrence and Ibarburu (2007) estimated the cost savings of pharmaceutical technologies known for considerably improving feed efficiency and average daily gain of feedlot cattle. Altogether they found beta-agonists, antibiotics, ionophores, implants, and dewormers jointly reduced the cost of feedlot production by $126 per animal.[23]

Studies often use trend variables to measure technological advancements when direct measures are unavailable. Kulshreshtha and Wilson (1972) and Marsh (1999) estimate average carcass weight equations using trend variables. Altogether average carcass weights increased 53 pounds from 1980-1997 in the Marsh study, of which 44 pounds were a result of the trend. In a Canadian study, inclusion of a time trend indicated average carcass weights rose 6.7 pounds per year over the period 1959-1969 (Kulshreshtha and Wilson 1972).

The impact of technological change on cattle supplies has also been studied (Marsh 2003). Marsh (2003) estimated feeder cattle supplies using the average live weight of slaughter cattle to proxy feeder cattle production technologies. Calf weaning weights would have been preferred over slaughter cattle weights, however the author did not have access to these data. As expected, greater live weights of fed cattle were found

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[23] See Nomenclature on pg. ix for definitions on common pharmaceutical technologies in feedlot production.

to reduce the quantity of feeder cattle supplied. Fed cattle supplies were also estimated by Marsh (2003), where feedlot technologies were proxied using the proportion of fed cattle marketings for feedlots with at least 32,000 head. A negative coefficient was found on the feedlot technology variable, which was opposite the theoretical prediction. The author hypothesized the result was due to the short-run supply effect.

Labor Costs

Feedlot surveys indicate labor accounts for a significant proportion of cattle finishing costs. For instance, over one third of the yardage fee was reported to cover labor costs in a Nebraska feedlot survey (Jensen and Mark 2010). In the same survey, feedlots reported on average paying $0.10 per head day for labor (Jensen and Mark 2010). For cattle on feed 180 days this would be equivalent to $18 per head in labor costs. Similarly, a survey of Great Plains feedlots found labor accounted for costs up to $52/head for a 1,000 head feedlot and $23.38/head for a 20,000 head feedlot (Duncan et al. 1997).

Despite the importance of labor costs to cattle finishing returns the relationship between labor costs and cattle supply has yet to be researched empirically. Marsh (1999) developed a theoretical average carcass weight model incorporating labor costs, however labor costs were excluded in the estimation of the final model.

In past studies, wage rates have been used in estimating the retail-farm price margins for fed beef (Langemeier and Thompson 1967; Freebairn and Rausser 1975; Arzac and Wilkinson 1979; Brester and Marsh 1983). These studies have found that as wages increased in meat packing plants, the cost of providing retail services rose. With greater retail costs, the retail-farm marketing margin rose. Another report assessed the effect of wages not only between the fed cattle to wholesale sectors, but also between the feeder cattle to fed cattle sectors (Harri et al. 2010). As a result of a one percent increase in the processing wage, the fed-wholesale margin increased 0.844 percent. Likewise, a one percent increase in the farm wage increased the feeder-fed margin 1.334 percent (Harri et al. 2010).

1975 USDA Grading Change

As discussed in Chapter 2, the USDA changed its meat grading standards in 1975. Nelson (1977) analyzed the effects of the 1975 grading change using Agricultural Marketing Service price data for the period January 1974 to August 1976. Results of the study indicated the grading change had no impact on consumer demand for beef. There was, however, a larger proportion of carcasses grading in the Choice category and smaller proportion grading in the Good category following the change. The dual grading requirement also caused a widening of premiums and discounts associated with yield grade categories (Nelson 1977).

CHAPTER FOUR

THEORETICAL MODEL

Profit Maximization Model of Average Carcass Weight

A theoretical model is developed to demonstrate the profit maximizing behavior of a cattle feeder. In the model, a cattle feeder's goal is to maximize profits per animal by adding additional carcass (slaughter) weight. Similar to the Marsh (1999) model, cattle finishing profitability depends on the difference between revenue and costs:

(4.1) $$Profit = Revenue - Animal\ Cost - Cost\ of\ Gain$$

Cattle feeders generate revenue by selling their output (fed cattle) to packers. Revenue generated from the sale is dependent on the per pound slaughter price (P_W) and the final carcass weight (W) of cattle, as in equation (4.2). Cattle feeders are assumed to be price takers in a competitive market, and as such are unable to influence the slaughter price.

(4.2) $$Revenue = P_W W$$

Carcass weight (W) can be modeled as a production function, dependent on the placement weight (F) and the weight gain (G) of the feeder animal. Cattle weight gain is dependent on the quantities of the two inputs corn (C) and labor (L).

(4.3) $$W = F + G\,(C, L)$$

The total production costs for producing a slaughter animal include the cost of the feeder animal and the cost of gain. The cost of purchasing a feeder animal is the weight of the feeder at placement (F), multiplied by the per pound feeder price (P_F) at placement. We assume that at the time the feedlot operator makes decisions regarding the optimal weight gain, the feeder animal cost is a sunk cost, and as such is irrelevant to a cattle feeders' profit maximizing decision regarding weight.

(4.4) $$Animal\ Cost = (P_F F)^0$$

All costs incurred while adding weight to an animal during the finishing period fall under the cost of gain. Examples of these costs include: feed costs, veterinary expenses, yardage fees, interest charges, death loss, and miscellaneous costs (Albright et al. 1993). Of these costs, feed costs accounts for the most significant proportion. Past studies have suggested up to 63 percent of the variation in the feedlot cost of gain is explained by variation in the corn price (Albright et al. 1994). The numerous other non-feed costs in a feedlot, such as labor, often fall under the category of yardage. In this theoretical model, however, only labor costs and corn costs are included in the cost of gain equation (4.5). Other cost of gain variables are not included because of lack of available empirical proxies. Although if these variables were available, the year-to-year variability is likely low and is not expected to explain the variation in average carcass weights. For instance, average annual rainfall could be used to proxy feedlot performance but does not vary considerably on a year basis. Additionally, these other costs represent a small proportion of the total costs in comparison to the feed costs (Albright et al. 1994).

(4.5) $$Cost\ of\ Gain = Cost\ of\ Feed + Cost\ of\ Labor + Other\ Costs$$

The cost of feed and labor in equation (4.6) and (4.7) are equal to the price of the input (P_C or P_L) multiplied by the quantity of the input (C or L) used during the finishing period. Corn prices are used to proxy ration costs because corn is the most commonly fed grain in commercial feedlot production. The labor component accounts for the labor required to perform activities such as: feeding, pen checking, bedding, treating, weighing, and sorting of cattle.

(4.6) $$\textit{Feed Costs} = P_C C$$

(4.7) $$\textit{Labor Costs} = P_L L$$

Using the equations above, the cattle feeder's unconstrained profit expression for a single animal is displayed in equation (4.8). Note that the production function for slaughter weight in equation (4.3) is substituted for carcass weight (*W*) in the profit expression below.

(4.8) $$\text{Max } \pi = P_W W - (P_F F)^0 - P_C C - P_L L$$

$$= P_W (F + G(C, L)) - (P_F F)^0 - P_C C - P_L L$$

The first order conditions for maximizing profits with respect to the inputs corn and labor are below. The usual second order conditions are assumed to hold (see appendix A for more details).

(4.9) $$\Pi_C = P_W G_C - P_C = 0$$

$$\Pi_L = P_W G_L - P_L = 0$$

Rearranging the first order conditions in equation (4.9) yields equation (4.10), where the value of the marginal product of each of the factors corn and labor is equal to the cost of an additional unit of the factor, corn or labor. The feeder cattle input does not enter the first order conditions because its cost is sunk at the point in time the feedlot owner makes the decision regarding optimal slaughter weight.

(4.10) $$P_W G_C = P_C$$

$P_W G_L = P_L$

The first order conditions suggest we have the following factor demand functions for corn and labor:

(4.11) $C = C^*(P_W, P_C, P_L)$

(4.12) $L = L^*(P_W, P_C, P_L)$

Plugging the factor demand functions back into the first order conditions and differentiating with respect to P_C and P_L yields the following definitive predictions:

(4.13) $\partial C^*/\partial P_C < 0$

(4.14) $\partial L^*/\partial P_L < 0$

The predictions in equation (4.13) and (4.14) show that the factor demand curves are downward sloping. For the empirical analysis, however, our interest is in deriving testable predications for changing input prices on average carcass weight. Plugging the factor demand functions back into the production function for slaughter weight gives the optimal slaughter weight function in equation (4.15). This function provides the profit maximizing level of carcass weight for any given corn price, labor price, and slaughter price.

(4.15) $W = W^*(P_W, P_C, P_L)$

Using the optimal slaughter weight function and the factor demand curves for corn and labor, comparative static predictions can be derived for carcass weight in terms of each of the prices (equations 4.16). Specifics on deriving these comparative static relations are presented in appendix A.

(4.16) $\partial W^*/\partial P_W > 0$

$\partial W^{*}/\partial P_{C} < 0$

$\partial W^{*}/\partial P_{L} < 0$

The predictions in equation (4.16) arise because the value of the marginal product of corn and labor are downward sloping and an increase in the price of the inputs reduces the quantities of corn and labor used (Silberberg and Suen 2001, p.80). Under circumstances where corn and labor are complements, an increase in the input price reduces the optimal amount of corn and labor, leading to a reduction in average carcass weights.[24] If corn and labor are strong substitutes then it is possible for a rise in the input prices to increase average carcass weight. See appendix A for the circumstances where corn and labor are not complements. Because we find it implausible that, in the context of feedlot operations, labor and corn are strong substitutes, the prediction for this study is that average carcass weight and the corn and labor prices are negative related. A positive coefficient estimate is predicted on the slaughter price variable in the average carcass weight equation. This is because when cattle feeders are compensated with a higher output price the law of supply states producers increase output, increasing average carcass weight.

[24] If instead corn and labor are substitutes we cannot sign the comparative static predictions for $\partial W/\partial P_{C}$ and $\partial W/\partial P_{L.}$ because it depends on the relative magnitude of the second cross partial derivative, G_{LC}.

CHAPTER FIVE

DATA

Determinants of the variation in average carcass weight are examined in the empirical analysis. Explanatory variables to be considered include the corn price, manufacturing wage, slaughter price, number of cattle slaughtered, feeder price, consumer income, and the United States population.

Data Description and Sources

National observations for the United States over the period 1930 to 2014 (n=85) are used to estimate the model. All variable values are expressed in annual terms in the empirical analysis. See table 5.1 for a listing of the primary variables tested in the average carcass weight model, as well as their units, source, and descriptive statistics. All prices are deflated using the annual gross domestic product implicit price deflator obtained from the Federal Reserve Bank of St. Louis (base year = 2014).

Average Carcass Weight

Of primary interest in this analysis is explaining the determinants of average carcass weight over time. Average carcass weight data are obtained from the monthly National Agricultural Statistics Service (NASS) report entitled, *Livestock Slaughter*. NASS retrieves the original average carcass weight data from the Food Safety Inspection Service (FSIS) (NASS 1921-2014). Inspectors at the FSIS are required to inspect all

Table 5.1. List of Variables[25]

Variable	Units	Source	Report	Avg.	Std. Dev.	Min.	Max.
Average Carcass Weight	lb/hd	NASS, USDA	*Livestock Slaughter*	623.94	95.43	470.42	808.25
Corn Price	$/bu	NASS, USDA	*Agricultural Prices*	6.69	3.23	2.35	18.15
Manufacturing Wage	$/hr	Govt. Print. Office	*Economic Report President*	14.94	4.12	6.25	19.91
All Cattle Slaughter Price	$/cwt	NASS, USDA	*Agricultural Statistics*	115.45	28.45	55.29	211.19
Number of Cattle Slaughtered	1,000 hd	NASS, USDA	*Livestock Slaughter*	25,364	10,122	7,626	38,992
Feeder Price	$/cwt	NASS, USDA	*Agricultural Statistics*	140.60	36.05	68.20	254.58
1975 Grading Dummy				0.47	0.50	0.00	1.00
Trend				43.00	24.68	1.00	85.00

[25] Data for average carcass weight and the number of cattle slaughtered are retrieved from: U.S. Department of Agriculture, National Agricultural Statistical Survey. *Livestock Slaughter*. Washington, DC. Various issues, 1921-2014. Online at: http://quickstats.nass.usda.gov/.
Data for the corn price, all-cattle slaughter price, and feeder price are retrieved from: U.S. Department of Agriculture, National Agricultural Statistical Survey. *Agricultural Prices.* Washington, DC. Various issues, 1920-2014. Online at: http://quickstats.nass.usda.gov/.
Data for the manufacturing wage are retrieved from: Congress of the U.S., Council of Economic Advisors. *Economic Report of the President.* Washington D.C: Government Printing Office. Various issues, 1947-2014. Online at: https://fraser.stlouisfed.org/title/?id=45.
Data for the all-Choice slaughter price are retrieved from: U.S. Department of Agriculture, National Agricultural Statistical Survey. *Agricultural Statistics Annual.* Washington, DC. Various issues, 1936-2014. Online at: http://www.nass.usda.gov.

federally inspected commercial slaughter plants daily. During inspection, FSIS employees record individual animal carcass weights after the head, hide, and offal have been removed and the carcass has been chilled. Daily FSIS records are then sent electronically to NASS as weekly averages, and NASS aggregates these data and reports them on a monthly basis. Monthly NASS average carcass weight measurements are a weighted average of steers, heifers, bulls, and cows slaughtered. For this empirical analysis, the average carcass weight variable is constructed by taking the simple average of the NASS monthly weights. Average carcass weight is expressed as pounds per head.

Ideally a separate dressed weight data series would have been collected for each class of cattle (i.e. steer, heifer, cow, and bull) so that fed (steer and heifer) cattle carcass weights could be separated from non-fed (culled cow and bull) cattle, however these data do not exist prior to 1960. Figure 1.2 displays the time series for average carcass weight used in this study. Between 1930 and 2014 the range of average carcass weights for all cattle was 337 pounds. The maximum-recorded average carcass weight over the sample period was 808 pounds reported in 2014.

Corn Price

The majority of cattle finishing in the United States is corn-based. As such, the price of No. 2 yellow corn is an appropriate proxy for feedlot feed costs. Every month NASS publishes nominal corn prices in the *Agricultural Prices* report. Monthly corn prices are then weighted by monthly corn marketings to yield average annual corn prices. Annual corn prices are based on the grain marketing year, September to August. Prices are reported in dollars per bushel.

Figure 1.5 illustrates real prices of corn, ranging from $2.35/bu to $18.15/bu (NASS). Corn prices appear to trend downward since spiking in 1947. Contrast the declining corn prices with corn yield (bu/acre), which shows tremendous upward growth over time (figure 5.1). Falling corn prices are likely a result of high corn yields from improving farm technologies.

