Wholesale Beef Price Forecasting: A Prototype of How ARIMA Methods can be Used to Model Boxed Chuck Prices.

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1 Introduction

This project prototype seeks to create a forecasting model for wholesale beef prices and attempt to use beef cattle trading as an explanatory variable. This paper will go over the context of the wider market, the economic theory of how beef is priced, the statistical models to be used in forecasting, and an overview of the success of these models. The factors affecting beef supply and demand and how these can tie into the model will be explained by drawing on previous research and building on relevant theory. This problem is of great importance to some firms in the food sector, and this approach may be applicable to other meat products.

1.1 Motivation

Beef is one of the most popular foods in the United States, ranking as the second most consumed meat behind chicken since 2010 (USDA, 2022). As a result, it is important for grocers, restaurants, and other retailers to stock beef products and the ability to predict the coming prices of wholesale beef would be of great use to these firms. One way to go about this would be to identify trends in the market that may have some affect on the supply and demand of beef and one such indicator could be cattle trading trends. Some cattle are sold at auctions, from ranching operations to beef packers, while others are sold via private negotiations. Both types of transaction are publicly available through the United States Department of Agriculture (USDA), but this prototype will focus on the auctions as the results are more concise and standardized, and it will be shown later that these can be assumed to be representative of the entire market.

1.2 Objectives

To begin answering this question, an understanding of what it implies must be developed. First, create a model of the beef supply chain. Luckily this has been done countless times by others and plenty of examples exist in the literature. Second, find what indicators can are already known to affect beef prices. Again, this is not a new problem and has been addressed before. Third, draw a connection between current feeder and slaughter cattle auction results and future wholesale beef prices. This will be the majority of what this paper focuses on. Finally, use this connection to forecast the market for wholesale beef prices. This is what will be of most use to businesses and is the ultimate objective of this project.

2 Background

The USDA has a division called the Agricultural Marketing Service (AMS) which publishes market reports, called Market News, on a variety of agricultural commodities. This project uses data from the *National Weekly Fed Cattle Comprehensive Overview*, *National Feeder & Stocker Cattle Summary*,*National Weekly Boxed Beef Cuts - Formulated Sales*, and *National Weekly Boxed Beef Cuts - Negotiated Sales*. The first two, report the auction results of fed and feeder cattle at every market across the country. These report aggregated price, weight, and quality data grouped by cattle type and weight class. The latter two are the data on wholesale beef, called boxed beef. Variables include date, Institutional Meat Purchase Specifications (IMPS), quantity sold, grade (quality), and price. The IMPS is a system for coding the cut of beef consisting of three numbers, a letter, and an optional final number that designates the specific cut of the cattle. More information on these variables is in Appendix I.

The boxed beef data includes over fifty unique wholesale cuts of beef, and this project will prototype a model for only one. The cut chosen to focus on was Chuck, roll lxl neck/off (IMPS 116A 3), determined by analyzing the summary statistics of the different cuts including the average, min, and max of both price and quantity along with total quantity traded over all periods, see Tables 4 and 5. This cut, which will be referred to as boxed chuck or just chuck in this paper, has the highest total and average quantity traded. So as a popular cut, it will be useful for firms to forecast, and having a lot of data may give a more accurate model. Now, an explanation of the supply chain and a few key terms will give a better understanding of the surrounding context in which the price discovery process of boxed chuck takes place.

2.1 Beef Supply Chain

The beef supply chain is full of complexity, with many intersecting markets and the inherent variability that comes with biological assets (Fisher et al., 2021, p. 4). The model of the supply chain used in this paper will follow the example of *U.S. Beef Supply Chain* by J. Musengezi et al (2016, pp. 9-10). Before the discussion begins, a few key terms are necessary to know.

Boxed Beef: Wholesale beef that has been cut into primal and subprimal cuts, as opposed to the traditional distribution of entire carcasses to local butchers.

Bull: Male cattle that is used for reproductive purposes.

Calf: A newborn cattle of either sex.

Cow: Female cattle that has given birth, used mainly for reproduction and diary production.

Fed Cattle: Heifers and steers that have grown to slaughter weight.

Feeder Cattle: Younger steers or heifers, old enough to begin the process of fattening up to slaughter weight.

Grading: The quality assigned to beef, according to the level of marbling. The levels, in order, are prime, choice, select, and lower grades generally not sold as full cuts.

Head: Number of cattle.

Heifer: Female cattle that has not had a calf, some used to replace aged out cows while the rest are used for beef production.

Hundred weight (CWT): Price per hundred pounds.

Marbling: The intramuscular fat in meat, important determinant of flavor and quality.

Oligopoly: A market structure with a few firms controlling an output market.

Oligopsony: A market structure where a few firms exhibit out-sized control over an input factors market.

Primal Cuts: Large sections of meat divided from the carcass (Rib, chuck, loin, etc.).

Retail Cuts: Derived from sub-primal cuts, generally sold to consumers or restaurants (Steaks, roasts, ground beef, etc.).

Steer: A castrated male used exclusively for beef production.

Sub-Primal Cuts: Smaller sections of meat taken from the primal cuts and cut down to the consumer cuts (Rib-eye, chuck roll, short loin, etc.)

Weaning: The transition of calves from milk fed to pasture grazing.

With this terminology in hand, the breakdown of the supply chain can begin.

Cow-Calf

These operations involve a mixed breeding herd of cattle, consisting mostly of cows, or young replacement heifers, and a few bulls. Operators attempt to produce at least one calf per cow per year and raising the calves until weaned, approximately four to seven months. These calves then begin grazing until sold to a grower operation or feedlot. Occasionally, aging cows and bulls that are no longer useful for breeding will be sold directly to slaughter houses, to be replaced by calves.

Grower

Grower operations consist of two types, stockers and backgrounders. Both focus on growing weaned cattle, developing a larger frame and putting on muscle weight, with the difference being stockers have the calves open graze and backgrounders use a mostly forage diet but include more energy dense feed. The cattle are grown until they hit the target weight for feedlots, usually around a year to eighteen months of age, after which they are sold off to feedlots.

Feedlots

The final step of growth for the cattle, where they will spend four to six months, being fed diets of mostly grain in order to rapidly gain weight. Most feedlots are what is called Animal Feeding Operations (AFOs) for operations under 1000 head or Concentrated AFOs (CAFOs) for operations over 1000 head, defined as facilities that confine the cattle in pens for 45 or more days a year and do not produce on site vegetation. Once the cattle reaches the optimal slaughter weight, discussed in a later section, the animal is sold to a slaughterhouse for further processing.

Beef Packing

Following the feedlot phase the cattle are sent to slaughter and dressed (the removal of the hide and organs), then butchered and cut into primal and sub-primal cuts. This process is the most highly concentrated stage of beef production, with the top four beef packers having control of 85% of the market (Fisher et al., 2021, p. 45). Fisher et al. conjecture that these four firms have economies of scale that influence price discovery of boxed beef, and according to research investigating the levels of market control, it was shown that beef packers exhibit oligopoly/oligopsony power, yet they have more power in the inputs market than the outputs(Azzam and Pagoulatos, 1990). The effects this has on the forecasting techniques will be explained in a later section.

Distribution

Boxed beef is sold to grocers, food distributors, butchers, and some restaurants where it is cut down to retail cuts. This group is the targeted user of the forecasting model developed later in this paper, as projecting the costs of wholesale beef will improve cost planning.

Cattle Trading

There are multiple steps along the supply chain where cattle need to be moved from one operation to the next. There are three main ways this is facilitated. First, vertical integration, some large firms may own operations in multiple stages and thus do not need to go through markets to acquire cattle. Second is private negotiation, where buyers and sellers negotiate one on one to make trades for both feeder and fed cattle. The final method of trading, auctions, are expected to be representative of the market as a whole. According to a study of Iowan cattle ranchers engaging in private sales that asks whether they used public cattle auction data when making marketing decisions, around 80% of both fed and feeder cattle buyers and sellers said they do (Lawrence et al., 1996, p. 26). Feeder cattle auctions occur between either cow-calf or grower operations and feed lots and are usually sold at futures markets in double auctions while fed cattle are sold from feed lots to packers following an English auction format (Fisher et al., 2021, pp. 66-67).

2.2 Beef Demand

According to previous research, the major factors that effect beef demand are its price and expenditure elasticity, and the price of substitutes (Schroeder et al., 2000). The paper finds beef has a price elasticity of -0.68, suggesting that the demand is price inelastic. Also, beef has a cross price elasticity with pork and chicken of 0.041 and 0.016 respectively, showing that they are substitutes, as expected. Finally, the paper found an expenditure elasticity of .900, much higher than that of pork (0.731) and chicken (-0.403). These findings will be useful as the effects of these elasticities can be taken into consideration in the model formulated later.

3 Economic Model

3.1 Market Structure

As mentioned previously, the market structure of the beef packing industry is assumed to be an oligopsony in the input market and an oligopoly in the output market, facing competitive suppliers in the inputs and competitive buyers in the outputs. This structure is useful in informing the necessary covariates that will determine the price of wholesale beef. To see why, first assume the supply of beef comes from a monopolist that faces a competitive input market, where it has no market power, and a competitive output market. Using a Cournot competition framework developed by Antoine Cournot, translated and published by Irving Fisher (Fisher, 1898) . Under this construction, a rational firm would maximize the objective function,

$$\max_{Q} \pi(Q) = P(Q)Q - wQ \tag{1}$$

Where Q is the quantity produced, P(Q) is the inverse demand function, and w is the price of Q in the input market. The resulting maximizing quantity is,

$$Q^* = \frac{-1}{P'(Q^*)}[P(Q^*) - w] \tag{2}$$

Now, assume that the monopolist has monopsony power in the input market, but the supply is still from perfect competition.

$$\max_{Q} \pi(Q) = P(Q)Q - C(Q)Q \tag{3}$$

With a maximizing quantity of,

$$Q^* = \frac{1}{C'(Q^*) - P'(Q^*)}[P(Q^*) - C(Q^*)] \tag{4}$$

Where C(Q) represents the inverse supply function. Assuming the monopolist faces the inverse demand and supply functions,

$$P(Q) = \alpha - \beta Q \tag{5}$$

$$C(Q) = \gamma + \phi Q \tag{6}$$

Where α, β, γ, and $\phi > 0$. Substituting (5) and (6) into (4), it becomes clear that the maximizing quantity is,

$$Q^* = \frac{1}{2}\,\frac{\alpha - \gamma}{\beta + \phi} \tag{7}$$

and output price becomes,

$$P^* = \alpha - \frac{\beta}{2}\,\frac{\alpha - \gamma}{\beta + \phi} \tag{8}$$

This implies that a monopolist/monopsonist will price their output according to features of both the supply side and demand side factors. Generalizing this to an oligopoly/oligopsony market structure, equation (3) becomes,

$$\max_{q_i} \pi(q_i|Q) = P(Q)q_i - C(Q)q_i \tag{9}$$

Where i represents the ith firm in the market, and Q is the sum of all firms' output quantity. The individual maximizing quantity becomes,

$$q_i^* = \frac{1}{\frac{dC(Q^*)}{dq_i} - \frac{dP(Q^*)}{dq_i}}[P(Q^*) - C(Q^*)] \tag{10}$$