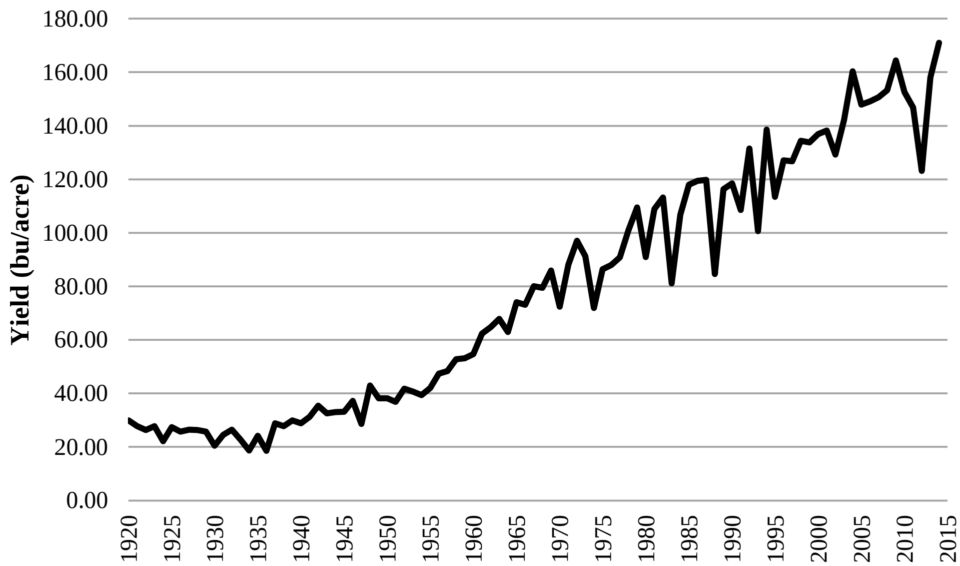

Figure 5.1: Corn Yield, 1920-2014.

Manufacturing Wage

Manufacturing wages are retrieved on an annual basis from the *Economic Report of the President* (figure 5.2). These wages measure the average hourly earnings of employees in non-agricultural goods and service producing industries. Assuming non-agricultural goods and service producing employees possess similar skills as feedlot employees, then it is expected that laborers may move between agricultural and non-agricultural markets if a wage differential exists. Such movement between the two sectors

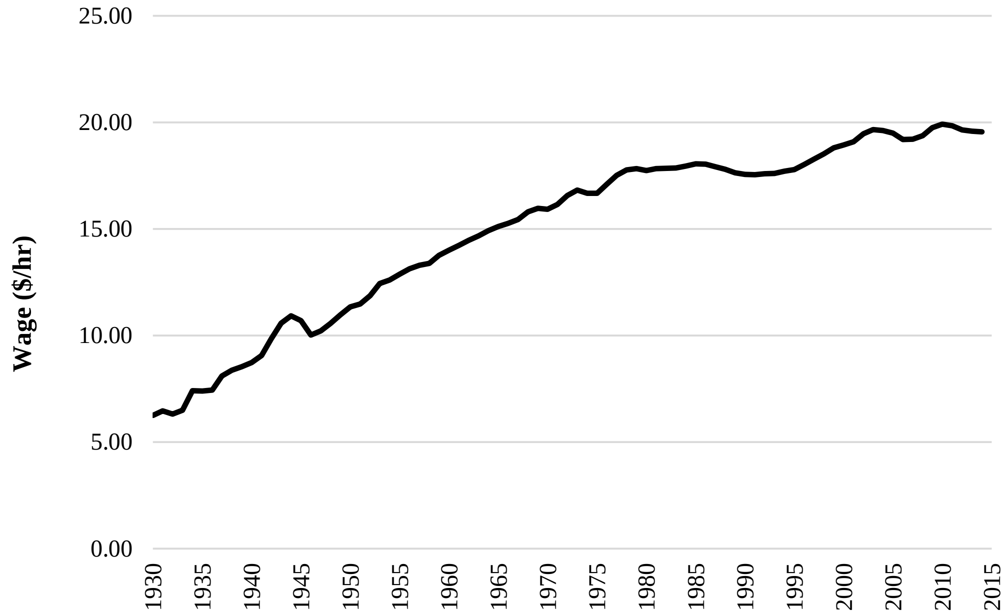

Figure 5.2: Real Manufacturing Wage ($ 2014), 1930-2014.

causes the separate sector wages to tend to move closely together. As a result, the manufacturing wage may be an appropriate proxy for feedlot wages.

Real manufacturing wages follows an upward linear trend (R^2= 0.96), similar to average dressed weight (figure 5.2).[26] On average, real manufacturing wages are $14.94/hr for the 85 years of study data. Real wage rates in the manufacturing sector have grown substantially with time, from $6.25/hr in 1930 to $19.56/hr in 2014. Growth in the manufacturing wage slows beginning in the mid-80s.

Slaughter Price

Several marketing options exist for cattle feeders selling fed cattle. Pricing may

[26] A Pearson's correlation coefficient is reported for the correlation between the real manufacturing wage and a time trend over the years 1930-2014.

be based on carcass merit, quality and yield grade, and/or on weight, live or carcass.[27] Typically the greatest proportion of cattle slaughtered and graded, fall under the Choice quality grade, making the Choice price a reasonable output price. In terms of live- or carcass-weight pricing, some regions of the United States appear to prefer one measure over the other. Historically Texas has favored a live-weight price and Nebraska a carcass-weight price (AMS 2015). Over time however, carcass weight pricing has become increasingly popular.

In this study a carcass-based price series is not constructed because of the absence of publicly available information dating back to 1930. A continuous pricing series for Choice slaughter cattle is also unavailable because of changes to the grading categories and changes to the location where price data was collected over time. Instead two slaughter prices are collected: (1) an aggregate all-cattle price representing steer, heifer, and cow slaughter and (2) a spliced Choice live steer price representing data collected from Chicago, Omaha, and the state of Nebraska.

The all-cattle slaughter price is published monthly by NASS in the *Agricultural Price* report, and is the weighted average of steer, heifer, and cow slaughter prices (figure 5.3). Using a simple average the monthly data is converted to the annual level. Units of the all-cattle slaughter price are in dollars per hundred weight.

The Choice live price is constructed by splicing together the Chicago, Omaha, and Nebraska Direct Choice steer price datasets reported in the *Annual Agricultural Statistics*

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[27] See Chapter 2 for a description of the various pricing methods when marketing slaughter cattle.

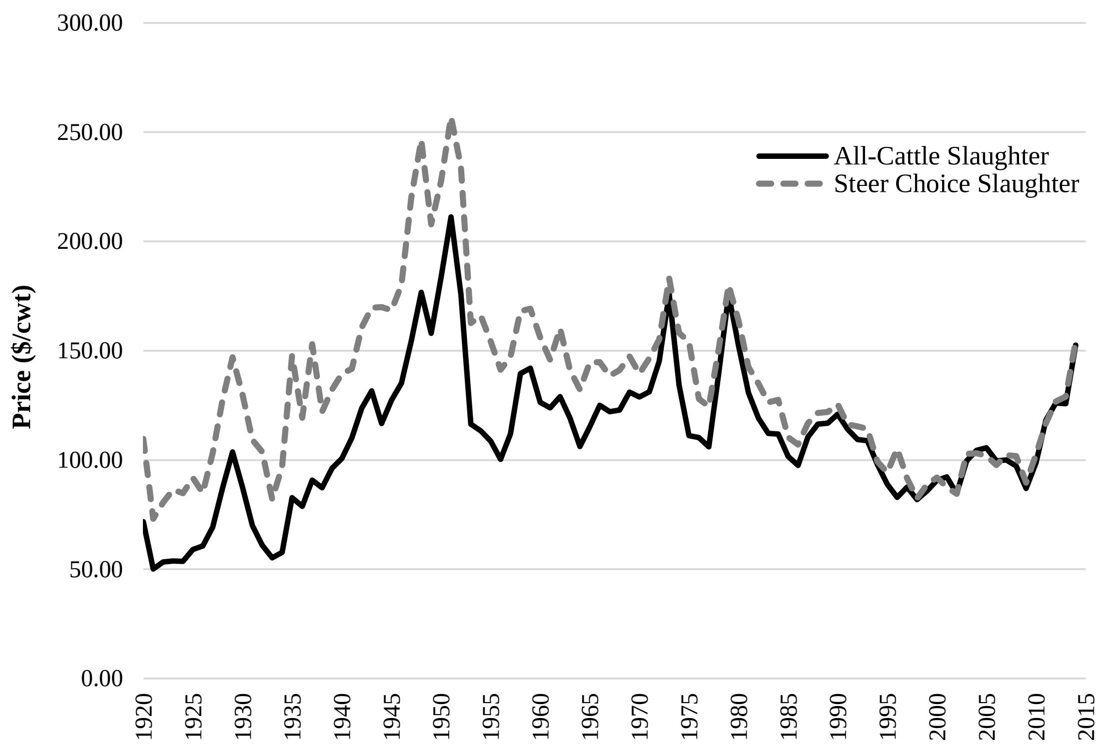

Figure 5.3: Real Slaughter Prices ($ 2014), 1920-2014.

publication by NASS.[28] The Chicago dataset includes the years 1930-1949 and consists of steers weighing 1000-1100 pounds. The Omaha dataset goes from 1950-1998, recording prices for steers weighing 1000-1100 pounds up until 1991, and prices of steers weighing 1100-1300 pounds thereafter. The Nebraska Direct dataset begins in 1999 and continues to 2014. Steers marketed in the NE Direct dataset from 1999-2003 weigh 1100-1300 pounds and grade 65-80 percent Choice. Following 2003, the NE Direct dataset expands to all cattle grading Choice in the 1100-1500 pound weight range. Units of the

[28] The term "Direct" refers to a price determined in a cash market versus a price determined from a non-cash market (e.g. forward contracting). See Chapter 2 for a discussion on marketing cattle in cash versus non-cash markets.

Choice live price are dollars per hundredweight.

The real ($ 2014) all-cattle and Choice slaughter prices track each other closely (figure 5.3). The correlation between the two price series is 0.85. In recent years, the similarity between these two slaughter prices is likely due to the greater reduction in cow slaughter numbers (figure 5.4) and the narrowing of the spread between the steer/heifer and cow slaughter prices (figure 5.5).

Over the 85 years of data there is substantial variability among both price variables. In 1933 both slaughter prices are at their lowest level, and in 1951 their highest level. Averages for the all-cattle slaughter price and steer Choice slaughter price are $115.45/cwt and $138.17/cwt, respectively.

Number of Cattle Slaughtered

Data on the number of federally inspected commercially slaughtered cattle are published monthly by NASS in the report entitled *Livestock Slaughter*. Cattle slaughter numbers represent steers, heifers, cows and bulls. Cattle slaughter numbers indicate the number of cattle on feed less those that die in feedlots. For this analysis, annual slaughter numbers are a simple average of NASS monthly estimates. Figure 5.6 indicates cattle slaughter numbers peak in 1977 at 39 million head. Lower cow numbers and increasing slaughter weights in recent years have contributed to slaughter numbers declining to levels comparable to the late 1960s. For example, in 2014 29.7 million head were slaughtered, similar to 1968 slaughter numbers of 29.6 million head.

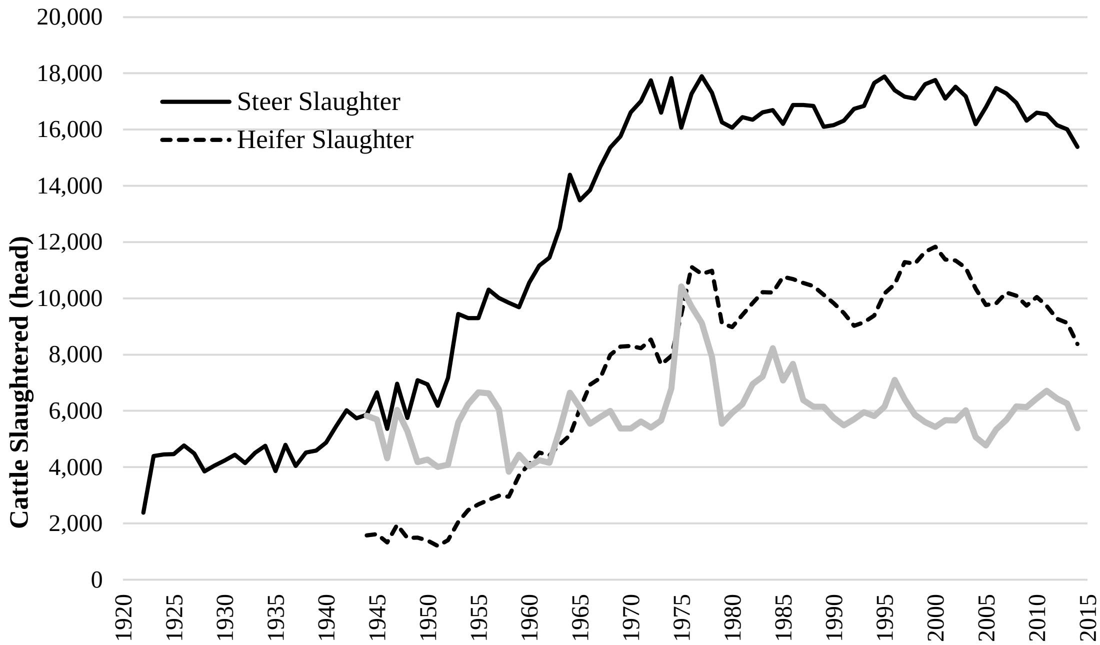

Figure 5.4: Quantity of Steers, Heifers, and Cows Slaughtered in Federally Inspected Slaughter Plants, 1922-2014.

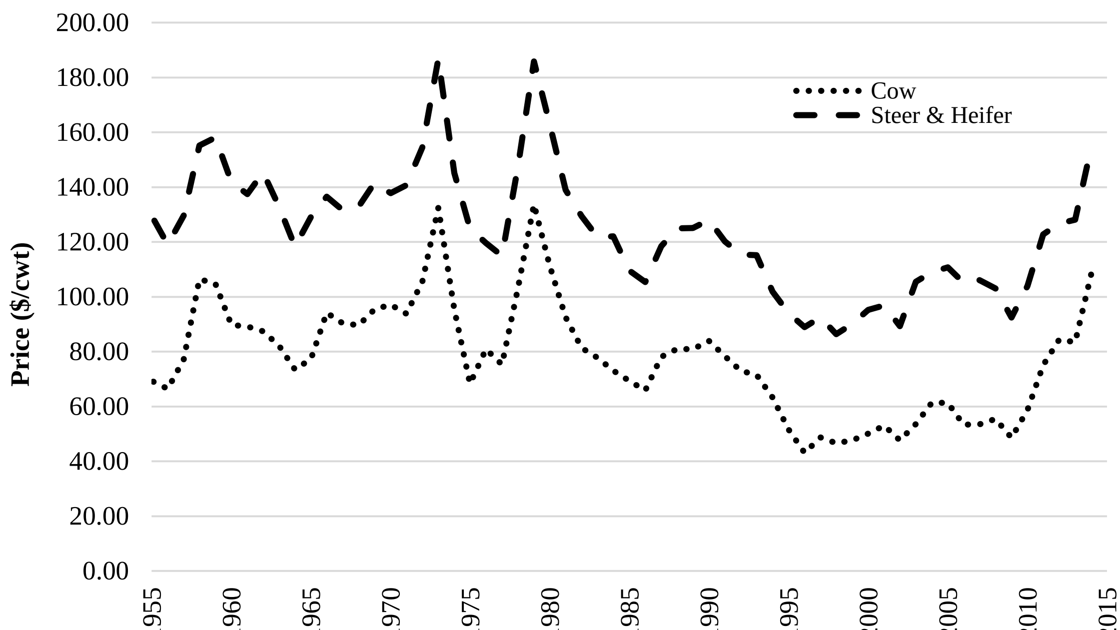

Figure 5.5: Real Cow and Steer/Heifer Prices ($ 2014), 1955-2014.