Using the generalization of the Cournot equilibrium result and assuming the market is made up of N symmetric firms, maximizing individual quantity is,

$$q_i^* = \frac{1}{N+1}\,\frac{\alpha - \gamma}{\beta + \phi} \tag{11}$$

And finally, the price of the market output is,

$$P^* = \alpha - \beta\,\frac{N}{N+1}\,\frac{\alpha - \gamma}{\beta + \phi} \tag{12}$$

The relevant comparative statics can be derived $\frac{dP(Q)}{d\alpha} > 0$, $\frac{dP(Q)}{d\beta} < 0$, $\frac{dP(Q)}{d\gamma} > 0$, $\frac{dP(Q)}{d\phi} > 0$, and $\frac{dP(Q)}{dN} < 0$

These results align with general economic theory, but are useful to inform the type of data needed. Most importantly, the costs of inputs and the factors affecting demand. As mentioned in the discussion on the beef supply chain, the direct inputs to the beef packers are fed cattle whose market prices are publicly available from the USDA, to be discussed further in a later section. However, these fed cattle come from a herd of feeder cattle which also have publicly available auctions, and since these cattle affect the supply of fed cattle, they should have an effect on beef prices. Sticking with supply side, the price of feed for cattle is another factor in the cost of cattle ranching and should be taken into account. Along with these, factors effecting demand will be necessary to collect. Mentioned previously, beef is known to be substitutes with pork and chicken, and be positively expenditure elastic. The collection and specification of these variables will be discussed in a later section. For now, focus will be directed toward the theory of the cattle supply.

3.2 Optimal Slaughter Weight

The supply of cattle is hypothesized to be a major component of the price of wholesale beef and in this section an understanding of when a rancher or operator decides to send a cattle to auction will be developed. First, all credit to the following models goes to Lovell S. Jarvis (1974) and Harry J. Paarsch (1985). Feedlot and cow-calf operators face similar but different problems. Feedlot operators only need to decide when an animal is ready to go to slaughter, based on its weight, the price of beef, and other exogenous factors. Cow-calf operators need to make similar decision with their calves, but also need to decide when to sell aging cows based on their marginal productivity as compared to heifers. To address the problem of the feedlot, assume the operator chooses a time to slaughter that maximizes the present value of their operation. This optimal time maximizes per period profits to the extent where it does not reduce the present value of the revenue of subsequent herds. Also assume the operator has a fixed herd composition. Paarsch describes the model in much more detail, and the following is presented (1985, pp. 643-645),

$$\max_{T} V(T) = \sum_{j=0}^{\inf} \pi_f(T)exp(-rjT) = \frac{\pi(T)}{1 - exp(-rT)} \tag{13}$$

where,

$$\pi(T) = M[-p_c - k - c\overline{f} \int_0^T exp(-rt)dt + pw(T)exp(-rT)] \tag{14}$$

V(T) is the present value of a series of profits $\pi(T)$, with T as the amount of periods until sale for slaughter. M is the number of cattle in the herd, r is the interest rate, p_c is the price of a calf, c is the cost of feeding, $\overline{f}$ is the fixed ration of feed, p is the price of beef, w(T) is the predicted weight after t periods, and k is the fixed costs per cattle. The comparative static of note to this paper is,

$$\frac{dT}{dp} < 0 \tag{15}$$

This condition says that as the price of beef rises, the operator should sell their cattle earlier. Paarsch explains this result is due to the opportunity cost of delaying slaughter rises with price, because the discounted value of future revenues also is increasing. So slaughter earlier to capitalize on this increased price, getting more cattle through quicker. Since weight is also a function of T, when the price of beef rises, a subsequent fall in weights of cattle sold at auction should decrease.

3.3 Rational Expectations

Rational expectations, introduced by John F. Muth in a paper from 1961, describes how rational economic agents use all available information to form expectations of value, and that any systematic errors in valuation will be exploited until corrected (Muth, 1961). Muth uses this hypothesis on the movements of prices in financial markets, arguing that prices reflect the rational expectations of agents. He notes that this should cause prices to follow a random walk, as price expectations will be effected by external variables that are unpredictable within the model. Lars P. Hansen and Thomas J. Sargent expand on this hypothesis by integrating rational expectations into economic modeling via Dynamic Linear Rational Expectations Models (DLREMs) (Hansen and Sargent, 1980). They show how stochastic time series models like the Box-Jenkins autoregressive integrated moving average (ARIMA) methods (Box and Jenkins, 1970), can be used to model the dynamic behavior of prices. Under the assumptions of rational expectations, all agents have perfect information and know how this should affect prices, so any differences in price between periods should be from random shocks. ARIMA handles these shocks by observing the relationships between current period and previous periods, incorporating the random but periodic cycles of shocks into the model. This paper will seek to apply this methodology to wholesale chuck prices, comparing the results of an ARIMA and linear regression models to see if rational expectations are applicable to this problem.

4 Data

This section will provide a brief description of the most relevant data, with a full breakdown in Appendix I. Table 6 shows the summary statistics of some relevant numeric variables, the chuck and cattle prices are all measured in price per hundred weight, the chicken breasts and pork chops are measured in price per pound, and feedstuff corn (cattle feed) is measured in price per ton. Finally, the cattle weights are measured in pounds. Figures displaying the time series plots of these variables will be available in Appendix II. All data was collected between January 2000 and January 2020, but all not variables had data for all years. The full combined dataset is weekly data spanning from January 12th, 2004 and May 6th, 2019.

5 Statistical Model

5.1 ARIMA Model

ARIMA is a class of time series model developed by GEP Box and Gwilym M. Jenkins in the 1970s. It is a purely statistical model and is not driven by economic theory, instead it is composed of three components: Autoregressive (AR), integrated (I), and moving average (MA). Autoregressive accounts for the relationship between the current periods value and the p periods preceding it, for example,

$$AR(1) : y_t = \alpha_1 y_{t-1} \tag{16}$$

$$AR(2) : y_t = \alpha_1 y_{t-1} + \alpha_2 y_{t-2} \tag{17}$$

$$AR(p) : y_t = \sum_{i=1}^{p} \alpha_i y_{t-i} \tag{18}$$

The moving average (MA) aspect of ARIMA states the relationship between the previous q values' errors, and the current period's value. This is the part of ARIMA that should represent the rational expectations, where the error terms can be thought of as the shocks.

MA models look like the following,

$$MA(1): y_t = \phi_1 \epsilon_{t-1} \tag{19}$$

$$MA(2): y_t = \phi_1 \epsilon_{t-1} + \phi_2 \epsilon_{t-2} \tag{20}$$

$$MA(q): y_t = \sum_{i=1}^{q} \phi_i \epsilon_{t-i} \tag{21}$$

The integrated (I) in ARIMA states how many levels of differencing (d) needed to have the data fit the requirements of ARIMA. I(1) means the ARIMA fits to the differences between the values, and not the actual values while I(2) means that ARIMA is fit to the differences of the first differences. ARIMA is hypothesized to be useful for rational price modeling as it incorporates the perfect information from periods previous, however, new information comes out every period that effect the chuck prices. In this case these are the cattle auction results and demand factors. Along with these, there may be a seasonal component to this model. Thus the final model is represented as,

$$ARIMA(p, d, q): y_t = \alpha(L)y_{t-1} + \alpha_{t-12}y_{t-12} + \phi(L)\epsilon_{t-1} + \phi_{t-12}\epsilon_{t-12} - X_t\beta \tag{22}$$

Where $\alpha(L)$ represents the lag operator and α coefficients of the AR(p) components, $\phi(L)$ is the lag operator and ϕ coefficients of the MA(q) errors, and $X_t\beta$ is the current period exogenous variables and their coefficients. The subscript t-12 components represent the AR and MA components from the previous year, showing the effects of seasonality. The actual specifications for p,d, and q will be explained and decided in the next section on empirical specification. For now the discussion will be switched to the linear regression model.

5.2 Linear Model

Recall (12),

$$P^* = \alpha - \beta \, \tfrac{N}{N+1} \, \tfrac{\alpha-\gamma}{\beta+\phi}$$

Where as ARIMA is a purely statistical model, this paper intends to create a competing theory driven model. A linear regression model will be used, with coefficients meant to represent the components that makes up th price.

$$P_t^* = X_t\beta \tag{23}$$

This model represents price as a function of the exogenous variables of cattle auction results and other economic factors. Incorporated into the model are lags of the variables, it is hypothesized that the cattle auction results from the period when the input cattle were bought will be more significant than the results of auctions in the current period. This will be tested and the process of identifying these lags will be discussed further in the Empirical Specification section.

6 Specification

This section will be focused on the empirical specification of the two proposed statistical models. First the ARIMA model will be specified, where th p,d, and q parameters will need identification. The p and q parameters will be done through the use of the autocorrelation and partial autocorrelation functions (ACF and PACF respectively). The d parameter is to be found by finding at what level of differencing the time series becomes stationary. The following subsection will present this information via plots produced in R. Now, lags of the variables to be included in the linear regression will be covered. To identify the delay between changes in input prices and boxed chuck prices, a crosscorrelation function was used. This function produces the correlations between one variable and every lagged value of another variable, up to a specified maximum.

6.1 ARIMA Specification

To begin, the time series of boxed chuck is shown in Figure 1 and the ACF and PACF of the boxed chuck prices are shown in Figure 2. Figure 1 informs the data is not very stationary, and this is made evident by the pattern in the ACF that displays highly significant correlations between the current value and all previous values. This means at least one order of differencing is needed.