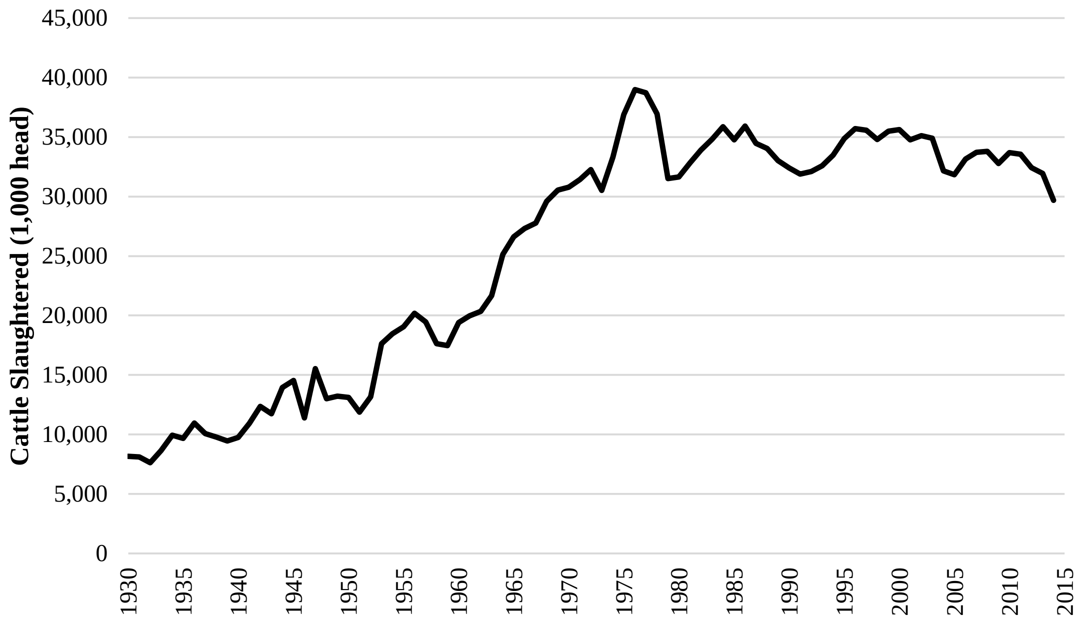

Figure 5.6: The Number of Cattle Greater than 500 Pounds Slaughtered in Federally Inspected Slaughter Plants, 1930-2015.

<u>Feeder Price</u>

The price series for feeder cattle comes from NASS, the *Agricultural Prices* report. Prices are collected monthly and represent a calf price in dollars per hundred weight. Feeder prices are aggregated to the annual level using a simple average. Feeder cattle prices are shown in figure 1.5. Average real feeder prices are $140.60/cwt, with a minimum of $68.20/cwt in 1933 and maximum of $254.58/cwt in 2014.

<u>Time Trend</u>

In this analysis, a trend variable is used to indicate improvements in feedlot technologies. The value of the trend variable increases from one in 1930 to 85 in 2014.

<u>1975 Grading Change</u>

An economically important grading change is the 1975 USDA beef grading amendment described in Chapter 2. Resulting from the change is a widening of the Choice quality grade and mandatory joint grading for quality and yield. Capturing the grading change is a 0-1 dummy variable constructed and assigned a value of zero for years prior to 1975 and a value of one for years greater than or equal to 1975.

Income

Four income variables are collected in this study: (1) total personal income, (2) per capita personal income, (3) total disposable personal income, and (4) per capita disposable personal income.[29] Personal income represents all sources of income less social insurance, while disposable income represents personal income less taxes (USDA-BEA 2014). All income data are annual from the Federal Reserve Bank of St. Louis (FRED). Total income variables are measured in billions of dollars and per capita income variables are measured in dollars per person. Figures 5.7-5.8 show total and per capita personal and disposable income in real (2014) dollars. For the entire United States, on average total real personal income is $5,624 billion and total real disposable income is $4,983 billion. Per capita real personal income averages $23,151 and per capita real disposable income averages $20,576. All four income variables display upward linear trends.

United States Population

The United States Census Bureau releases estimates of the national population.[30]

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[29] Data for the income variables are retrieved from the Federal Reserve Bank of St. Louis. *FRED Economic Data, Personal Income and Outlays.* 1929-2014. Online at: https://research.stlouisfed.org

[30] Data for the U.S. Population are retrieved from: U.S. Census Bureau. *Population Estimates.* National Tables: Pre-1980, 1990s, 2000s, 2010s. Online at: https://www.census.gov.

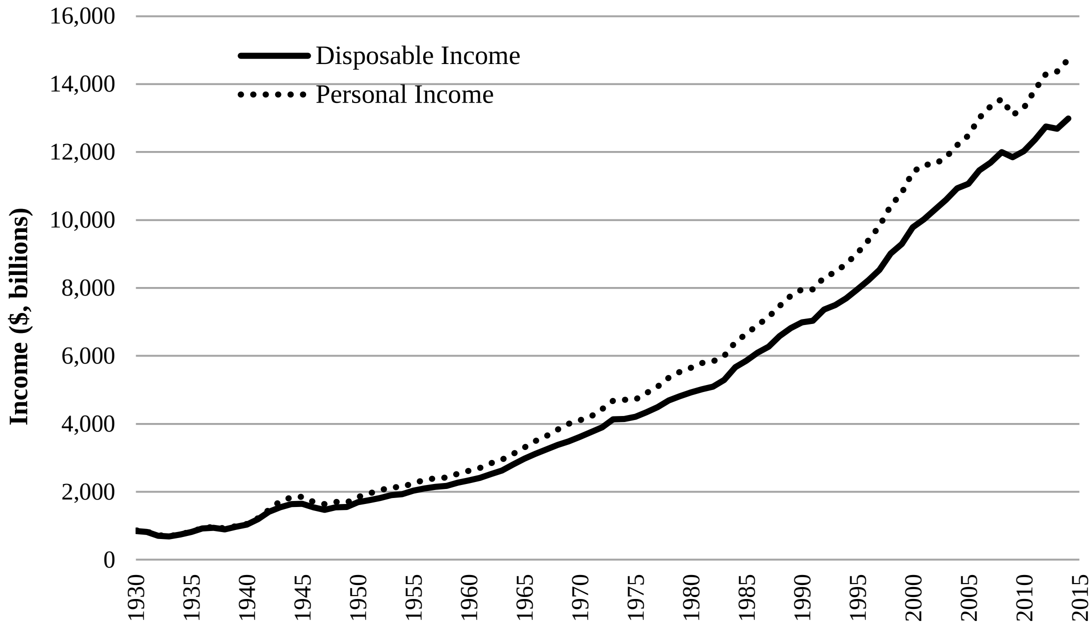

Figure 5.7: Real United States Total Personal and Disposable Income ($ 2014), 1930-2014.

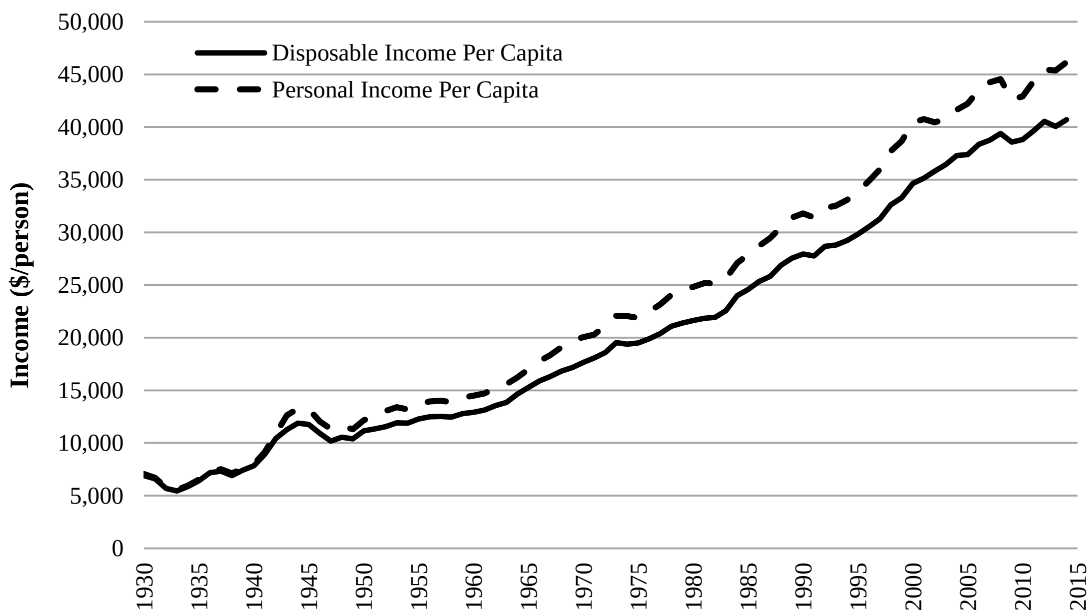

Figure 5.8: Real United States Per Capita Personal and Disposable Income ($ 2014), 1930-2014.

National population estimates are calculated based on the population from the latest decennial census adjusted for births, deaths, and migrations. Prior to 1980 all census estimates were reported for July 1 of each year, beginning in 1981 they were reported monthly. In this analysis, the annual population variable is created from the July 1 estimates for each year. Figure 1.2 displays the United States population over time. Since 1930 the national population has grown 59 percent, from 123 million in 1930 to 318.9 million in 2014.

GDP Implicit Price Deflator

In the empirical analysis to follow, all price variables are deflated using the gross domestic product implicit price deflator (GDP IPD; figure 5.9). A base year of 2014 is used. Data for the GDP IPD are collected annually from the FRED.

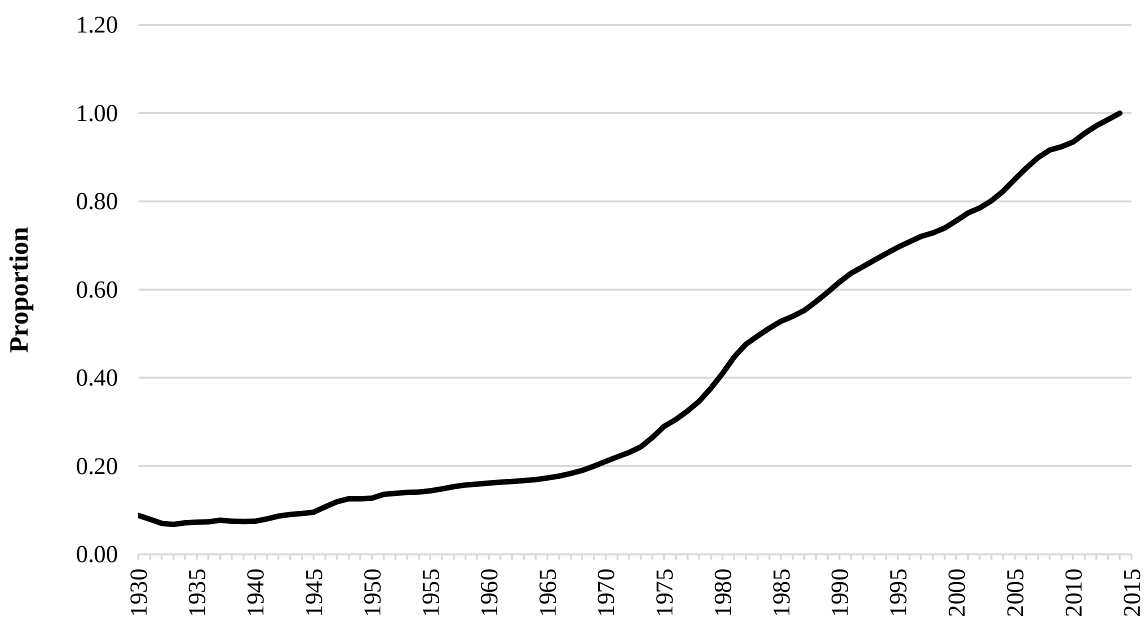

Figure 5.9: Gross Domestic Product Implicit Price Deflator, 1930-2014

CHAPTER SIX

EMPIRICAL SPECIFICATION

This chapter reviews the distributed lag model used to identify determinants of the variation in cattle carcass weights. Methods for calculating long-run prices, elasticities, and beta-coefficients are outlined. Statistical considerations such as variable stationarity, model autocorrelation, and co-integration are reviewed.

Average Carcass Weight Equation

Based on the optimal weight function in equation (4.15), average carcass weight is empirically estimated as a function of the corn price, labor price, and slaughter price. Equation (6.1) represents the level of average carcass weight a cattle feeder desires to produce, which is determined by contemporaneous and lagged values of the corn price, labor price, and slaughter price. Other control variables are also expected to affect average carcass weight but for simplicity are left unlisted in equation (6.1). Note that the variable abbreviations in equation (4.15) have been replaced with full variable names in equation (6.1).

Equation (6.1) represents a distributed lag model for average carcass weight, characterized by lags on the independent variables (Kmenta 1971, p.473). The lagged variable terms are meant to reflect the dynamics in feedlot production (Marsh 1994; Marsh 1999). Dynamics in feedlot production can arise because of producer expectations, biological constraints, technology adoption, weather, contract constraints, and institutional rigidities (Brester and Marsh 1983). A distributed lag model is also used to reflect the temporal nature of cattle feeders' production decisions. Annual data are used in this study, yet feedlot production decisions occur more frequently than annually. For example, cattle slaughter is an event that occurs approximately 6 months after a feeder animal has been placed in the feedlot. Because the future slaughter price is unknown at the time of the feeder animals' placement, cattle feeders estimate an expected slaughter price. The additional specification of lagged price variables accounts for the fact that expected future prices are a function of current prices, as well as observed past prices.

$$(6.1) \qquad \textit{Carcass Weight}_t^* = \beta_0 + \beta_1 \textit{Slaughter Price}_t + \beta_2 \textit{Slaughter Price}_{t-1} + \beta_3 \textit{Corn Price}_t + \beta_4 \textit{Corn Price}_{t-1} + \beta_5 \textit{Labor Price}_t + \beta_6 \textit{Labor Wage}_{t-1} + \varepsilon_t$$

t = 1930,…2014

In reality cattle feeders may not be able to attain the full amount of the desired change in the level of average carcass weight. Reasons for the deviation in the desired and actual level of average carcass weight relate to the timing of technology adoption, genetic change, marketing contracts, or producer habits. The discrepancy between the desired and actual level of output over the past period can be represented using equation (6.2). There, the observed change in average carcass weight represents the difference between the desired level of carcass weight and the observed carcass weight last period weighted by a factor λ.

$$(6.2) \qquad \textit{Carcass Weight}_t - \textit{Carcass Weight}_{t-1} = \lambda(\textit{Carcass Weight}_t^* - \textit{Carcass Weight}_{t-1})$$

The term λ in equation (6.2) represents the rate of adjustment of the current carcass weight to the desired carcass weight, also known as the partial adjustment parameter (Kmenta 1971, p.476). If $\lambda = 1$ the observed average carcass weight is equal to the desired average carcass weight and the adjustment process occurs within a year. If $\lambda = 0$ there is no adjustment, and the observed average carcass weight does not move towards the desired average carcass weight. In order to empirically estimate λ, equation (6.1) is substituted into (6.2) and solved for *Carcass Weight*$_t$:

(6.3) $$\textit{Carcass Weight}_t = \lambda\beta_0 + (1-\lambda)\textit{Carcass Weight}_{t-1} + \lambda\beta_1\textit{Slaughter Price}_t + \lambda\beta_2\textit{Slaughter Price}_{t-1} + \lambda\beta_3\textit{Corn Price}_t + \lambda\beta_4\textit{Corn Price}_{t-1} + \lambda\beta_5\textit{Labor Price}_t + \lambda\beta_6\textit{Labor Price}_{t-1} + \lambda\varepsilon_t$$

Using the following relationships, $\alpha_0 = \lambda\beta_0$, $\alpha_1 = \lambda\beta_1, \ldots \alpha_6 = \lambda\beta_6$, $u_t = \lambda\varepsilon_t$, equation (6.3) can be written as (6.4) where OLS estimation of (6.4) allows for the calculation of short-run and long-run price effects on average carcass weight.

(6.4) $$\textit{Carcass Weight}_t = \alpha_0 + (1-\lambda)\textit{Carcass Weight}_{t-1} + \alpha_1\textit{Slaughter Price}_t + \alpha_2\textit{Slaughter Price}_{t-1} + \alpha_3\textit{Corn Price}_t + \alpha_4\textit{Corn Price}_{t-1} + \alpha_5\textit{Labor Price}_t + \alpha_6\textit{Labor Price}_{t-1} + u_t$$

For example, in period *t* the short-run effect of the corn price on average carcass weight is determined by taking the derivative $\partial\textit{Carcass Weight}_t/\partial\textit{Corn Price}_t = \alpha_3$. The effect of the current corn price on next periods' average carcass weights is calculated by rolling equation (6.4) forward one period. Based on equation (6.5) a one-unit change in the current corn price causes the next period average carcass weights to increase by $\alpha_3+(1-\lambda)\alpha_4$.

(6.5) $Carcass\ Weight_{t+1} = \alpha_0 + (1-\lambda)Carcass\ Weight_t + \alpha_1 Slaughter\ Price_{t+1} + \alpha_2 Slaughter\ Price_t + \alpha_3 Corn\ Price_{t+1} + \alpha_4 Corn\ Price_t + \alpha_5 Labor\ Price_{t+1} + \alpha_6 Labor\ Price_t + u_{t+1}$

To find the cumulative (long-run) effect of a price shock, the short-run effects are summed over time. Appendix B shows the algebra for calculating the long-run effect of a corn price shock on average carcass weight. A short cut for finding the long-run effect is to convert equation (6.4) to a steady state equation. In the steady state equation in which average carcass weight and its determinants are stable. Steady state values are time invariant so equation (6.4) can be written without the time subscripts:

(6.6) $\lambda Carcass\ Weight = \alpha_0 + (\alpha_1 + \alpha_2)Slaughter\ Price + (\alpha_3 + \alpha_4)Corn\ Price + (\alpha_5 + \alpha_6)Labor\ Price + \varepsilon_t$

In equation (6.6) the long-run cumulative effect of permanent change in the corn price on average carcass weight is $\partial Carcass\ Weight/\partial Corn\ Price = (\alpha_3 + \alpha_4)/(\lambda)$. If $\lambda < 1$, a complete adjustment to a price shock will occur in an infinite period, whereas a less than complete adjustment will occur in a finite period. To determine the amount of time it takes for 90 percent of the cumulative impacts of a corn price shock to be transmitted to average carcass weight, equation (6.7) is solved for N (Nerlove and Addison 1958, p.874).

(6.7) $\lambda^N = 0.10$

$N\ln(\lambda) = \ln(0.10)$

$N = \ln(0.10)/\ln(\lambda)$

Equation (6.4) represents the average carcass weight model to be estimated using

OLS. One possible issue with specifying this model under the competitive scenario is the endogeneity of the *Slaughter Price*$_t$ variable at the aggregate market level. At the aggregate level, an increase (decrease) in average carcass weight increases (decreases) the supply of beef from feedlots, resulting in a decrease (increase) in the slaughter price. At the individual level, however, a cattle feeder has no effect on the output price so the slaughter price is exogenous. A solution to the joint dependence of the slaughter price and average carcass weight is to include the value of the slaughter price lagged. The lag on the slaughter price acts like an instrument, where a past slaughter price may influence the current level of carcass weight, but the current level of carcass weight cannot influence a past slaughter price.

In the final regression model (6.4), standardized (or beta) coefficients are calculated to determine the relative importance of each of the economic variables. Beta coefficients indicate how many standard deviations the dependent variable will change per one standard deviation increase in the independent variable (Wooldridge 2009). In multiple regression analysis, beta coefficients may be useful because the independent variables often have varying units (Wooldridge 2009). Additionally, the absolute value of a beta coefficient can be used rank the independent variables, indicating which variables have the largest standardized effect on average carcass weight. Mathematically, standardized coefficients are calculated by subtracting the mean of the variable from its value and then dividing by its standard deviation. From the normalized values OLS coefficients are estimated.[31]

[31] In Stata (StataCorp LP, College Station, Texas) beta coefficients can be calculated manually or through the “beta” function when an OLS regression is specified.

Elasticity coefficients are calculated at the mean of the independent variables in the final regression model (6.4). In this context, each OLS parameter estimate is multiplied by the ratio of the mean of the corresponding independent variable to the mean of average carcass weight to yield the elasticity estimate.

Statistical Issues with Time Series Data

All variables in the final model are tested for stationarity using methods discussed by Pindyck & Rubinfeld (1998) and Wooldridge (2009). A variable is non-stationary if it varies over time, for example, a deterministic time trend or a random walk (Pindyck and Rubinfeld 1998). Spurious findings may arise from non-stationarity. For instance, if two time series variables trend upward with time, one may wrongly conclude that one of the variables is causing the other to move upward. Detrending a variable takes care of non-stationarity from a time trend but not if the non-stationarity arises from a random walk process (Pindyck and Rubinfeld 1998; Wooldridge 2009). A random walk process is one in which the current value of a variable is determined by its past value plus an error term that is independent and identically distributed with mean zero and a constant variance (Wooldridge 2009). A random walk process contains a unit root, which is a highly persistent time series, where shocks do not die out with time. A time series with a unit root process is known as a series that is integrated of order one I(1) (Wooldridge 2009). First differencing an I(1) series leads to stationarity. In some cases, differencing can be avoided for two I(1) time series. If a linear combination of two I(1) series is stationary then the two variables are co-integrated (Pindyck and Rubinfeld 1998). Data series with trends and random walks are common in time series analysis. Tests for detecting unit roots and time trends are discussed below. Also described is the co-integration test for variables with unit root processes.

Autocorrelation occurs when the errors in the regression model are correlated between different time periods. In time series analysis, a positive correlation between the current and past period errors is common (Pindyck and Rubinfeld 1998, p.159). The Durbin alternative test is commonly used for detecting autocorrelation in the presence of a lagged dependent variable and is discussed below.

Non-Stationarity Statistical Tests

A Dickey Fuller test is used to test for a unit root process in the final model variables. A unit root is present when $\rho = 1$ in equation (6.8). To achieve, non-stationarity ρ must be less than one, so shocks die out with time. If $\rho > 1$, then shocks increase with time. Equation 6.8 is often adjusted so the dependent variable is differenced as in equation (6.9) (Wooldridge 2009). This allows researchers to test the null hypothesis that $\theta = 0$ to determine if a unit root is present.

(6.8) $$y_t = \alpha + \rho y_{t-1} + \varepsilon_t$$

(6.9) $$y_t - y_{t-1} = \alpha + \theta y_{t-1} + \varepsilon_t \quad \text{Note: } \theta = \rho - 1$$

More commonly, unit root tests are run using an augmented form (equation 6.10) of the Dickey Fuller (ADF) test (Wooldridge 2009). In the ADF specification, auto correlation of the error is allowed by including lagged values of the differenced dependent variable (Pindyck & Rubinfeld 1998; Wooldridge 2009). The lag length (k) is determined by performing a t-test for the null hypothesis that $\beta_k = 0$. If the first lag on the differenced dependent variable is significant then a second lag is tested and so on until additional lags are insignificant. A time trend is also specified because time series variables often exhibit trends over time. Evidence of a unit root is the null hypothesis for an ADF test. Specifically, the restrictions are $\theta = 0$ and $\delta = 0$, there is no restriction placed on β (Pindyck & Rubinfeld 1998). Test statistics for the ADF test are calculated as θ divided by the standard error of θ, while the critical values are retrieved from a Dickey Fuller distribution.

(6.10) $$\Delta y_t = \alpha + \theta y_{t-1} + \delta t + \beta_1 \Delta y_{t-1} + \ldots \beta_{k-l} \Delta y_{t-k+1} + \varepsilon_t \qquad \text{Note: } \theta = \rho - 1$$

Co-Integration Statistical Tests

If two I(1) series are co-integrated the relationship of interest may be estimated in level form (Pindyck and Rubinfeld 1998; Wooldridge 2009). Conversely, if the I(1) data series are not co-integrated the model must be estimated in first differences. Co-integrating relationships can be detected using an ADF test of the OLS regression residuals in the final model of interest (Pindyck and Rubinfeld 1998). The ADF test is run as in equation (6.11) but without the time trend. The null hypothesis for the ADF test is no co-integration.

Autocorrelation Statistical Tests

Autocorrelation of the final model errors are tested using a Durbin's alternative test (Pindyck and Rubinfeld 1998, p.169). The alternative version of the Durbin-Watson test is required when there is an endogenous explanatory variable, such as a lagged dependent variable (Wooldridge 2009, p.416). To perform a Durbin's alternative test, an

OLS regression is run with the lagged dependent variable as one of the explanatory variables. Using the residuals from this regression, a second OLS regression is run with the residuals specified as the dependent variable. The lagged residuals, and the lagged dependent variable are included with the explanatory variables in the second regression. From the second regression, a t-test is performed on the coefficient from the lagged residual. The null hypothesis of the t-test is no first-order autocorrelation of the errors (Pindyck and Rubinfeld 1998, p.170). If autocorrelation of the errors is detected, the Prais-Winsten method in Stata is used to correct the problem. This method estimates the correlation of the residuals and uses the correlation estimation to transform the OLS variables (Wooldridge 2009, pp.419–422). The variables are transformed using generalized differencing which yields independent errors, solving the autocorrelation problem.

CHAPTER SEVEN

EMPIRICAL RESULTS

The final OLS regression model for average carcass weight is presented in this section. Variation in average carcass weight is explained by input prices, the output price, a trend variable, and a dummy variable for the 1975 grading change. Robustness checks are performed on the final model using control variables. The final model variables are also tested for stationarity using Dickey fuller tests.

Final Model

Results of the OLS regression estimation of equation (6.4) are reported in table 7.1. Average carcass weight is explained by the corn price, manufacturing wage, and slaughter price, with a trend and a dummy variable included to control for technological change and the 1975 USDA grading change. A lag on the dependent variable is incorporated to represent the dynamics of fed cattle production. A second-order lag of the dependent variable was also included as an explanatory variable but was insignificant ($p = 0.16$).

All variables in this base OLS regression model are highly significant at the 1 percent level (table 7.1). Overall model fit is high, $R^2 = 0.991$. Ljung-Box Q-statistics (not shown) for the first (ρ_1) through third (ρ_3) autocorrelation coefficients indicate stationary autoregressive model errors.[32] Additionally results of the Durbin alternative test indicate

[32] The Ljung-Box Q-statistic is the test statistic for the null hypothesis of no autocorrelation of a specified number of lags. The Q-statics are not shown in table 7.1, only the autocorrelation coefficients.

Table 7.1: Base OLS Regression Results for Average Carcass Weight

VARIABLES	Base Model
Corn Price$_{t-1}$ ($/bu)	-4.804***
	(0.598)
Manufacturing Wage$_{t-1}$ ($/hr)	-8.285***
	(1.319)
Slaughter Price$_{t-1}$ ($/cwt)	0.240***
	(0.0533)
Trend$_t$	3.631***
	(0.434)
1975 Grading Dummy$_t$	-17.56***
	(4.664)
Carcass Weight$_{t-1}$ (lb/hd)	0.380***
	(0.0686)
Constant	367.5***
	(40.28)
Autocorrelation	
(ρ_1)	-0.036
(ρ_2)	0.098
(ρ_3)	0.136
Durbin	0.171
ADF	-6.521***
Observations	85
R-squared	0.991

Variables are defined in table 5.1. Standard errors are shown in parenthesis. Autocorrelation indicates the first through third autocorrelation parameters on the errors using the corrgram function in Stata. The Durbin alternative test statistic follows a chi-squared distribution and tests the null hypothesis of no first order serial correlation. Failure to reject the null hypothesis for the Augmented Dickey Fuller (ADF) test suggests evidence of no co-integration. The ADF statistic is calculated using one lag of the dependent variable. *** p<0.01, ** p<0.05, * p<0.1

failure to reject the null of no first order serial correlation.

Prior to performing the regression analysis, all model variables are tested individually for stationarity. Stationarity tests are run using the standard Dickey Fuller (DF) test and the Augmented Dickey Fuller (ADF) test in equation 6.8 and 6.10 both with and without a trend variable. The ADF test differs from the DF test by including first differences of the lagged value of the dependent variable. Results are presented in table 7.2 for the DF tests and table 7.3 for the ADF tests. Many of these variables show evidence of a unit root. For example, average carcass weight is non-stationary in the DF and ADF test without a trend but is stationary using both of these tests when a trend is specified. The corn price series is I(1) using the standard ADF test without a trend but I(0) otherwise. While the manufacturing wage series is I(0) based on the DF test without a trend and I(1) otherwise. Cattle slaughter numbers and the slaughter price appear to have a unit root in all DF and ADF specifications. These results suggest non-stationarity needs to be adjusted for in the final model specification.

Unit roots in the individual variables are of concern because they may lead to spurious OLS regression correlation. The unit root problem is solved if the OLS model variables are co-integrated or first differenced. Table 7.1 presents the ADF results for testing co-integration of the residuals in the base OLS regression model. The null hypothesis of no-cointegration is rejected, suggesting there is no need to transform the data and that the average carcass weight model in table 7.1 can be estimated in level form (Pindyck and Rubinfeld 1998, p.513).