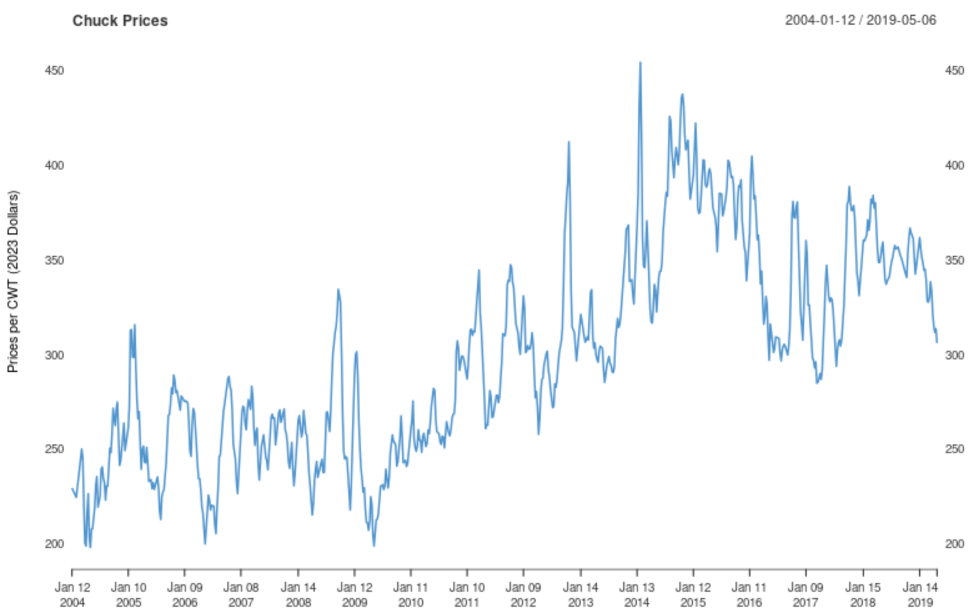
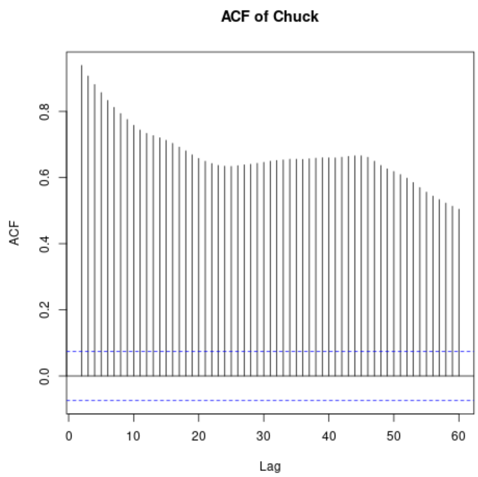
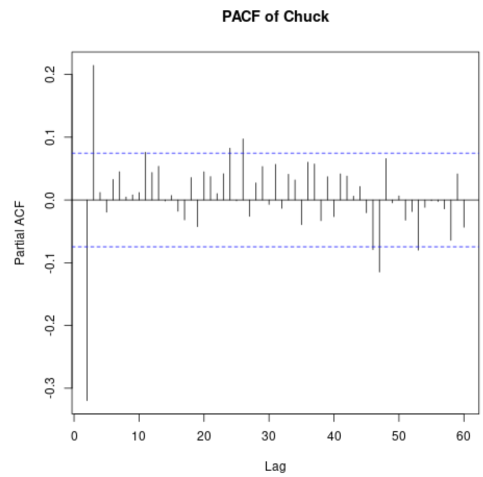


Figure 1: Chuck Price Time Series

Figure 3 contains the time series of the first differences in chuck prices, showing much more stationarity than the non-differenced data. Subfigure 4a displays the ACF significant correlations up to about lag 10, while the PACF in Subfigure 4b does not exhibit much pattern in the significant lags. The ACF also shows significant lags around 45 and 46, which could be an indicator that there is some seasonality in the time series (recall the data is indexed weekly). These results are hopeful for the success of an ARIMA model in fitting



(a) ACF



(b) PACF

Figure 2: Chuck Price ACF and PACF

this data; different q's will be used and d will be set at one, some testing will be required to identify if a p parameter is necessary.

Along with these attempting different p and q values, a simple ARIMA model will be compared to an ARIMA that incorporates exogenous variables. These external factors will all be current period, as any lagged value will have been incorporated into previous prices according to the rational expectations framework. The results of this model will be reported in the next section. To assess the effectiveness of this model, the data will be split into three parts: training, validation, and testing. Since this model requires a time series, the data will be split into continuous blocks of time. The test data is the last year of the dataset, the validation set will be the three years previous, and the training data will be the rest of the approximately nine years. The root mean square error (RMSE) will be the metric used to compare the ARIMA models to each other and the linear regression. The results of these models will be presented in the next section.

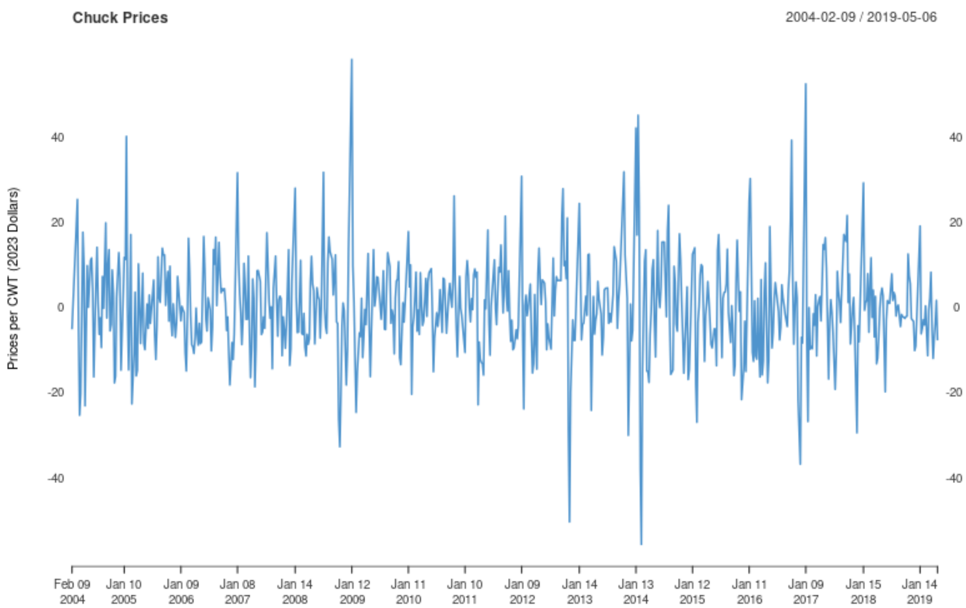
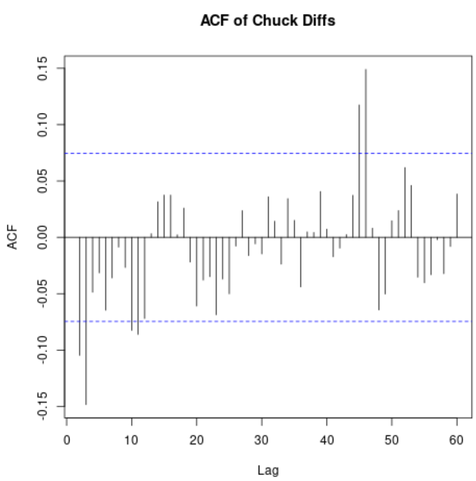
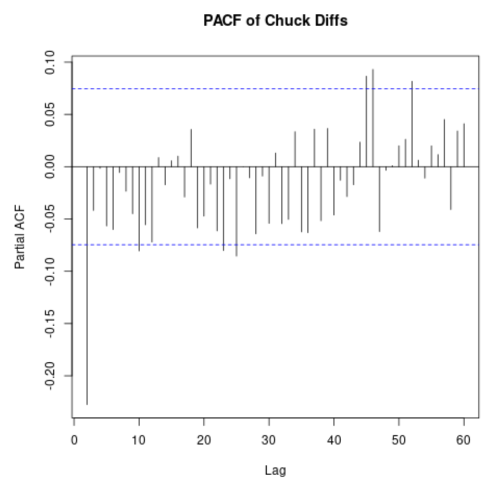


Figure 3: First Differences Chuck Price Time Series



(a) ACF



(b) PACF

Figure 4: ACF and PACF

6.2 Linear Regression Specification

As mentioned previously, a crosscorrelation function was used to identify significant lags between the first differences of the dependent variables and the first differences of chuck prices. This was done to find how the changes in input costs or demand factors relate to changes in chuck prices. To summarize, the largest correlation lags are shown in Table 1.

Dependent Variable	Top Significant Lags (Limit 5)
Bulls	2, 12, 18, 28, 45
Cows	19, 28, 33, 45, 46
Heifers	0, 1, 3, 4, 37
Steers	0, 1, 3, 4, 35
Feeder Steers	0, 1, 8, 47
Feedstuff Corn	12, 48
Chicken	6, 26, 36, 42
Pork	0, 12, 27, 28
Expednitures	3

Table 1: Top Significant Lags between First Differences of the Dependent Variables and Boxed Chuck.

The first model will include all variables with all specified lags, and then using techniques, such as stepAIC in R, to reduce the model and remove insignificant variables (referring to each individual lag of the independent variables). For this model, the testing set will be the same as the ARIMA model as to compare its accuracy, while the rest of the data willl be split 70/30 into training and testing respectively. The linear models will be compared on the validation set, and the final model will be compared to ARIMA on the test set. The results of these models, and the final included variables, will be listed in the next section.

6.3 Composite Forecast

Depending on the predictive abilities of the previous two approaches, a combined model is hypothesized to perform better than the component models. This will be created by finding the predictions of the individual models on a validation set and testing set. Then, different weights will be applied to each prediction and summed to make a combined prediction. The combination of weights with the lowest RMSE on the validation set will be chosen, and a set of test predictions will be produced and measured against the individual component models.

7 Results

7.1 ARIMA Results

As stated previously, multiple p and q parameters were attempted in the ARIMA modeling. After multiple different combinations were attempted, it was determined that there is no autoregressive component of the data. Seasonality was determined to have an impact, with seasonal parameters of (1,1,1). For the moving average parameter, Table 2 shows the results of the simple and full models RMSEs on the validation set with different q parameters. Recall, the simple model is a purely statistical and does not include the exogenous variables, while the full model includes all the external factors. As can be seen from Table 2, the best performing q was twelve for the simple model and eleven for the full model and it is apparent that the full models perform much better than the simple models, confirming the hypothesis that selected explanatory variables do have an effect on the price of boxed chuck.

Figure 5 shows the performance of the full ARIMA model predictions against the test set. The model performed fairly well, able to correctly predict every point within its 95% confidence interval, however the standard errors are quite large. Overall, this is a good sign in displaying the use of ARIMA modeling for predicting boxed beef prices, but first it must be compared to a simpler linear regression to gauge the effectiveness of the increased complexity.