OLS Results

The coefficient estimate on the lag of the dependent variable in the base OLS regression model (table 7.1) is significant and suggests a price shock leads to a moderate long-run partial adjustment in average carcass weight. The partial adjustment parameter is equal to $\lambda = 0.620$ [1-0.380]. In comparison, Marsh (1999) estimated a quarterly partial adjustment parameter of 0.481% for a 1% increase in the last period steer carcass weight.

Table 7.2: Dickey Fuller Test Results

VARIABLE	No Trend	Trend
Regression Equation	$\Delta y_t = \alpha + \theta y_{t-1} + \varepsilon_t$	$\Delta y_t = \alpha + \theta y_{t-1} + \delta t + \varepsilon_t$
<u>Critical Value</u>		
1% Significance	-3.531	-4.073
5% Significance	-2.902	-3.465
10% Significance	-2.586	-3.159
<u>Test Statistic</u>		
Carcass Weight	0.280	-3.486**
	(0.017)	(0.065)
Corn Price	-2.701*	-3.855**
	(0.061)	(0.079)
Manufacturing Wage	-3.406**	-0.618
	(0.006)	(0.021)
Slaughter Price	-2.495	-2.464
	(0.060)	(0.060)
Cattle Slaughter	-1.623	-0.507
	(0.016)	(0.038)

Critical values for the Dickey Fuller (DF) test are shown above. Test statistics for the DF test are shown above and calculated as: $(\theta)/SE_\theta$. Failure to reject the null hypothesis for the DF test suggests evidence of a unit root (H_0: $\theta = 0$ or $\rho = 1$). MacKinnon P-values are indicated with asterisks and represent: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. Standard errors are in parentheses. Number of observations is 85.

A t-test for H_0: $\lambda = 1$ reveals the adjustment process does not occur within a year ($p < 0.001$). The time required for average carcass weight to adjust to within 10 percent of the cumulative adjustment is 2.38 years, which is calculated using the formula from Nerlove and Addison (1958; p. 874).[33] Overall, the partial adjustment effect shows average carcass weight adjusts relatively quickly to changing economic conditions.

[33] As discussed in chapter 6, the cumulative adjustment period is calculated using the formula $[(1-\lambda)^n = \alpha]$ where α is the alpha level, n is the period, and λ is the partial adjustment parameter estimate (Nerlove and Addison 1958, p.874). The first order difference equation equilibrium value is calculated as: $\ln(0.10)/\ln(0.380) = 2.38$ years.

Table 7.3: Augmented Dickey Fuller Test Results

VARIABLE	No Trend	Trend	Lag Order (k)
Regression Equation	$\Delta y_t = \alpha + \beta_1 \Delta y_{t-1} + \theta y_{t-1} + \varepsilon_t$	$\Delta y_t = \alpha + \delta t + \beta_1 \Delta y_{t-1} + \ldots \beta_{k-l} \Delta y_{t-k+1} + \theta y_{t-1} + \varepsilon_t$	
Critical Value			
1% Significance	-3.531	-4.073	
5% Significance	-2.902	-3.465	
10% Significance	-2.586	-3.159	
Test Statistic			
Carcass Weight	0.505	-3.163*	1
	(0.017)	(0.068)	
Corn Price	-2.289	-3.701**	1
	(0.064)	(0.075)	
Manufacturing Wage	-2.373	-0.540	2
	(0.006)	(0.021)	
Slaughter Price	-3.182**	-2.327	2
	(0.060)	(0.060)	
Cattle Slaughter	-1.609	-0.721	1
	(0.016)	(0.039)	

Critical values for the Dickey Fuller (DF) test are shown above. Test statistics for the DF test are shown above and are calculated as: $(\theta)/SE_{\theta}$. Failure to reject the null hypothesis for the DF test suggests evidence of a unit root (H_0: $\theta = 0$ or $\rho = 1$). The lag order indicates the number of lags (k) on the lagged difference of the dependent variable in the model with a constant and a trend. The lag length is determined by significance of the t-test for $\beta_k = 0$. MacKinnon p-values are indicated with asterisks and represent: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Standard errors are in parentheses. Number of observations is 85.

The relationship between average carcass weight and the two specified input prices are negative as hypothesized. The coefficient on the corn price variable indicates that a one dollar per bushel increase in the current corn price reduces average carcass weight 4.8 pounds the next year. Figure 7.1 shows the impulse response function for the marginal impact of the current period average carcass weight in response to an increase in the last period corn price. Langemeier and Thompson (1967) specified a different corn price variable than the one specified here. They used the ratio of the market corn price to the government support price and found both current (-37.3) and lagged (-37.9) variables were significant. In this study, a one dollar per hour increase in the one period lagged manufacturing wage results in an 8.3 pound reduction in average carcass weight (figure 7.2). No past studies report the effects of labor costs on slaughter cattle supply or average carcass weights.

As expected, the relationship between average carcass weight and the slaughter output price is positive, although it is relatively small in magnitude. Increasing the slaughter price $10 per hundred weight in year *t*, causes cattle feeders to increase average carcass weights by 2.4 pounds the following year (figure 7.3). Indicated in table 3.1 above, Langemeier and Thompson (1967) estimated a significant coefficient of 5.48 on the slaughter price when predicting average carcass weight. Others found a positive but insignificant parameter estimate on the ratio of the slaughter price to grain index price in their average carcass weight equation (Kulshreshtha and Wilson 1972). Conversely, Marsh (1999) found that for a 10 percent increase in the slaughter price to corn price ratio, average carcass weights declined by 0.25 percent (table 3.1).

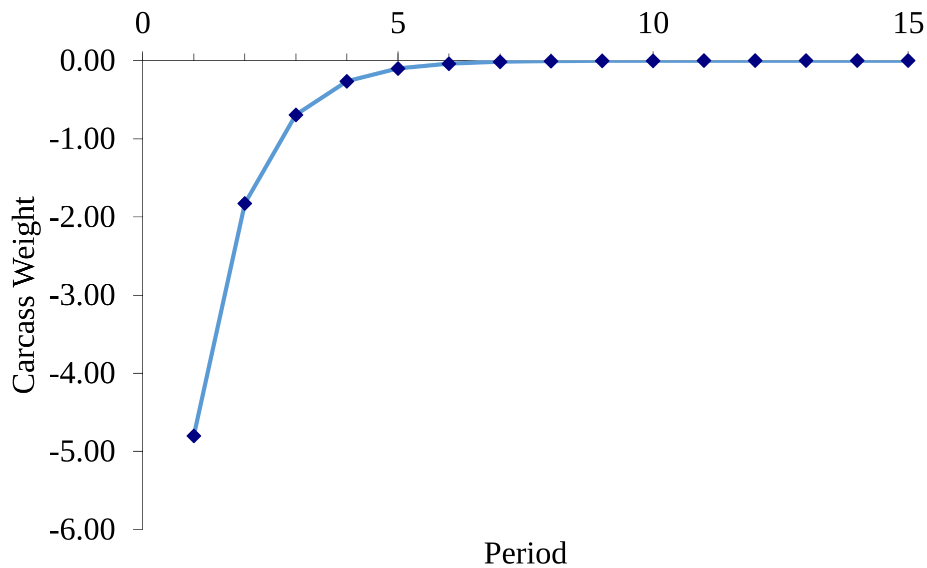

Figure 7.1: Effects of a Change in *Corn Price*$_{t-1}$ on *Carcass Weight*$_t$

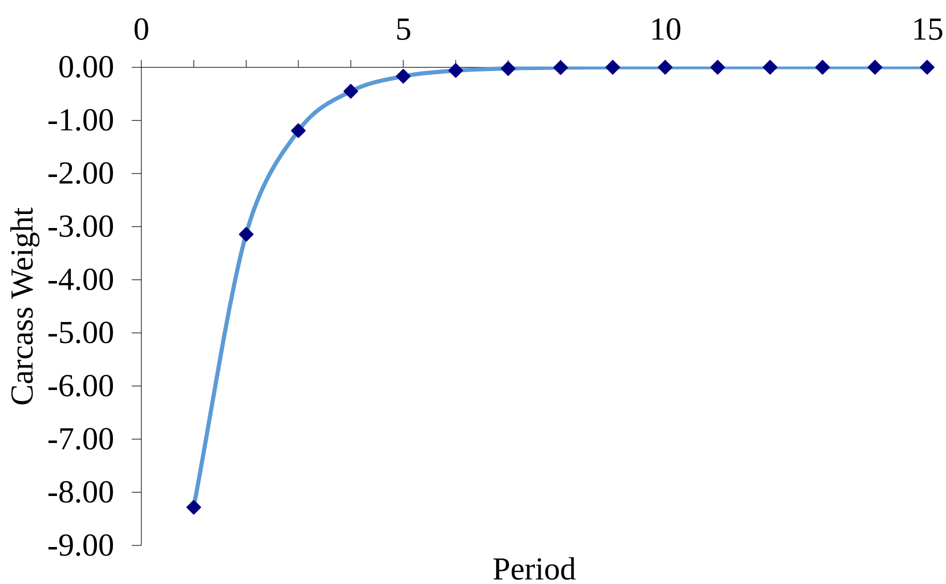

Figure 7.2: Effects of a Change in the *Manufacturing Wage*$_{t-1}$ on *Carcass Weight*$_t$

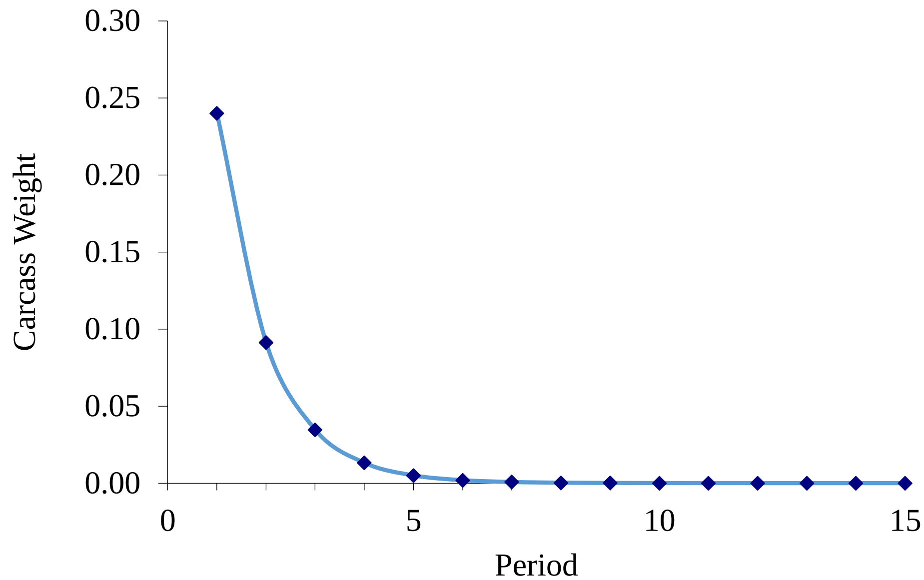

Figure 7.3: Effects of a Change in *Slaughter Price*$_{t-1}$ on *Carcass Weight*$_t$

A dummy variable is included for the year 1975 to account for the revisions to the USDA beef grading standards discussed in Chapter 2. The grading change is expected to reduce average carcass weights. On average, carcass weights are 17.6 pounds lower after the grading change, suggesting the reduction in Choice marbling requirements and the dual grading requirement led to lower average carcass weights. A reduction in the Choice marbling requirement has the effect of reducing days on feed because marbling is positively associated with days on feed. Reduced days on feed minimizes the period for weight gain, leading to smaller carcasses at slaughter. The second part of the grading change was the dual grading requirement. Dual grading caused a price differential to arise between carcasses of different yield grades (Purcell and Nelson 1976). Information on carcass yields would have provided buyers the opportunity to reduce prices for less desirable yield grades (YG 5 and YG 5). Consequently, pens of cattle with overweight carcasses were more likely to be offered a lower slaughter price. In response, cattle feeders may have reduced carcass weights at marketing to avoid a price reduction.

Average carcass weight demonstrates a significant upward trend verifying the observation of increasing annual average carcass weights in figure 1.2. The yearly growth in average carcass weight amounts to about 3.6 pounds per year. The trend effect is interpreted as representing technological advancements within the beef industry, while holding all other model variables constant. Trend coefficients from 1980-1997 in the Marsh (1999) study indicated average carcass weights increased 0.6 and 0.9 pounds per year for steers and heifers. Kulshreshtha and Wilson (1972) reported average carcass weights increased 140 pounds (6.67 pounds/year) over the period 1949-1969 using a trend variable, which is almost double the observed average carcass weight shown in figure 1.2 for that period.

Long-Run Effects

Table 7.4 and figure 7.4-7.6 present the cumulative (long-run) change in average carcass weight from a corn price, manufacturing wage, and slaughter price shock. In the long-run, a one dollar per bushel increase in the corn price causes average carcass weight to decline by 7.75 pounds [= -4.80/(1-0.62)]. For the manufacturing wage the long-run response is relatively large and negative, with a value of -13.36 [-8.29/(1-0.62)]. The long-run response for the fed output price is relatively small at 0.39 [= 0.24/(1-0.62)]. Marsh (1999) found an opposite long-run elasticity relation for the fed price to corn price ratio compared to the input and output price estimates reported here. The coefficient estimated by Marsh suggested that as the profitability of cattle feeding increased, average

Table 7.4: Short-Run and Long-Run Price Effects for Average Carcass Weight

VARIABLES	Short-Run Effect	Long-Run Effect
Corn Price	-4.804	-7.748
Manufacturing Wage	-8.285	-13.363
Slaughter Price	0.240	0.387

Short-run effects are the marginal effect of a one-unit increase in the lagged price variable on the current period average carcass weight. The long-run effect represents the cumulative short-run effects divided by the partial adjustment factor. The partial adjustment factor is 0.620

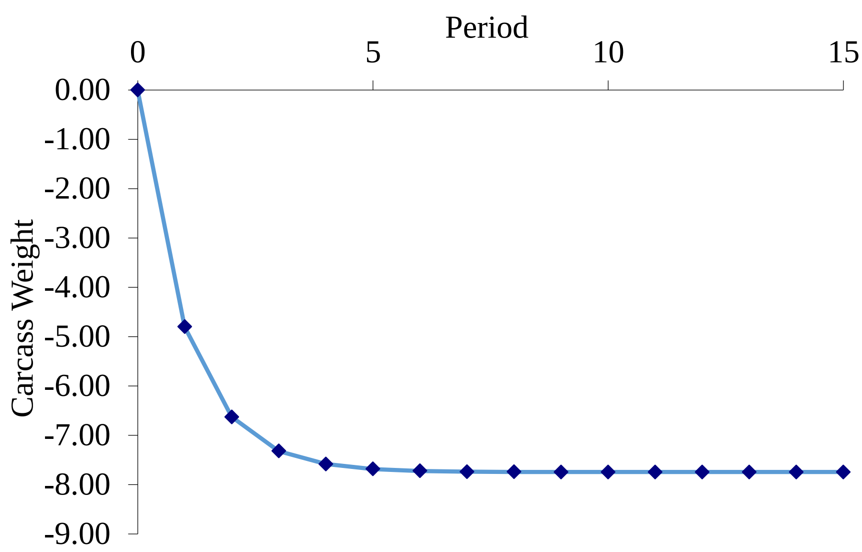

Figure 7.4: Effects of a Cumulative Change in *Corn Price* on *Carcass Weight*

carcass weights declined (-0.052) in the long-run.

Table 7.5 presents alternative measures for the impact of the three price variables on average carcass weight: standardized coefficients, elasticities, and the change in carcass weight in pounds. The absolute values of the beta coefficients indicate the relative magnitudes of the impact of the price variables on average carcass weight. Overall the manufacturing wage and corn price beta coefficients are largest, and therefore account for the most variation in average carcass weight. The slaughter price has the smallest effect

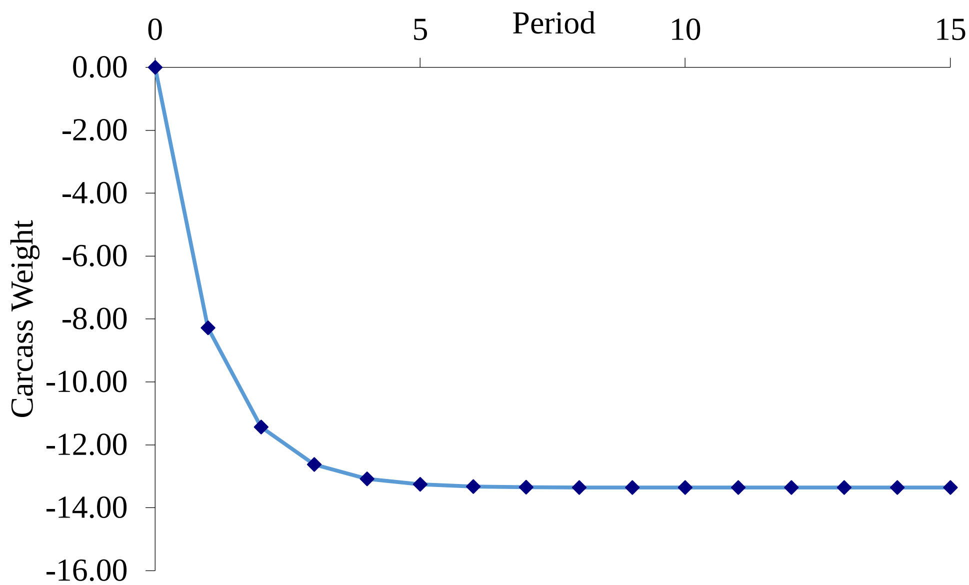

Figure 7.5: Effects of a Cumulative Change in *Manufacturing Wage* on *Carcass Weight*

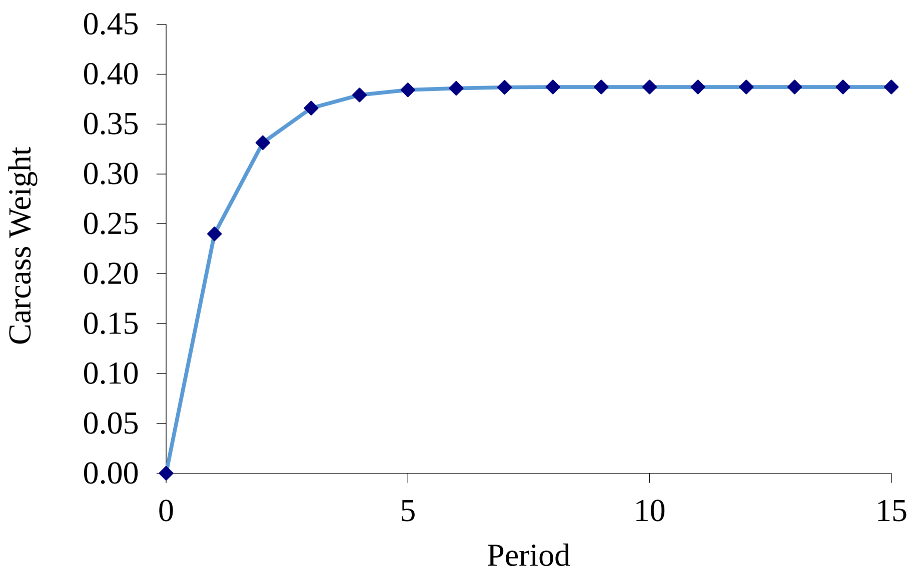

Figure 7.6: Effects of a Cumulative Change in the *Slaughter Price* on *Carcass Weight*

Table 7.5: The Impact of Prices on Average Carcass Weight

VARIABLES	OLS Estimate	Sample Mean	Standard Deviation	Beta Coefficient	Elasticity	Carcass Weight Δ (Pounds)
Corn Price	-4.804	6.744	3.216	-0.162	-0.052	-15.45
Manufacturing Wage	-8.285	14.779	4.194	-0.364	-0.196	-34.75
Slaughter Price	0.240	114.870	28.188	0.071	0.044	6.77

The OLS Estimate displays the parameter estimate from the final OLS model in Table 7.1. For each independent variable the sample mean and standard deviation are listed for the sample period 1930-2014. The beta coefficient measures the standard deviation change in average carcass weight for a 1 standard deviation increase in the independent variable and is calculated using the beta function in Stata. Similarly, the elasticity measures the percentage change in average carcass weight for a 1 percent increase in the independent variable. The elasticity is calculated by multiplying the OLS estimate by the mean of the independent variable divided by the mean of average carcass weight, 623.94 pounds. The carcass weight change in pounds measures the change in average carcass weight due to a one standard deviation change in the independent variable. To calculate the change in average carcass weight in pounds the OLS estimate is multiplied by the standard deviation of the independent variable.

on average carcass weight, with a beta coefficient less than 0.10. The smaller beta coefficient on the slaughter price is surprising because past research suggests the slaughter price has the greatest impact on cattle feeding profitability compared to other price and feedlot performance variables (Langemeier et al. 1992; Mintert et al. 1993; Lawrence et al. 1999).

Elasticities indicate for a 1 percent change in the price variables, the responding percentage change in average carcass weight. The elasticity estimates in this study are highly inelastic (table 7.5), where a 1 percent change in each of the independent variables results in a considerably smaller percentage change in average carcass weight. The change in average carcass weight in pounds is also indicated for a 1 standard deviation increase in the corn price, manufacturing price, and slaughter price and results in a -15.45 pound, -34.75 pound, and 6.77 pound change in average carcass weight. Out of the three price variables, the manufacturing wage accounts for 61 percent (= 34.75/(15.45 + 34.75 + 6.77)) of the variation in average carcass weight.

Robustness Checks and Specification Tests

Table 7.6 reports results from three alternative specifications of the price variables in the base regression model in table 7.1. These specifications differ in the lag structure of the two input prices and the output price. In model (1) both current and lagged price variables are included. Variables that are insignificant or marginally insignificant in model (1) include the current corn and slaughter price coefficients and the contemporaneous and lagged coefficients on the manufacturing wage. Alternately, model

Table 7.6: Contemporaneous and Lagged Price Models for Average Carcass Weight

VARIABLES	(1) Current & Lagged Prices	(2) Current Prices	(3) Lagged Prices
Corn Price$_t$ ($/bu)	-1.223*	-3.082***	
	(0.630)	(0.645)	
Corn Price$_{t-1}$ ($/bu)	-4.151***		-4.804***
	(0.688)		(0.598)
Manufacturing Wage$_t$ ($/hr)	-5.717	-6.027***	
	(4.673)	(1.406)	
Manufacturing Wage$_{t-1}$ ($/hr)	-2.818		-8.285***
	(4.811)		(1.319)
Slaughter Price$_t$ ($/cwt)	0.0917	0.142**	
	(0.0737)	(0.0607)	
Slaughter Price$_{t-1}$ ($/cwt)	0.187**		0.240***
	(0.0741)		(0.0533)
Trend	3.580***	2.776***	3.631***
	(0.437)	(0.480)	(0.434)
1975 Grading Dummy	-18.15***	-16.93***	-17.56***
	(4.789)	(5.738)	(4.664)
Carcass Weight$_{t-1}$ (lb/hd)	0.389***	0.539***	0.380***
	(0.0695)	(0.0770)	(0.0686)
Constant	368.1***	272.4***	367.5***
	(40.90)	(44.80)	(40.28)
Autocorrelation (ρ_1)	-0.072	-0.299	-0.036
(ρ_2)	0.107	0.019	0.098
(ρ_3)	0.226	0.118	0.136
Durbin	0.615	15.518***	0.171
ADF	-6.400***	-8.098***	-6.521***
Observations	85	85	85
R^2	0.9913	0.9869	0.9906

Variables are defined in Table 5.1. Standard errors are shown in parenthesis. Autocorrelation indicates the first through third autoregressive parameters on the errors using the corrgram function in Stata. The Durbin alternative test statistic follows a chi-squared distribution and tests the null hypothesis of no first order serial correlation. Failure to reject the null hypothesis for the Augmented Dickey Fuller (ADF) test suggests evidence of no-cointegration. The ADF statistic is calculated using one lag of the dependent variable. *** p<0.01, ** p<0.05, * p<0.1. *** p<0.01, ** p<0.05, * p<0.10

(2) shows only current price variables all of which are significant at $\alpha < 0.05$. Model (3) includes only lagged price variables, all of which are significant at $\alpha < 0.01$. Comparing the current and lagged price models, the Durbin alternative (table 7.6) and the Ljung Box Q test (not shown) indicate evidence of first order serial correlation in the current price model. After correcting for the serial autocorrelation in the current price model (also not shown), the magnitude and interpretation of the price coefficients appear similar to the lagged price model.[34] For instance, an increase in the corn price whether current or lagged reduces average carcass weight. Model fit appears to be slightly better in the lagged compared to the contemporaneous price model, as judged by the higher R^2 value.

The correct empirical lag specification of the price variables is related to the formulation of price expectations by cattle feeders and the partial adjustment of carcass weight due to the biology of cattle weight gain (Marsh 1999). Because feedlot cattle are finished over a period of 6-8 months, producers make production decisions more frequently than annually. The fact that the data used in this study are annual, suggests it is possible that either the current corn price or the last period corn price are more important in explaining the current average carcass weight. It would depend on how individual cattle feeders formed expectations about corn prices. For instance, cattle feeders expecting to finish cattle in period *t* may have used futures prices and hedging strategies in period *t-1* to lock in prices for part of their corn requirement for period *t*. Other cattle

[34] The Prais-Winsten estimation method is used to correct for the first order serial correlation in the current price model in table 7.6. After correction, all model variables remain significant at the 1 percent level, and the coefficients on the corn price, slaughter price, and lagged dependent variable increase in magnitude and the coefficients on the manufacturing wage, trend, and grading dummy decrease in magnitude. Even after correction for serial autocorrelation the magnitude of the price coefficients appear similar between the current and lagged price model in table 7.6.

feeders may choose to make a contemporaneous corn purchasing decisions in period *t* for cattle finished in period *t.* The lagged price specification is chosen for the base model because it appears to fit the data slightly better, the estimates are similar to the current price specification, possible endogeneity is controlled for, and the lagged price specification (combined with impacts through the lagged value of the dependent variable) represents the non-static nature of price determination in fed cattle production.

Two alternative variables are tested as proxies for the slaughter price in the base model - the all cattle price and the Choice steer price.[35] Comparable OLS coefficient estimates are obtained from specifying each of these slaughter prices separately in the final model, a coefficient of 0.240 for the all-cattle and 0.221 for the Choice steer price (table 7.7). Data for the all-cattle price are collected from steers, heifers, cows, and bulls, similar to the dependent variable average carcass weight. For this reason, and the similarity between the parameter estimates, the all-cattle slaughter price is chosen over the Choice steer price.

Several control variables are tested in the base model to account for other sources of variability that could alter the estimated input and output price effects on average carcass weight. The control variables that are added to the base model are meant to represent additional input costs, carcass quality, and variables that other researchers have used as control variables. Specific variables tested as controls are: prime and AAA interest rates, crude oil price, gas price, energy index, feeder price, cattle slaughter

[35] The all cattle price represents the weighted live slaughter price of steer, heifers, and bulls. The Choice steer price represents three pricing series spliced together from Chicago (1930-1949), Omaha (1950-1998), and Nebraska (1999-2014). See Chapter 5 for a more detailed description of these two price variables.

Table 7.7: Slaughter Price Models for Average Carcass Weight

VARIABLES	Choice Slaughter Price	All Cattle Slaughter Price
Corn Price$_{t-1}$ ($/bu)	-4.869***	-4.804***
	(0.600)	(0.598)
Manufacturing Wage$_{t-1}$ ($/hr)	-7.034***	-8.285***
	(1.207)	(1.319)
Slaughter Price$_{t-1}$ ($/cwt)	0.221***	0.240***
	(0.0479)	(0.0533)
Trend	3.266***	3.631***
	(0.422)	(0.434)
1975 Grading Dummy	-15.56***	-17.56***
	(4.723)	(4.664)
Carcass Weight$_{t-1}$ (lb/hd)	0.454***	0.380***
	(0.0684)	(0.0686)
Constant	315.4***	367.5***
	(40.14)	(40.28)
Autocorrelation	-0.082	-0.036
	0.039	0.098
	0.114	0.136
Durbin	0.791	0.171
ADF	-7.019***	-6.521***
Observations	85	85
R-squared	0.9907	0.9906

Variables are defined in table 5.1. Standard errors are shown in parenthesis. Autocorrelation indicates the first through third autoregressive parameters on the errors using the corrgram function in Stata. The Durbin alternative test statistic follows a chi-squared distribution and tests the null hypothesis of no first order serial correlation. Failure to reject the null hypothesis for the Augmented Dickey Fuller (ADF) test suggests evidence of no-cointegration. The Augmented Dickey Fuller statistic was calculated using one lag. *** p<0.01, ** p<0.05, * p<0.1

numbers, the proportion of cattle slaughtered by gender and type, and alternative measures of income. Of these control variables the number of cattle slaughtered, feeder prices, and aggregate income are significant when included separately in the base model.

Other researchers have used cattle slaughter numbers or cattle inventory numbers to explain average carcass weight. In this study, the first difference of cattle slaughter numbers significantly explains average carcass weight and is shown in table 7.8.[36, 37] Inclusion of cattle slaughter numbers does not alter the signs or significance of the other price variables. The coefficient on this variable indicates that an increase in the change in cattle slaughter numbers per 1,000 head from period *t-1* to *t* results in a 0.0027 pound reduction in average carcass weight. The negative sign could indicate that as the number of cattle slaughtered increases, current cattle feeders move up their marginal cost curves and possibly, new cattle feeders with higher marginal costs enter the market and supply cattle. As marginal costs increase, cattle feeders will produce less output, reducing average carcass weights.