Name	Type	q	RMSE
Model 1	Simple	9	75.98
Model 2	Simple	10	65.28
Model 3	Simple	11	57.56
Model 4	Simple	12	55.19
Model 5	Full	9	29.36
Model 6	Full	10	29.31
Model 7	Full	11	28.31
Model 8	Full	12	28.48

Table 2: ARIMA model RMSEs broken down by type and q parameter.

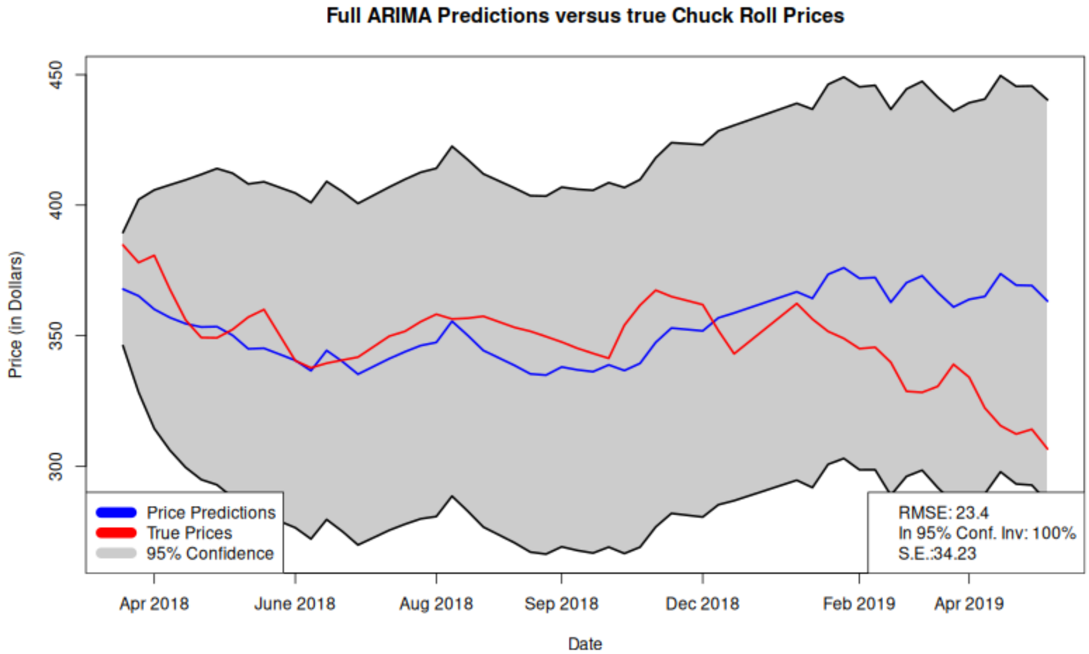


Figure 5: Forecast of Full ARIMA Model with q=11

7.2 Linear Regression Results

First, a model was created using every lag identified in Table 1, but this model had issues with correlated variables and many coefficients were unable to be estimated as there were singularity issues. Because of this, the stepAIC function in R was used to reduce the model. The final model had a validation RMSE of 29.49 compared to 23.18 of the full model. However, since there was an issue with singularities in the full model, it was not used in testing as interpretable coefficients were desired. The coefficients and p-values can be seen in Table 3, the model had an adjusted R^2 of 0.94. Next, the reduced model was re-estimated using the entire training and validation sets combined,to produce a set of predictions to measure against the test set. The resulting forecast can be seen in Figure 6. This model has a higher RMSE than the ARIMA model and the standard errors are much lower, causing the true prices to rarely fall within the 95% confidence interval. This model performed slightly worse than the ARIMA, but it does have coefficients with interpretable meanings, which may be of use to a firm when making quick estimates.

As hypothesized, the cattle auction prices, for the most part, do have a statistically significant effect on the prices of wholesale beef. The signs of the coefficients for cattle prices is interesting, steer and bull prices positively effect price while heifers and cows affect negatively. This warrants more attention if a follow up to this project were to be made. Another interesting finding from this model was the lack of any cattle weight variables, all had been dropped from the model for insignificance. This could be due to the fact that cattle auction prices are already measured in hundred weight so the animal weight might not be as important. Along with this, the only head variable that was kept in the model was that of heifers from forty weeks prior, with a negative coefficient. This lines up with economic theory, as more feeder heifers are sold to feedlots, more beef cattle become available, thus the market price should fall and lower production costs for packers. Another trend in the results was the importance of the time of year, the summer months all had negative coefficients, while the winter and fall months had positive coefficients (barring December, which is not statistically significant). This may only be true of the cut chosen for this project, but it would be interesting to see if this trend is true more broadly. Finally, both expenditures and pork prices were dropped from the model, yet chicken remained and is highly significant. Retail chicken breasts prices have a large effect on the price of wholesale beef. The coefficients may seem high, but the chicken breasts have a mean real price of only about $1.80 per pound in 2023 dollars and a standard deviation of 9 cents, meaning there is never a full dollar increase in price. These results would be expected since chicken and beef are substitutes; when the price of chicken rises more people will buy beef, this increase in demand causes an increase in equilibrium price. Overall, the model performed well in one way, but underperformed the ARIMA in another. Now, as the discussion moves to the composite forecast, the hope is to have a balance in performance.

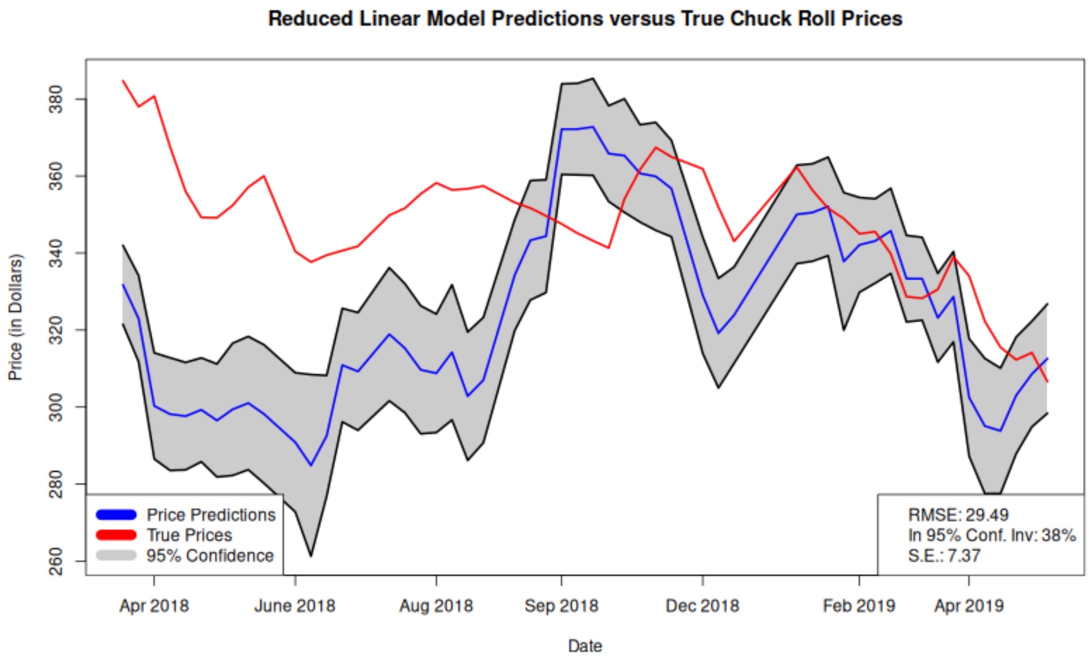


Figure 6: Forecast of Reduced Linear Regression Model

7.3 Composite Forecast

The composite forecast is a simple 50/50 weighting of the predictions and confidence interval of the previous two forecasts. An even split was chosen as the goal is to minimize the RMSE and maximizing the amount of data in the confidence interval, while minimizing the standard errors to get a more concise forecast. This model was a slight success, as seen in Figure 7. It not only has a lower RMSE than both other models, it has a much smaller confidence interval and still contains 92% of the true points. This shows promise for a composite forecast being a sensible option to explore further with more research.

8 Conclusions

The goal of this paper was to prototype a model to forecast wholesale beef prices, in this case focusing on the cut choice chuck, roll. This was without a doubt a success, ARIMA

Variable, Lag	Coefficient	P-value	Significant ($\alpha = 0.05$)
Steers Price, 4	0.65	1.3e-5	Y
Steers Price, 35	0.44	0.035	Y
Heifers Price, 37	-0.26	0.18	N
Cows Price, 28	-2.60	1.02e-11	Y
Bulls Price, 18	0.61	4.67e-6	Y
Bulls Price, 28	1.27	1.13e-5	Y
Feeder Price, 8	0.13	.1319	N
Feeder Price, 47	0.05	.316	N
Heifers Head, 40	-0.02	7.15e-7	Y
Chicken, 26	40.58	0.04	N
Chicken, 42	185.50	2.66e-16	Y
Feed Stuff Corn, 12	0.23	.003	Y
Feed Stuff Corn, 13	-0.17	0.03	Y
January	25.92	2.84e-8	Y
February	10.60	0.02	Y
April	-18.79	3.82e-5	Y
May	-26.22	9.72e-8	Y
June	-26.26	8.59e-9	Y
July	-24.68	3.11e-7	Y
August	-18.36	7.36e-6	Y
October	22.97	8.78e-8	Y
November	22.89	3.44e-07	Y
December	-1.07	0.82	N

Table 3: Reduced Linear Model coefficients and p-values

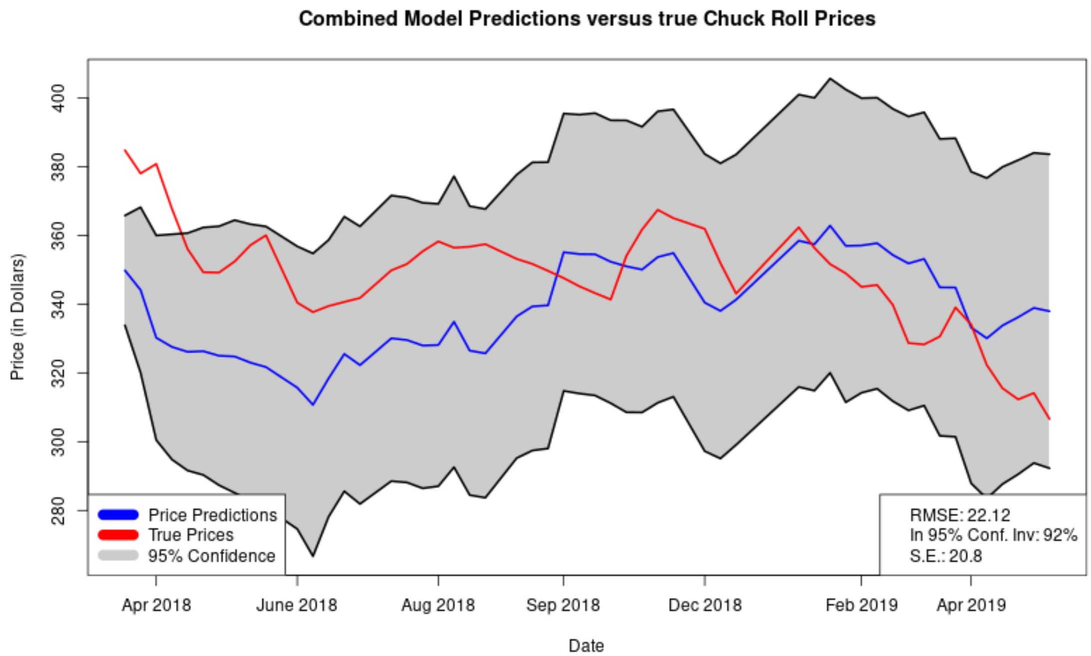


Figure 7: Composite Forecast of Chuck Roll Prices

modeling proved very useful and powerful in predicting prices accurately. However, it did so at the expense of large standard errors, giving wide ranges in th 95% confidence interval. This was contrasted by the linear regression model, which had a higher RMSE but much smaller standard errors and interpretable coefficients. Creating a composite forecast of these two models proved useful, it had much smaller standard errors, and even a lower RMSE than either individual model. There is more that could be explored here, and a more accurate forecast is definitely possible. Further investigation of this topic is warranted, but for now it has clearly shown its value in a business setting. Any business that wants to try to predict coming beef prices could follow a similar strategy to the one in this paper. All of the data was publicly available, discussed further in Appendix I, and all tools used were in R, an open source programming language.

If this paper were to get follow up research, other market forces should be investigated. This includes the rising demand for organic beef and the possibilities of lab grown meat, which are hypothesized to have a major impact on the beef market. Also, a greater understanding of how these markets work and interact with each other. In Figures 9, 12, 18, 15, and 21 there is a noticeable spike in the price of all cattle type used in this project. Along with this, in Figures 11, 14, 20, and 23 there is a large decline in the total head counts of the fed cattle. These must have large effects on the price of wholesale beef that should be investigated. There are many other questions that could be addressed, but for now there is a working prototype forecasting tool that can only get better.

Acknowledgments

I would like to acknowledge and give thanks to my advisor and professor Dr. Harry J. Paarsch. The assistance provided and knowledge shared on the methods of going about economic analysis and structuring of a research project was vital in getting this paper created. Also, for his previous research in which some of this paper relied on.

I also would like to give thanks to Dr. Leeland Morin, Dr. Michael Tseng, and Dr. Majid Mahzoon of the University of Central Florida Economics Department for the courses they taught as a part of my masters program, and my fellow course mates for the support structure we all provided each other.

Finally, I would like to thank my family for their support over my time in this program. It has not been easy on them, and yet they have stood by me through it all and I know they will stand by me into the future.

Appendices

I - Data Appendix

This appendix will discuss the data used in this paper, its sources, structure, and manipulations. The amount of raw data used in this project is much to vast to include in this appendix, however all data is available upon request. All reports of boxed beef and cattle sales are mandatory reported to the United States Department of Agriculture (USDA)

Wholesale Beef: Sourced from the USDA Agricultural Marketing Service (AMS), via their tool Market News available to use online, please see in references. This data was gathered by the *National Weekly Boxed Beef Cuts - Formulated Sales*, and *National Weekly Boxed Beef Cuts - Negotiated Sales* reports. Formulated sales are those that followed a preset pricing framework and negotiated are sales that where buyer and seller reach an agreement through classical bartering. The information included in these reports include grade, report date, item description, total pounds traded, the high and low prices, and the weighted average. The data is aggregated by grade, item description, and then report date. Grade is a USDA enforced measure of marbling in the meat, the grades used gathered for this paper were choice and select. The date range used for this project was weekly June 2002 to June 2024, not all of which ended up being used. The item description is the Institutional Meat Purchase Specifications (IMPS) system, a code that includes three numbers and a letter specifying the primal and sub-primal cut, and an optional last number for further specification, such as the trim level. For example, the cut used in this project was 116A 3; 116A specifies Chuck roll, and 3 refers to the fat trim, in this case lxl, neck/off. So 116A 3 is Chuck, roll lxl, neck off [1]. The total pounds is the amount of that grade cut was sold in the market since the last report, measured in pounds. Then they report the high, low and weighted average price, measured by dollars per hundredweight.

[1] lxl - lip off, extra lip meaning the outer fat on the edge is not trimmed all the way down, and even extra than normal.
neck/off - The neck muscles connected to the chuck has been removed

Item Description	Average Price	Min Price	Max Price
Loin, tndrloin, trmd, heavy (189A 4)	$1,003.53	$558.28	$1,807.33
Rib, ribeye, bnls, heavy (112A 3)	$694.42	$384.29	$1,468.82
Rib, ribeye, lip-on, bn-in (109E 1)	$617.11	$337.34	$1,326.09
Loin, strip, bnls, 0x1 (180 3)	$580.53	$369.13	$1,110.86
Loin, bottom sirloin, flap (185A 4)	$482.66	$233.05	$1,075.58
Loin, top butt, boneless (184 3)	$314.03	$176.97	$714.31
Loin, strip loin, 1x1 (175 3)	$483.07	$293.69	$930.29
Chuck, roll, retail ready (916A 3)	$289.42	$139.62	$658.99
Chuck, shoulder clod, trmd (114A 3)	$205.99	$100.47	$664.84
Chuck, roll, lxl, neck/off (116A 3)	$246.23	$116.73	$623.79
Chuck, clod, arm roast (114E 3)	$265.28	$148.28	$800.94
Loin, top butt, 2 pc. bnls (184E 3)	$366.84	$279.58	$560.45
Rib, ribeye, bnls, light (112A 3)	$704.63	$393.51	$1,462.88
Chuck, clod, top blade (114D 3)	$314.61	$139.77	$649.89
Round, eye of round (171C 3)	$241.07	$130.02	$651.10
Loin, butt tender, trimmed (191A 4)	$958.72	$563.38	$1,718.31
Round, knuckle, peeled (167A 4)	$231.20	$122.98	$628.00
Round, top inside round (168 1)	$209.51	$108.30	$638.99
Flank, flank steak (193 4)	$486.27	$258.89	$958.40
Loin, sirloin, tri-tip, pld (185D 4)	$440.78	$248.59	$852.41
Chuck, chuck tender (116B 1)	$220.43	$110.89	$591.25
Chuck, semi-bnls, neck/off (113C 1)	$129.64	$0.00	$180.94
Chuck, flap (116G 4)	$641.46	$320.87	$896.58
Chuck, semi-bnls n/o sh-cut (3)	$205.27	$183.18	$230.75
Rib, roast-ready, heavy (109A 1)	$367.74	$274.94	$511.65
Loin, top inside round (168 3)	$217.26	$117.52	$638.63
Round, top inside, side off (3)	$251.51	$160.08	$667.30
Loin, ball-tip, bnls, heavy (185B 1)	$281.41	$163.13	$571.02
Round, top inside, denuded (169 5)	$252.92	$135.66	$689.80
Chuck, 2-piece, boneless (115 1)	$183.25	$98.43	$322.93
Chuck, clod tender (114F 5)	$281.46	$0.00	$835.21
Round, knuckle (167 1)	$162.43	$110.43	$243.76
Round, bottom gooseneck (170 1)	$218.04	$98.76	$622.20
Loin, strip loin bnls. 1x1 (1)	$444.78	$0.00	$796.48
Chuck, clod, neck/off (114A 3)	$205.99	$100.47	$664.84
Loin, top butt, CC (184B 3)	$484.46	$336.52	$1,026.55
Loin, ball-tip, bnls, light (185B 1)	$184.04	$123.21	$267.71
Chuck, clod, top blade (114D 3)	$314.61	$139.77	$649.89
Round, boneless (161 1)	$195.63	$0.00	$592.12
Round, top inside, cap off (169A 5)	$354.27	$263.23	$813.83
Round, top inside, side off (3)	$251.51	$160.08	$667.30

Table 4: Summary Price Statistics for Boxed Beef Cuts, sorted by Average Price.

Item Description	Average Quantity	Total Quantity	Min Quantity	Max Quantity
Chuck, roll, lxl, neck/off (116A 3)	1,207,219.29	1,395,545,494	531,087	2,082,494
Brisket, deckle-off, bnls (120 1)	1,152,273.74	1,332,028,445	215,089	2,953,745
Loin, strip, bnls, 0x1 (180 3)	876,520.99	1,012,381,750	157,746	2,086,189
Chuck, shoulder clod, trmd (114A 3)	732,109.02	845,585,914	168,924	1,614,182
Rib, ribeye, bnls, heavy (112A 3)	874,289.18	1,010,678,295	135,311	1,701,853
Rib, ribeye, lip-on, bn-in (109E 1)	694,862.52	802,566,209	81,252	4,036,270
Round, outside round (171B 3)	853,793.26	986,985,011	320,460	1,647,582
Flank, flank steak (193 4)	396,368.30	346,425,898	172,893	608,380
Loin, bottom sirloin, flap (185A 4)	594,550.12	533,311,455	119,088	1,187,969
Loin, ball-tip, bnls, heavy (185B 1)	581,288.27	468,518,347	196,798	1,167,306
Loin, top butt, boneless (184 3)	478,008.40	552,099,697	130,219	1,176,671
Round, eye of round (171C 3)	766,636.20	886,231,451	101,897	1,412,210
Rib, ribeye, bnls, light (112A 3)	258,222.04	298,246,459	12,954	867,332
Loin, strip loin, 1x1 (175 3)	161,049.66	181,502,963	1,012	1,302,430
Loin, short loin, 0x1 (174 3)	438,039.71	506,373,899	61,203	1,500,822
Loin, tndrloin, trmd, heavy (189A 4)	449,045.06	518,647,042	48,559	1,112,744
Chuck, chuck tender (116B 1)	378,753.88	437,460,735	146,843	941,763
Chuck, roll, retail ready (916A 3)	654,937.99	633,325,040	116,337	2,491,778