Other studies used beef cattle inventory and cattle on feed (1,000 head basis) to predict average carcass weights and obtained statistically significant estimates of -0.0205 (Kulshreshtha and Wilson 1972) and 0.013 (Langemeier and Thompson 1967), respectively. Marsh (1999) who specified the number of cattle slaughtered in steer, heifer, and cow equations, found that the coefficients in the heifer and cow equations were significant and opposite in sign.[38] In particular, Marsh reported an increase in the number of cows slaughtered decreased average carcass weights, while an increase in the number of heifers slaughtered increased average carcass weights.

In the base model augmented with cattle slaughter numbers the partial adjustment factor is 0.553. Further, the long-run price effects for the corn price, manufacturing wage,

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[36] The first difference of cattle slaughter numbers is used because the inclusion of cattle slaughter numbers both current and lagged results in parameter estimates the same in magnitude but opposite in sign.
[37] Beef cattle inventory is also tested in the base model but is not significant.
[38] Marsh (1999) reported a 10 percent increase in the number of heifers slaughtered increased average carcass weights of heifers 0.45 percent and a 10 percent increase in the number of cows slaughtered decreased average carcass weights of cows 0.54 percent.

Table 7.8: OLS Regression Model for Average Carcass Weight with Cattle Slaughter Numbers

VARIABLES	Cattle Slaughter Model
Corn Price$_{t-1}$ ($/bu)	-4.538***
	(0.550)
Manufacturing Wage$_{t-1}$ ($/hr)	-7.240***
	(1.231)
Slaughter Price$_{t-1}$ ($/cwt)	0.239***
	(0.0487)
ΔCattle Slaughter$_t$ (1,000 hd)	-0.00273***
	(0.000669)
Trend$_t$	3.212***
	(0.409)
1975 Grading Dummy$_t$	-17.75***
	(4.256)
Carcass Weight$_{t-1}$ (lb/hd)	0.447***
	(0.0647)
Constant	327.9***
	(38.01)
Autocorrelation	
(ρ_1)	-0.120
(ρ_2)	0.059
(ρ_3)	0.112
Durbin	1.592
ADF	-7.087***
Observations	85
R-squared	0.9923

Variables are defined in Table 5.1. Standard errors are shown in parenthesis. Autocorrelation indicates the first through third autocorrelation parameters on the errors using the corrgram function in Stata. The Durbin alternative test statistic follows a chi-squared distribution and tests the null hypothesis of no first order serial correlation. Failure to reject the null hypothesis for the Augmented Dickey Fuller (ADF) test suggests evidence of no co-integration. The ADF statistic is calculated using 1 lag. *** p<0.01, ** p<0.05, * p<0.1

and slaughter price are -8.21, -13.09, and 0.432. Altogether, the base model and the base model with cattle slaughter numbers yield comparable marginal and cumulative price estimates and can be interpreted similarly.

Income and U.S. population measures represent beef demand determinants and are tested in the base model (table 7.9). Rising incomes shift retail beef demand outward, causing a subsequent shift in fed beef demand. The slaughter price rises in response, as does average carcass weight. Demand for high quality beef (e.g., Prime retail cuts) also increases with rising income, which may not be reflected in the slaughter price used in this study. The slaughter price used in this study combines both low and high quality beef from non-fed and fed beef, respectively. If income has impacts beyond its effect on the slaughter price then we hypothesize rising incomes increase average carcass weight. To produce higher quality beef, cattle will be fed longer because marbling is positively correlated with days on feed. Increasing cattle days on feed increases average carcass weights. A similar response is hypothesized for a rising U.S. population on average carcass weight.

Specifying total U.S. personal income, total U.S. disposable income, and U.S. population as in models (1), (2), and (5) in table 7.9 resulted in significant coefficient estimates. Stationarity tests indicate each of these income and population variables are non-stationary but stationarity tests on the OLS errors suggests model co-integration. In comparison to the base OLS regression model, models (1), (2), and (5) have smaller trend and manufacturing wage coefficients. As a result, an additional marginal test is performed where the errors are retained from the standard Dickey Fuller test of

Table 7.9: OLS Regression Model for Average Carcass Weight with Income and U.S. Population Variables

VARIABLES	(1) Total Personal	(2) Total Disposable	(3) PC Personal	(4) PC Disposable	(5) US Population
Corn Price$_{t-1}$ ($/bu)	-5.264***	-5.313***	-4.957***	-5.014***	-5.099***
	(0.591)	(0.596)	(0.602)	(0.605)	(0.526)
Manufacturing Wage$_{t-1}$ ($/hr)	-3.518*	-3.479*	-6.715***	-6.349***	-7.667***
	(2.047)	(2.058)	(1.680)	(1.760)	(1.159)
Slaughter Price$_{t-1}$ ($/cwt)	0.272***	0.274***	0.248***	0.252***	0.325***
	(0.0520)	(0.0522)	(0.0532)	(0.0533)	(0.0496)
Trend$_t$	1.965***	1.979***	2.840***	2.722***	0.241
	(0.700)	(0.696)	(0.683)	(0.701)	(0.775)
1975 Grading Dummy$_t$	-16.02***	-15.70***	-17.94***	-17.77***	-16.01***
	(4.480)	(4.494)	(4.635)	(4.616)	(4.088)
Carcass Weight$_{t-1}$ (lb/hd)	0.324***	0.321***	0.365***	0.360***	0.154**
	(0.0682)	(0.0685)	(0.0689)	(0.0690)	(0.0750)
Total Personal$_t$ ($ billion)	0.00616***				
	(0.00209)				
Total Disposable$_t$ ($ billion)		0.00689***			
		(0.00233)			
Personal$_t$ ($/person)			0.00118		
			(0.000789)		
Disposable$_t$ ($/person)				0.00152	
				(0.000925)	
U.S. Population$_t$ (million people)					1.677***
					(0.335)
Constant	367.7***	368.5***	360.8***	359.4***	283.1***
	(38.42)	(38.43)	(40.22)	(40.16)	(39.02)
Observations	85	85	85	85	85
R-squared	0.992	0.992	0.991	0.991	0.993

Standard errors are shown in parenthesis. *** p<0.01, ** p<0.05, * p<0.10

stationarity on the income and population variables. These retained errors are placed into the final OLS regression equation, in place of the actual income or U.S. population variable. Significance of the error coefficient in the final OLS model specification would suggest that the income variable is explaining variation in average carcass weight, rather than coincidental upward trends causing spurious correlation. For models (1) - (5) in table 7.9 the marginal test on the residuals are insignificant, as a result the income and U.S. population variables are dropped from the final model specification.

The type of cattle slaughtered is predicted to affect average carcass weights. Average carcass weights are higher in fed cattle (e.g., steers and heifers) production versus non-fed cattle (e.g., bulls and cows) production, even though data from NASS shows bulls have the heaviest carcass weights followed by steers, heifers, and cows (NASS 1921). This is because, typically there is a small proportion of bulls slaughtered compared to cows. To proxy differences in the composition of cattle slaughtered, the proportion of bulls and steers slaughtered are tested separately and together in the base average carcass weight model. In the end, these variables are not included in the base model because they are insignificant, of the wrong sign, or they lead to insignificance of the slaughter price and grading dummy. Data for the proportion of cows and heifers slaughtered begins in 1944 rather than 1930 and therefore these variables are not tested in the base model.

Over time the breeds of cattle slaughtered have changed. For instance, the decline in veal production has resulted in more Holstein cattle being fed to finish in the United States. Unfortunately data are not available on the proportion of different cattle breeds slaughtered over time. The ratio of milk cows to beef cows is however, used to proxy the proportion of Holsteins fed with time but is not significant in the base model.

Feeder cattle prices are tested in the base model to confirm the theoretical prediction from Chapter 4 (table 7.10). We hypothesize that at the time the feedlot operator makes his decision regarding carcass weight, feeder cattle prices are a sunk cost that do not affect the profit maximizing decision regarding carcass weights. Inclusion of the current feeder price in the base model, however, leads to a significant ($p = 0.051$) and positive parameter estimate. Increasing the feeder price 10 dollars per hundred weight increases average carcass weight 0.87 pounds. One explanation for the positive coefficient is that as the feeder price increases, the opportunity cost of delaying cattle replacement is reduced. As the opportunity cost of delaying cattle replacement is reduced, the optimal replacement period (days on feed) increases causing carcass weights to increase.[39] Including the feeder price in the base model results in long-run price estimates for the corn price (-7.84), manufacturing wage (-12.94), and the slaughter price (0.264) that are similar to the base model.

In the base model with cattle slaughter numbers, the current feeder price coefficient is insignificant, while all other variables remain significant. This finding fits our hypothesis that the feeder price is a sunk cost and does not affect average carcass weights. Inclusion of the lagged feeder price in either the base or expanded model that includes cattle slaughter numbers, results in both the lagged feeder and slaughter

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[39] The hypothesis for the positive coefficient on the feeder price follows the multi-period tree harvest decision described by Deacon, R.T. and Johnson M.B. in Chapter 11 of the book entitled Forestlands Public and Private published in 1985 by Pacific Institute for Public Policy Research.

Table 7.10: OLS Regression Model for Average Carcass Weight with the Feeder Price Variable

VARIABLES	(1) Base Model	(2) Cattle Slaughter Model
Corn Price$_{t-1}$ ($/bu)	-4.642***	-4.572***
	(0.593)	(0.553)
Manufacturing Wage$_{t-1}$ ($/hr)	-7.661***	-7.367***
	(1.333)	(1.245)
Slaughter Price$_{t-1}$ ($/cwt)	0.156**	0.280***
	(0.0674)	(0.0717)
ΔCattle Slaughter$_t$ (1,000 hd)		-0.00319***
		(0.000897)
Feeder Price$_t$ ($/hr)	0.0871*	-0.0424
	(0.0440)	(0.0548)
Trend$_t$	3.360***	3.274***
	(0.447)	(0.418)
1975 Grading Dummy$_t$	-14.81***	-19.11***
	(4.784)	(4.619)
Carcass Weight$_{t-1}$ (lb/hd)	0.408***	0.444***
	(0.0688)	(0.0650)
Constant	347.8***	330.8***
	(40.78)	(38.30)
Autocorrelation		
(ρ_1)	-0.092	-0.116
(ρ_2)	0.071	0.066
(ρ_3)	0.174	0.110
Durbin	0.922	1.500
ADF	-7.002***	-6.986***
Observations	85	85
R-squared	0.991	0.992

Variables are defined in Table 5.1. Standard errors are shown in parenthesis. Autocorrelation indicates the first through third autocorrelation parameters on the errors using the corrgram function in Stata. The Durbin alternative test statistic follows a chi-squared distribution and tests the null hypothesis of no first order serial correlation. Failure to reject the null hypothesis for the Augmented Dickey Fuller (ADF) test suggests evidence of no co-integration. The ADF statistic is calculated using one lag on the independent variable. *** p<0.01, ** p<0.05, * p<0.1

price to be insignificant. The correlation between the feeder and slaughter price is 0.88, indicating collinearity is likely when the two variables are specified within the same time period.

In the base model labor costs, proxied by the manufacturing wage, accounted for the largest percent of variation in average carcass weight. One explanation for the large coefficient estimate on the manufacturing wage is omitted variable bias. To determine if the manufacturing wage reflects the costs of other feedlot inputs, the AAA bond rate, prime interest rate, gas price, crude oil price, and energy price index are also included in the base model. None of these variables significantly explain average carcass weight, and additionally the coefficient on the manufacturing wage is not affected when these variable are included.

Parameter estimates in the base model and the expanded model with the number of cattle slaughtered are tested for robustness. For the robustness test, the data are divided into two periods (1930-1974 and 1975-2014) and the parameter estimates from these two periods are compared to the final model (table 7.11-7.12). The grading dummy is removed because the grading change occurs the year the data are split.

Using a Chow test the null hypothesis of similar coefficients is tested in the split datasets of the base model (table 7.11). All variables in the base model except the lagged carcass weight variable possess similar coefficient estimates between the two split datasets. In the dataset encompassing the years 1930-1974, the coefficient on the lagged average carcass weight variable is insignificant and small in magnitude. This compares to the larger and significant coefficient estimate on the lagged average carcass weight variable in the dataset from 1975-2014. Also note the manufacturing wage is insignificant in each of the split datasets in the base model, but is significant in the full dataset regression. The manufacturing wage increased at a rapid rate from 1930-1974 and at a slower rate from 1975-2014. In the split datasets there does not appear to be enough variation in the manufacturing wage to explain average carcass weight, however, over 85 years the manufacturing wage significantly explains the variation in average carcass weight.

A Chow test is also run on the expanded model in table 7.12 and provides the same results and interpretation as the base model in table 7.11. These stability checks suggest the base and expanded average carcass weight models are robust.

Table 7.11: Stability Checks for the Base Average Carcass Weight Model

VARIABLES	(1) Base Model	(2) 1930-1974	(3) 1975-2014
Corn Price$_{t-1}$ ($/bu)	-4.460***	-5.062***	-4.151***
	(0.638)	(0.790)	(0.893)
Manufacturing Wage$_{t-1}$ ($/hr)	-7.129***	-6.373	-3.506
	(1.386)	(4.708)	(3.444)
Slaughter Price$_{t-1}$ ($/cwt)	0.270***	0.236***	0.336***
	(0.0570)	(0.0655)	(0.0911)
Trend	2.808***	3.008**	5.048***
	(0.405)	(1.273)	(0.721)
Carcass Weight$_{t-1}$ (lb/hd)	0.477***	0.413***	0.0729
	(0.0687)	(0.0883)	(0.119)
Constant	311.7***	344.2***	371.4***
	(40.46)	(58.95)	(68.09)
Observations	85	45	40
R-squared	0.989	0.962	0.985

Table 7.12: Stability Checks for the Average Carcass Weight Model with Cattle Slaughter Numbers

VARIABLES	(1) Expanded Model	(2) 1930-1974	(3) 1975-2014
Corn Price$_{t-1}$ ($/bu)	-4.193***	-5.053***	-3.732***
	(0.598)	(0.703)	(0.964)
Manufacturing Wage$_{t-1}$ ($/hr)	-6.083***	-6.334	-4.434
	(1.319)	(4.189)	(3.528)
Slaughter Price$_{t-1}$ ($/cwt)	0.269***	0.257***	0.300***
	(0.0530)	(0.0586)	(0.0963)
ΔCattle Slaughter$_t$ (1,000 hd)	-0.00270***	-0.00313***	-0.00124
	(0.000736)	(0.000934)	(0.00110)
Trend	2.384***	2.878**	4.722***
	(0.393)	(1.134)	(0.775)
Carcass Weight$_{t-1}$ (lb/hd)	0.544***	0.464***	0.146
	(0.0664)	(0.0800)	(0.135)
Constant	272.0***	318.2***	360.4***
	(39.13)	(53.02)	(68.52)
Observations	85	45	40
R-squared	0.991	0.970	0.986

CHAPTER EIGHT

CONCLUSIONS

A theoretical profit maximization model identifying determinants of average carcass weight is constructed and empirically tested. The empirical analysis uses annual U.S. data from 1930-2014 in a distributed lag model. Past studies estimating average carcass weights have reported opposing signs or insignificant parameter estimates on input and output prices likely to be important to slaughter cattle production. We obtain coefficient estimates consistent in sign with our theoretical predictions. From these estimates the long run price effects on average carcass weight are calculated.