Item Description	Average Quantity	Total Quantity	Min Quantity	Max Quantity
Loin, top inside round (168 3)	524,693.74	606,545,962	101,779	1,761,806
Chuck, short rib (130 4)	358,913.55	402,342,090	4,958	792,391
Round, top inside round (168 1)	661,741.91	764,973,643	18,904	1,517,093
Chuck, clod, arm roast (114E 3)	206,190.81	230,727,517	1,692	928,658
Loin, ball-tip, bnls, light (185B 1)	14,228.63	2,817,268	1,429	86,485
Round, knuckle, peeled (167A 4)	890,715.73	1,028,776,668	317,653	1,466,893
Round, top inside, cap off (169A 5)	379,193.19	150,160,502	161,196	747,671
Loin, sirloin, tri-tip, pld (185D 4)	340,631.72	305,546,649	70,296	645,595
Loin, top butt, 2 pc. bnls (184E 3)	56,980.47	10,028,562	8,051	545,351
Round, top inside, denuded (169 5)	294,081.46	339,664,082	28,140	797,058
Loin, butt tender, trimmed (191A 4)	129,045.37	149,047,403	18,789	310,168
Loin, top butt, CC (184B 3)	169,216.84	67,009,869	2,047	507,086
Chuck, semi-bnls, neck/off (113C 1)	246,038.06	34,691,366	0	418,470
Round, top inside, side off (3)	110,945.18	99,184,989	4,174	402,187
Chuck, clod tender (114F 5)	41,184.72	8,195,759	0	111,857
Chuck, clod, top blade (114D 3)	76,290.69	77,816,499	4,610	199,776
Rib, roast-ready, heavy (109A 1)	19,102.61	2,005,774	5,983	36,146
Round, boneless (161 1)	37,234.60	37,606,941	0	528,536

Item Description	Average Quantity	Total Quantity	Min Quantity	Max Quantity
Chuck, 2-piece, boneless (115 1)	83,597.29	61,694,797	2,390	666,472
Round, knuckle (167 1)	28,679.55	11,070,308	1,257	315,880
Round, bottom gooseneck (170 1)	25,786.79	21,635,119	1,377	391,728
Loin, strip loin bnls. 1x1 (1)	96,212.55	10,294,743	0	155,693
Chuck, flap (116G 4)	105,794.47	41,894,609	19,161	242,241
Chuck, semi-bnls n/o sh-cut (3)	15,564.70	622,588	3,511	53,249
Round, bone-in (160 1)	7,080.28	5,027,001	0	46,513

Table 5: Summary Quantity Sold Statistics for Boxed Beef Cuts, sorted by Average Quantity.

Cattle Auctions: Also reported by USDA AMS Market News in the reports *National Weekly Fed Cattle Comprehensive Overview* and *National Feeder & Stocker Cattle Summary*, see references section for more information. The data included are report date, market location, class description, selling basis, quality, head count, weight ranges, weighted average weight, and high, low, and weighted average price. The data is aggregated by type, report date, market, and then weight range. The market location is the auction house that reported the sales to the USDA. The class description specifies what type of cattle is being sold and what the animal is being sold for (slaughter heifers, feeder steers, etc.) and selling basis is whether the animal was alive, dead, or dressed. Quality is a measure of fat on the animal; Steers and heifers use grade (choice, select, etc.), bulls use yield grade (a numeric system that measures the external fat depth), and cows use body condition scores which measures the dressing (how much of the weight comes from meat). Head count is the amount of cattle in a class description that fall into the same weight class, which are predetermined weight ranges. measured in pounds. Finally, it reports the weighted average weight in pounds and the high, low, and weighted average price per hundredweight of the cattle. Along with this cattle data, feedstuff corn prices are used to track cost of cattle feed. This data contains report date, location, and high and low bid prices. Location is the branch where the transaction was reported. And bid prices are the results of the auctions for corn.

Economic Data: Consists of the Consumer Price Index (CPI), retail chicken breast prices, retail pork chop prices, and personal consumption expenditures (PCE) from the Federal Reserve Economic Data by the Federal Reserve Bank of St. Louis, all links to these series can be found in the references. These variables include the report date, and all but one are reported on the first of the month while PCE is reported quarterly. The CPI measures the change in overall cost of a basket of goods consumers purchase, its use in this project is to convert all prices to real prices for better modeling. Retail chicken breast and pork chop prices are reported in price per pound. PCE measures the amount people spend nationally every quarter, measured in billions of dollars. All data was collected in the date range

Variable	Mean	Median	Variance	Standard Deviation
Chuck Prices	$300.38	$295.94	3,014.98	$54.91
Steer Weights	1,333.86	1,334.03	993.47	31.52
Steer Prices	$148.78	$145.49	477.75	$21.86
Heifers Weight	1,214.38	1,215.78	1,268.24	35.61
Heifers Price	$147.67	$144.53	474.42	$21.78
Cows Weight	1,168.27	1,169.57	1,536.51	39.2
Cow Prices	$84.22	$78.2	497.96	$22.31
Bulls Weight	1,613.02	1,611.89	1,757.94	41.93
Bulls Price	$108.79	$101.33	563.27	$23.73
Feeder Weight	679.35	679.55	1,496.88	38.69
Feeder Price	$189.75	$183.05	1,628.75	$40.36
Feedstuff Corn Price	$267.45	$240.51	4,944.66	$70.32
Pork Chop Prices	$4.7	$4.7	0.14	$0.37
Chicken Breasts Prices	$1.8	$1.79	0.01	$0.09
Household Expenditures	$52,227.34	$50,659.1	12,945,460.19	$3,597.98

Table 6: Summary Statistics of Relevant Numeric Variables

January 1st, 2000 to January 1st, 2020.

Data Manipulations: All price data were converted to 2023 prices using the standard formula, $real\ price = \frac{CPI(BaseYear)}{CPI(CurrentYear)} \times nominal\ price$, and using the CPI of 308.742 from December 2023. When the cattle data was selected for the model, it was aggregated by cattle type and report date and calculated weighted averages of weights, prices, and head count so there was one value for each date, using SQL. The feedstuff corn prices were the only series which was missing data, between February and October of 2015 and between April and October of 2016. This data was replaced using a method from the zoo package in R called na.approx, which would take the two values surrounding the missing data and make a linear set of points to fill the gap.

Below, Table 6 shows the summary statistics of the numeric variables used in this project. Please contact the author for any other questions.

II - Time Series Plots

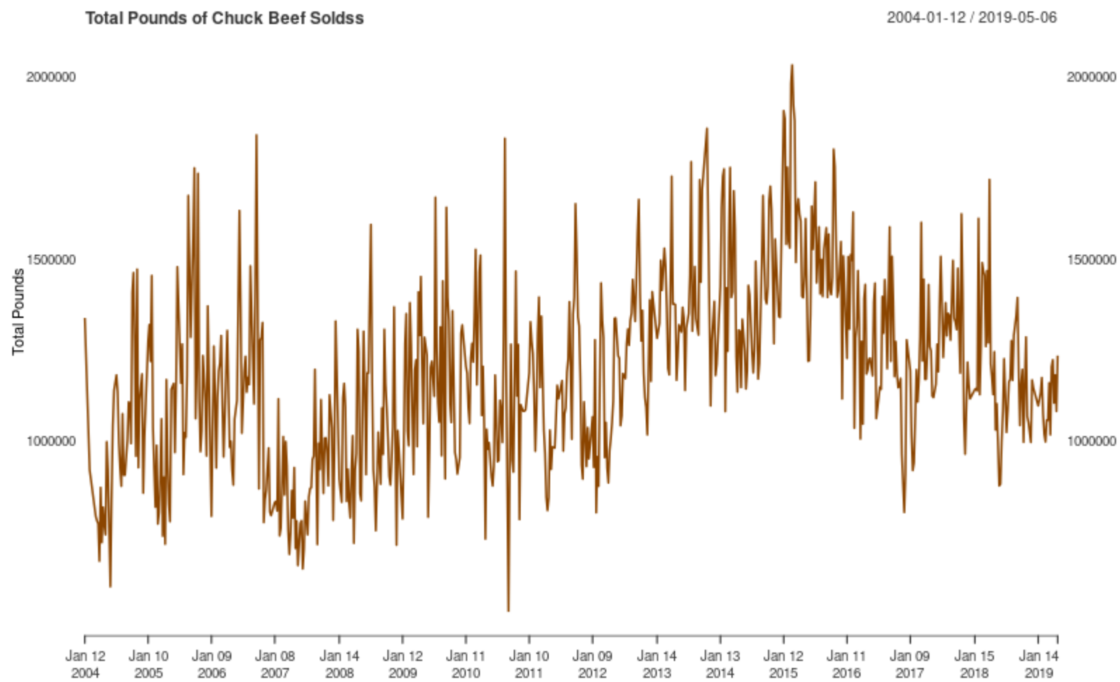


Figure 8: Time Series of Total Chuck, roll Sold

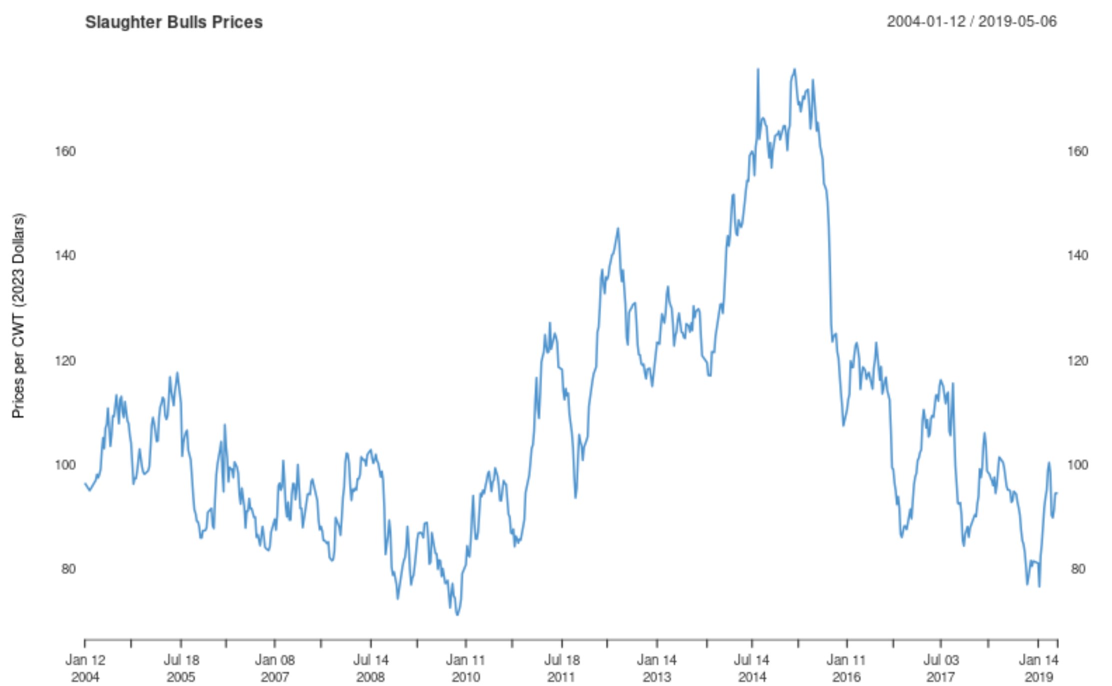


Figure 9: Time Series of Bull Real Prices

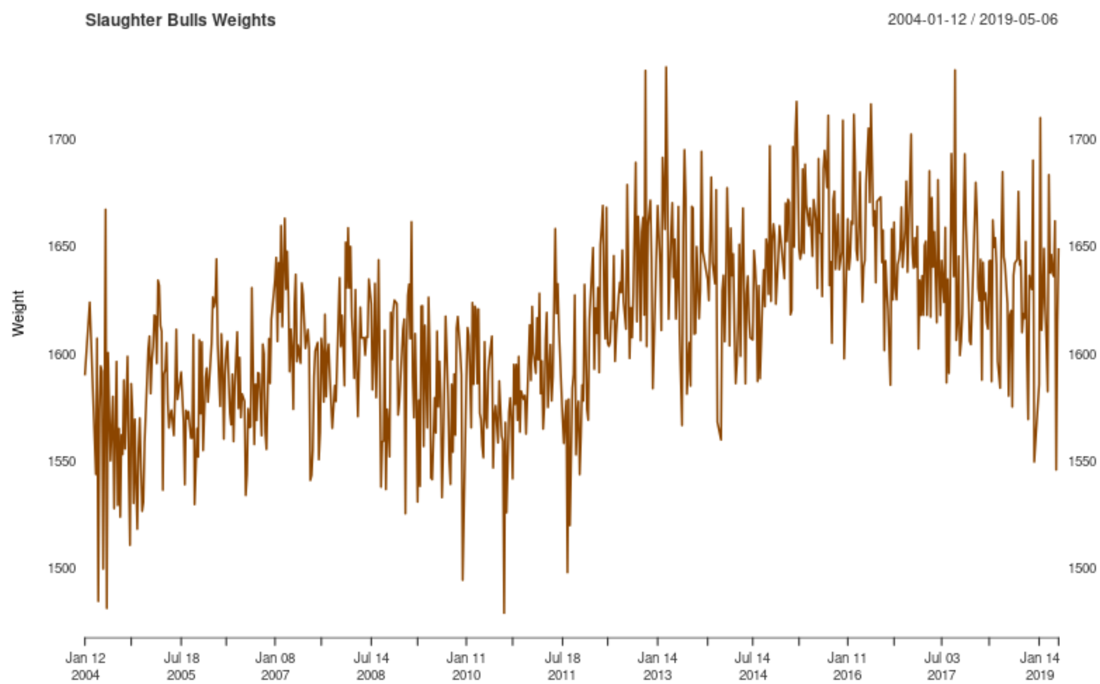


Figure 10: Time Series of Bull Weights

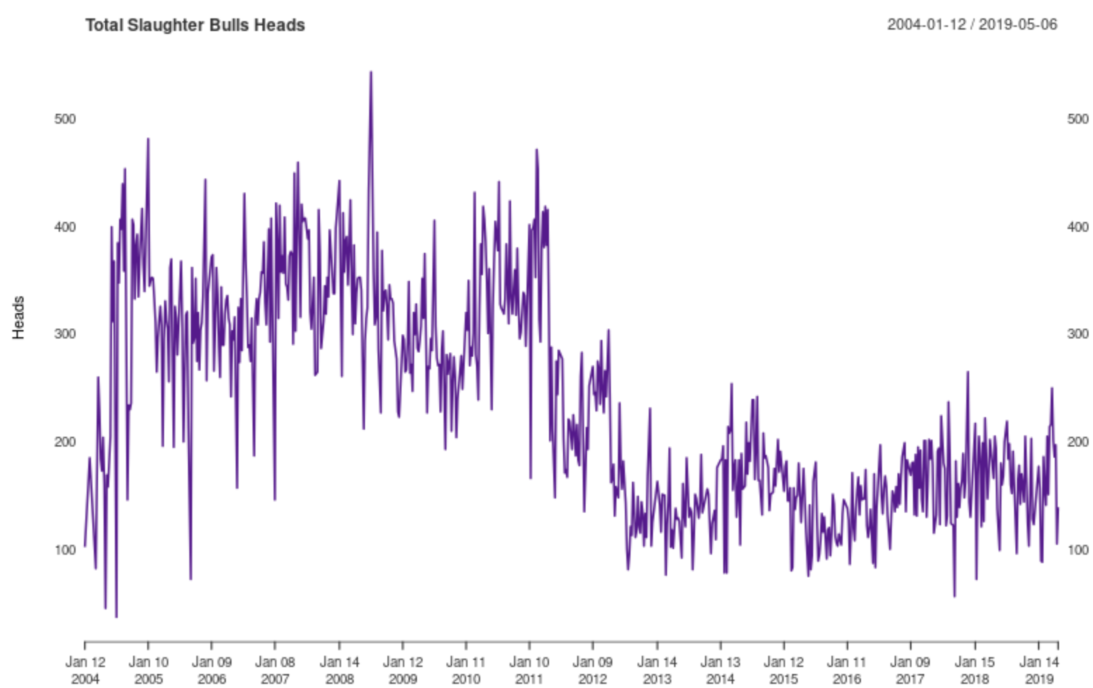


Figure 11: Time Series of Bull Head Sold

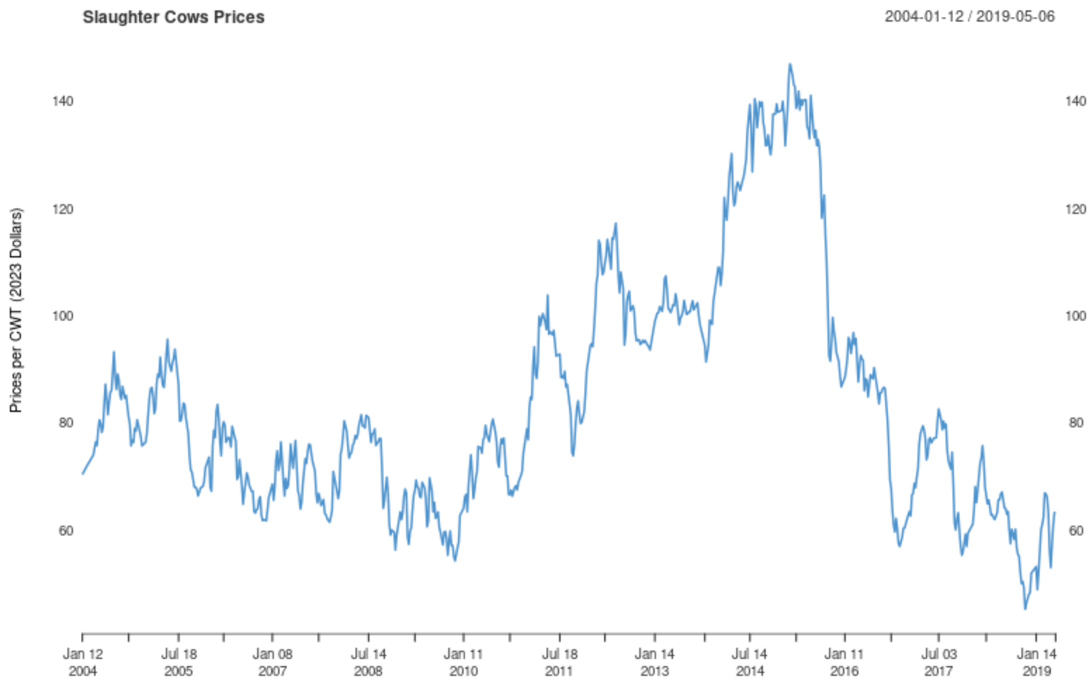


Figure 12: Time Series of Cow Real Prices