Results indicate that in addition to the corn price, the feeder price, the fed price, and cattle inventory or slaughter numbers reported in the literature, the manufacturing wage significantly impact average carcass weight. Altogether the manufacturing wage represents 61 percent (34.75 lb/56.97 lb) of the short-run price response on average carcass weight.[40] Long-run estimates of the impact of a one dollar change in the corn price, manufacturing wage, and fed price on average carcass weight are -7.75, -13.36, and 0.39, respectively. The estimated partial adjustment process suggests average carcass weight responds fairly quickly to changing economic conditions, stabilizing from price shocks in less than 2.38 years. A trend effect indicates growth in average carcass weight by 3.63 pounds each year is from feedlot technological advancements.

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[40] The number 56.97 pounds is the sum of corn price (15.45), manufacturing wage (34.75), and fed price (6.77) values from the column labelled change in carcass weight in pounds in table 7.5.

We find the manufacturing wage has a relatively large impact on average carcass weight, larger than any of the other price variables. Considering labor costs have not been reported in the literature before, the finding is rather surprising. The manufacturing wage is included in the final model based on standard economic theory; changes in the input costs are predicted to alter total output. An attempt is made to identify variables possibly correlated with the manufacturing wage but the inclusion of these variables in our regression equation models did not diminish the estimated impacts of the wage variable.

The annual average carcass weight data series used in the analysis is a weighted average of steers, heifers, and cows. As a result, the findings in this study generalize to fed and non-fed (culled) cattle production. The distribution of resources in culled cow production is different from steer or heifer production (Marsh 1999). An alternative approach would have been to estimate separate equations similar to Marsh (1999) for each class of cattle. The data for this approach however, would not have spanned 85 years like they did in this study.

The identification and quantification of the relative contribution of specific feedlot technologies to increasing average carcass weight would also have been of interest. Unfortunately public data on the use of feedlot technologies over time are not available. Moreover, the estimation of the impacts of the many individual technologies adopted by feedlot operations from a single annual time series on carcass weights would have been problematic. Accordingly we use a trend variable as a proxy of technological advancements.

In recent years, beef cattle inventories have declined, reducing the number of cattle available for beef production. Despite the declining cattle slaughter numbers, U.S. beef production has remained high. The U.S. beef industry requires at least two years to increase slaughter cattle production, through the cow-calf, stocker, and feedlot systems. In contrast, average carcass weights in a commercial feedlot setting can be adjusted in a moderately short period of time. This study indicates through a trend variable that average carcass weights have increased dramatically from 1930-2014, even when cattle slaughter numbers have declined. Beef production, therefore appears to be maintained by the technological advancements in cattle feeding, resulting in increasing average carcass weights.

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APPENDICES

APPENDIX A

THEORETICAL MODEL PREDICTIONS

Production function: $W = F + G(C, L)$

Over the relevant range $G(C, L)$ is well behaved in that:

$$G_L > 0,\ G_C > 0,\ G_{CC} < 0,\ G_{LL} > 0,\ G_{CC}G_{LL} - G_{CL}^2 > 0$$

The profit maximization equation:

$$\pi = P_W W - (P_F F)^0 - P_L L - P_C C$$

FOCs:

$$\pi_L = P_W G_L - P_L = 0$$

$$\pi_C = P_W G_C - P_C = 0$$

SOCs:

$$\pi_{CC} = P_W G_{CC} < 0$$

$$\pi_{LL} = P_W G_{LL} < 0$$

$$\pi_{LC} = P_W (G_{CC} G_{LL} - G_{LC}^2) > 0$$

Solve for the factor demand functions for C and L (see Silberberg and Suen 2001).

$$C = C^*(P_W, P_C, P_L)$$

$$L = L^*(P_W, P_C, P_L)$$

Substitute the factor demand functions back into the FOCs.

(1) $P_W G_C\big(C^*(P_W, P_C, P_L), L^*(P_W, P_C, P_L)\big) - P_C = 0$

(2) $P_W G_L\big(C^*(P_W, P_C, P_L), L^*(P_W, P_C, P_L)\big) - P_L = 0$

Differentiating (1) and (2) with respect to P_C.

(3) $P_W G_{CC} \frac{\partial C^*}{\partial P_C} + G_{CL} \frac{\partial L^*}{\partial P_C} - 1 = 0$

(4) $P_W G_{CL} \frac{\partial C^*}{\partial P_C} + G_{LL} \frac{\partial L^*}{\partial P_C} = 0$

Solving (3) and (4) for $\frac{\partial C^*}{\partial P_C}$ yields:

(5) $\frac{\partial C^*}{\partial P_C} = \frac{G_{LL}}{P_W(G_{CC}G_{LL}-G_{CL}^2)}$

Differentiate (1) and (2) with respect to P_L and solve for $\frac{\partial L^*}{\partial P_C}$:

(6) $\frac{\partial L^*}{\partial P_C} = \frac{-G_{LC}}{P_W(G_{CC}G_{LL}-G_{CL}^2)}$

Similarly solve for $\frac{\partial C^*}{\partial P_L}$ and $\frac{\partial L^*}{\partial P_L}$:

(7) $\frac{\partial C^*}{\partial P_L} = \frac{-G_{CL}}{P_W(G_{CC}G_{LL}-G_{CL}^2)}$

(8) $\frac{\partial L^*}{\partial P_L} = \frac{G_{CC}}{P_W(G_{CC}G_{LL}-G_{CL}^2)}$

Lastly, $\frac{\partial C^*}{\partial P_W}$ and $\frac{\partial L^*}{\partial P_W}$ are found:

(9) $\frac{\partial C^*}{\partial P_W} = \frac{-G_C G_{LL}+G_L G_{CL}}{P_W(G_{CC}G_{LL}-G_{CL}^2)}$

(10) $\frac{\partial L^*}{\partial P_W} = \frac{-G_L G_{CC}+G_C G_{CL}}{P_W(G_{CC}G_{LL}-G_{CL}^2)}$

The signs of $\frac{\partial C^*}{\partial P_C} < 0$, $\frac{\partial L^*}{\partial P_L} < 0$, $\frac{\partial C^*}{\partial P_L} = \frac{\partial L^*}{\partial P_C}$ is opposite of G_{CL}. If $G_{CL} > 0$ then $\frac{\partial C^*}{\partial P_W} > 0$, $\frac{\partial L^*}{\partial P_W} > 0$, if $G_{CL} < 0$ then the sign will depend on the relative magnitude of G_{CL}.

To find the marginal effects of carcass weight assume the optimal supply and factor demand functions hold:

$W = F + G(C^*, L^*)$ where $C = C^*(P_C, P_{L,} P_W)$ so that $W = W^*(P_{C,} P_L, P_W)$

Differentiate the supply function $W = W^*(P_{C,} P_L, P_W)$ with respect to P_W:

(11) $\frac{\partial W^*}{\partial P_W} = \frac{\partial G}{\partial C^*}\frac{\partial C^*}{\partial P_W} + \frac{\partial G}{\partial L^*}\frac{\partial L^*}{\partial P_W} = G_C \frac{\partial C^*}{\partial P_W} + G_L \frac{\partial L^*}{\partial P_W}$

Substituting (9) and (10) into (11):

$$\frac{\partial W^*}{\partial P_W} = \frac{-G_C^2\, G_{LL} + 2G_{CL} G_C G_L - G_L^2 G_{CC}}{P_W (G_{CC} G_{LL} - G_{CL}^2)}$$

If the isoquants are convex, then the numerator is positive so $\frac{\partial W^*}{\partial P_W} > 0$. The denominator is positive based on the second order conditions.

Differentiate the supply function with respect to P_C to find $\frac{\partial W^*}{\partial P_C}$:

(12) $\frac{\partial W^*}{\partial P_C} = \frac{\partial G}{\partial C}\frac{\partial C^*}{\partial P_C} + \frac{\partial G}{\partial L}\frac{\partial C^*}{\partial P_L}$

Substituting (5) and (6) into (12):

$$\frac{\partial W^*}{\partial P_C} = \frac{G_C G_{LL}}{P_W (G_{CC} G_{LL} - G_{CL}^2)} + \frac{G_L(-G_{CL})}{P_W (G_{CC} G_{LL} - G_{CL}^2)} = \frac{G_C G_{LL} + G_L(-G_{CL})}{P_W (G_{CC} G_{LL} - G_{CL}^2)}$$

If $G_{CL} > 0$ then $\frac{\partial W^*}{\partial P_C} < 0$ in equation (12)

If $G_{CL} < 0$ and $G_C G_{LL} > G_L G_{CL}$ then $\frac{\partial W^*}{\partial P_C} > 0$ in equation (12).

We get the usual negative response if $G_{CL} > 0$.

We get the unexpected response $\frac{\partial W^*}{\partial P_C} > 0$ if $G_{CL} < 0$ and relatively large.

The two responses above are analogous for P_L.

Based on these derivations the predictions for average carcass weight in terms of the corn price, labor price, and slaughter price are:

$$\frac{\partial W^*}{\partial P_C} < 0$$

$$\frac{\partial W^*}{\partial P_L} < 0$$

$$\frac{\partial W^*}{\partial P_W} > 0$$

APPENDIX B

ALGEBRA FOR LONG-RUN PRICE EFFECTS

To find the long run cumulative effects of a corn price shock on average carcass weight first the marginal effects are calculated. The marginal effects are calculated using the equations for average carcass weight written out over different periods.

$Carcass\ Weight_t = \alpha_0 + \alpha_1 Corn\ Price_{t-1} + \alpha_2 Slaughter\ Price_{t-1} + \alpha_3 Labor\ Wage_{t-1} + \alpha_4 Carcass\ Weight_{t-1} + \varepsilon_t$

$Carcass\ Weight_{t-1} = \alpha_0 + \alpha_1 Corn\ Price_{t-2} + \alpha_2 Slaughter\ Price_{t-2} + \alpha_3 Labor\ Wage_{t-2} + \alpha_4 Carcass\ Weight_{t-2} + \varepsilon_t$

$Carcass\ Weight_{t-2} = \alpha_0 + \alpha_1 Corn\ Price_{t-3} + \alpha_2 Slaughter\ Price_{t-3} + \alpha_3 Labor\ Wage_{t-3} + \alpha_4 Carcass\ Weight_{t-3} + \varepsilon_t$

$Carcass\ Weight_{t-3} = \alpha_0 + \alpha_1 Corn\ Price_{t-4} + \alpha_2 Slaughter\ Price_{t-4} + \alpha_3 Labor\ Wage_{t-4} + \alpha_4 Carcass\ Weight_{t-4} + \varepsilon_t$

$Carcass\ Weight_{t-s} = \alpha_0 + \alpha_1 Corn\ Price_{t-s-1} + \alpha_2 Slaughter\ Price_{t-s-1} + \alpha_3 Labor\ Wage_{t-s-1} + \alpha_4 Carcass\ Weight_{t-s-1} + \varepsilon_t$

The marginal effects for the current carcass weight with a change in the corn price in period *t*, *t-1*, *t-2*… are calculated by taking the derivative of the current carcass weight with respect to the corn price in the period of interest:

$\partial Carcass\ Weight_t / \partial Corn\ Price_{t-1} = \alpha_1$

$\partial Carcass\ Weight_t / \partial Corn\ Price_{t-2} = \alpha_4(\partial Carcass\ Weight_{t-1} / \partial Corn\ Price_{t-2}) = \alpha_4\alpha_1$

$\partial Carcass\ Weight_t / \partial Corn\ Price_{t-3} = \alpha_4(\partial Carcass\ Weight_{t-1} / \partial Corn\ Price_{t-3}) = \alpha_4(\partial Carcass\ Weight_t / \partial Corn\ Price_{t-2}) = \alpha_4(\alpha_4\alpha_1) = \alpha_4^2\alpha_1$

$\partial Carcass\ Weight_t / \partial Corn\ Price_{t-4} = \alpha_4(\partial Carcass\ Weight_{t-1} / \partial Corn\ Price_{t-4}) = \alpha_4(\partial Carcass\ Weight_t / \partial Corn\ Price_{t-3}) = \alpha_4(\alpha_4^2\alpha_1) = \alpha_4^3\alpha_1$

$\partial Carcass\ Weight_t / \partial Corn\ Price_{t-5} = \alpha_4(\partial Carcass\ Weight_{t-1} / \partial Corn\ Price_{t-5}) = \alpha_4(\partial Carcass\ Weight_t / \partial Corn\ Price_{t-4}) = \alpha_4(\alpha_4^3\alpha_1) = \alpha_4^4\alpha_1$

$\partial Carcass\ Weight_t / \partial Corn\ Price_{t-s} = \ldots..$

The long run cumulative effects for a corn price shock can be found using the following algebraic manipulation.

(1) Sum together the marginal effects: $\partial \textit{Carcass Weight}^{*}/\partial \textit{Corn Price}^{*} = \partial \textit{Carcass Weight}_{t}/\partial \textit{Corn Price}_{t-1} + \partial \textit{Carcass Weight}_{t}/\partial \textit{Corn Price}_{t-2} + \partial \textit{Carcass Weight}_{t}/\partial \textit{Corn Price}_{t-3} \ldots\ldots = \alpha_1 + \alpha_4\alpha_1 + \alpha_4^2\alpha_1 + \alpha_4^3\alpha_1 \ldots..$

(2) Pull out α_1 to get: $\partial \textit{Carcass Weight}^{*}/\partial \textit{Corn Price}^{*} = \alpha_1(1+ \alpha_4 + \alpha_4^2 + \alpha_4^3 \ldots..)$.

(3) Set $s = (1+ \alpha_4 + \alpha_4^2 + \alpha_4^3)$ to get: $\partial \textit{Carcass Weight}^{*}/\partial \textit{Corn Price}^{*} = \alpha_1(1+ \alpha_4 + \alpha_4^2 + \alpha_4^3 \ldots.) = \alpha_1 s$.

(4) Cancel the α_1 on both sides of the equation: $1+ \alpha_4 + \alpha_4^2 + \alpha_4^3 \ldots. = s$

(5) Multiply both sides by α_4: $(\alpha_4 + \alpha_4^2 + \alpha_4^3 + \alpha_4^4 \ldots.) = s\alpha_4$

(6) Subtract (3) from (4) above: $(1+ \alpha_4 + \alpha_4^2 + \alpha_4^3 \ldots).- (\alpha_4 + \alpha_4^2 + \alpha_4^3 + \alpha_4^4 \ldots.) = 1$ or $(s\text{-}s\,\alpha_4) = 1$

(7) Rearrange for s in (6) above: $s = 1 / (1- \alpha_4)$

(8) Multiply s by α_1 to get the cumulative effect of a corn price shock: $\partial \textit{Carcass Weight}^{*}/\partial \textit{Corn Price}^{*} = \alpha_1/(1- \alpha_4)$