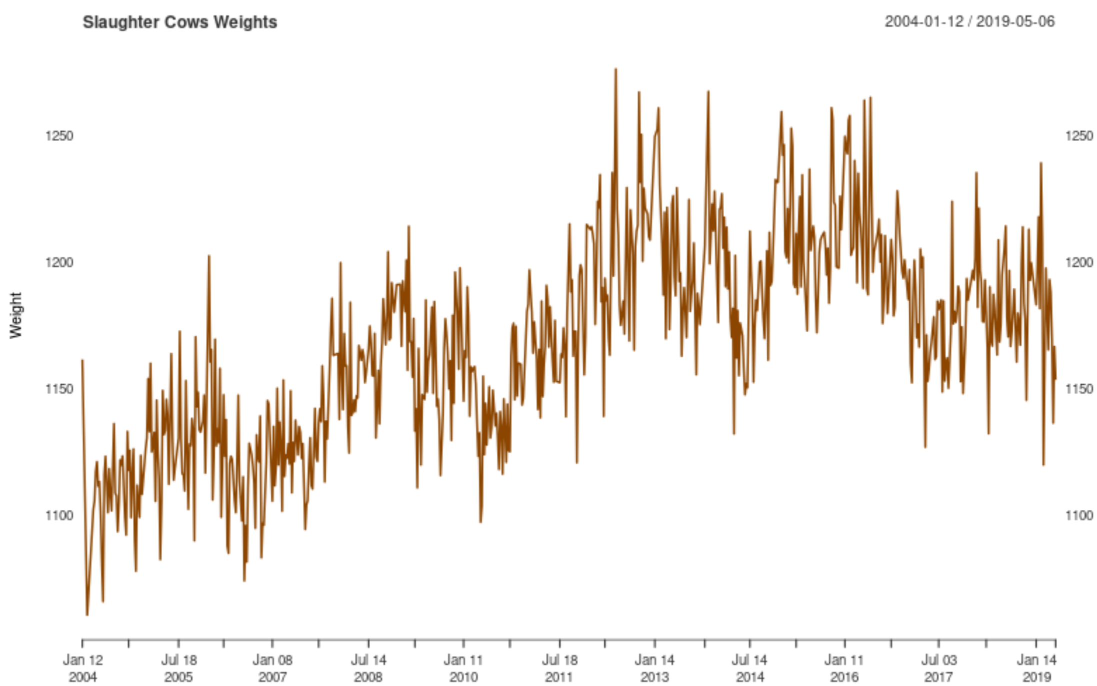


Figure 13: Time Series of Cow Weights

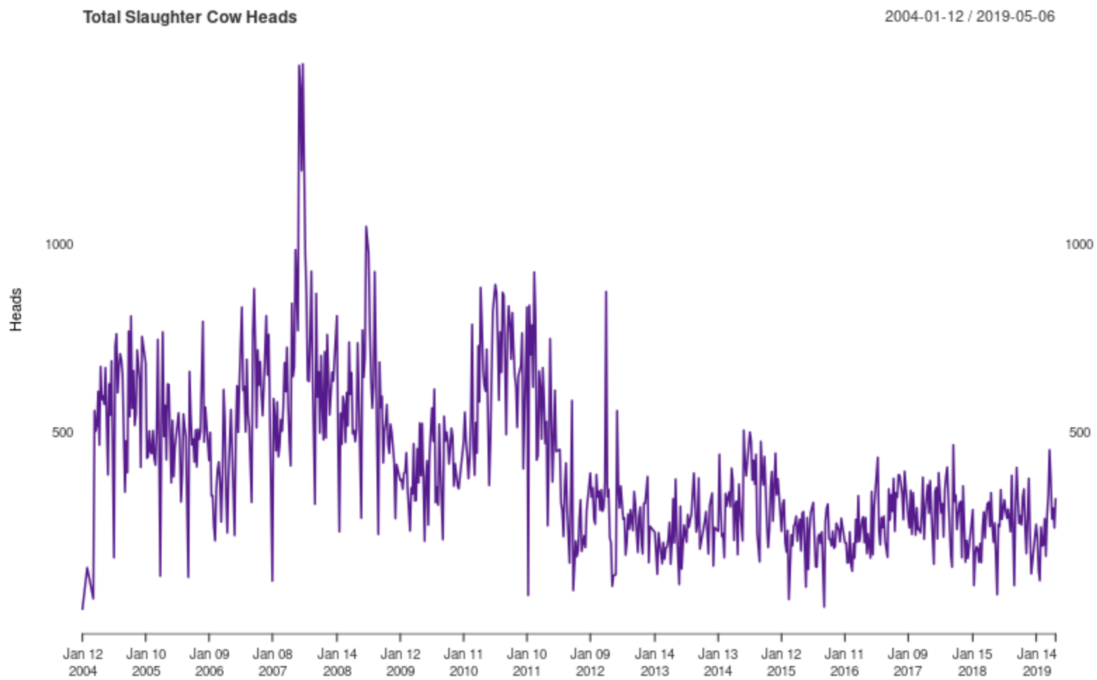


Figure 14: Time Series of Cow Head Sold

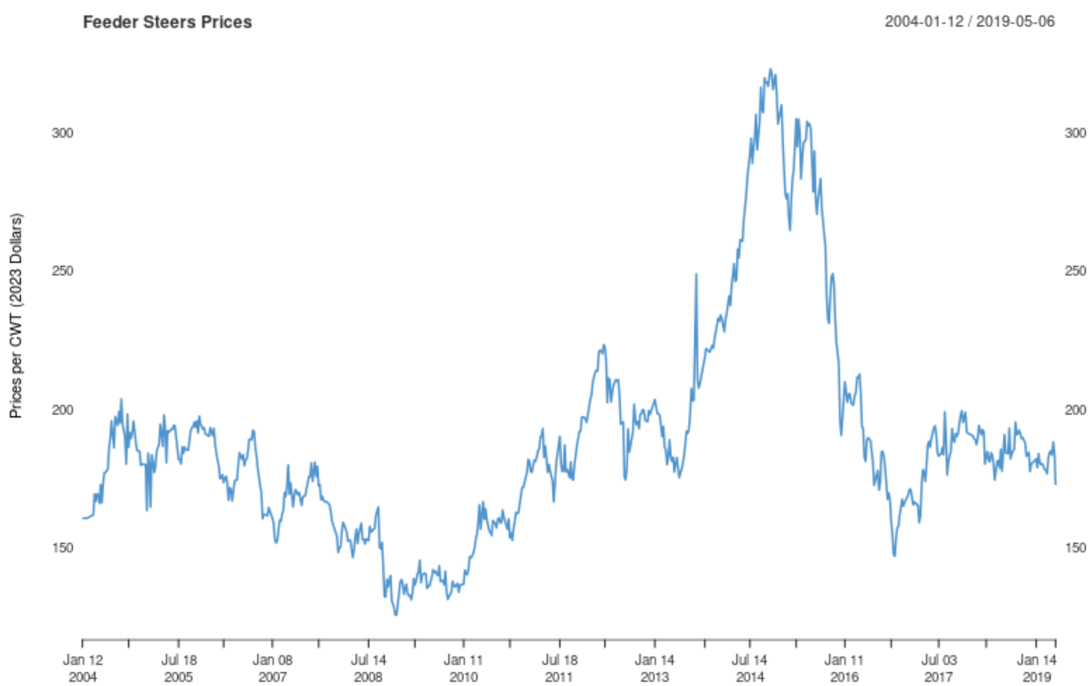


Figure 15: Time Series of Feeder Real Prices

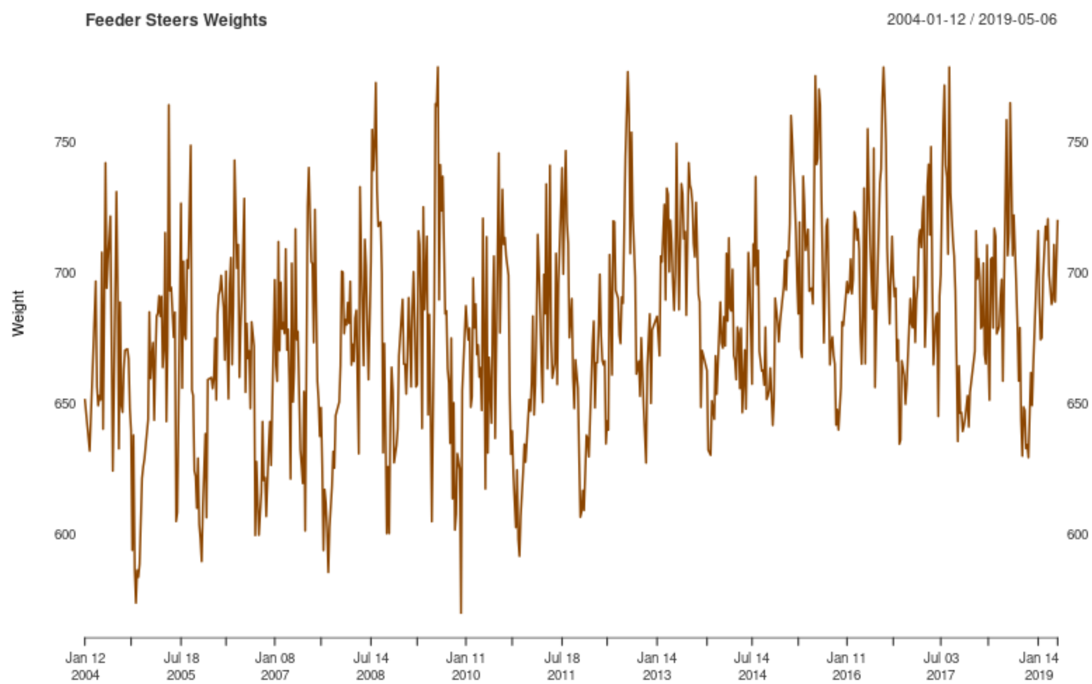


Figure 16: Time Series of Feeder Weights

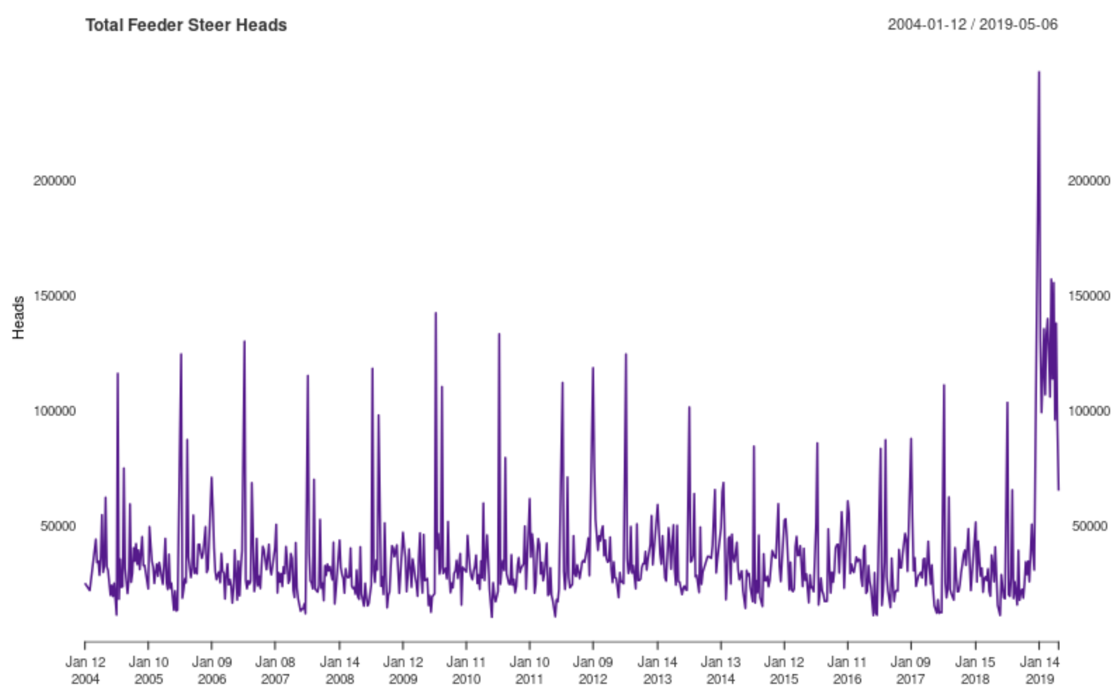


Figure 17: Time Series of Feeder Head Sold

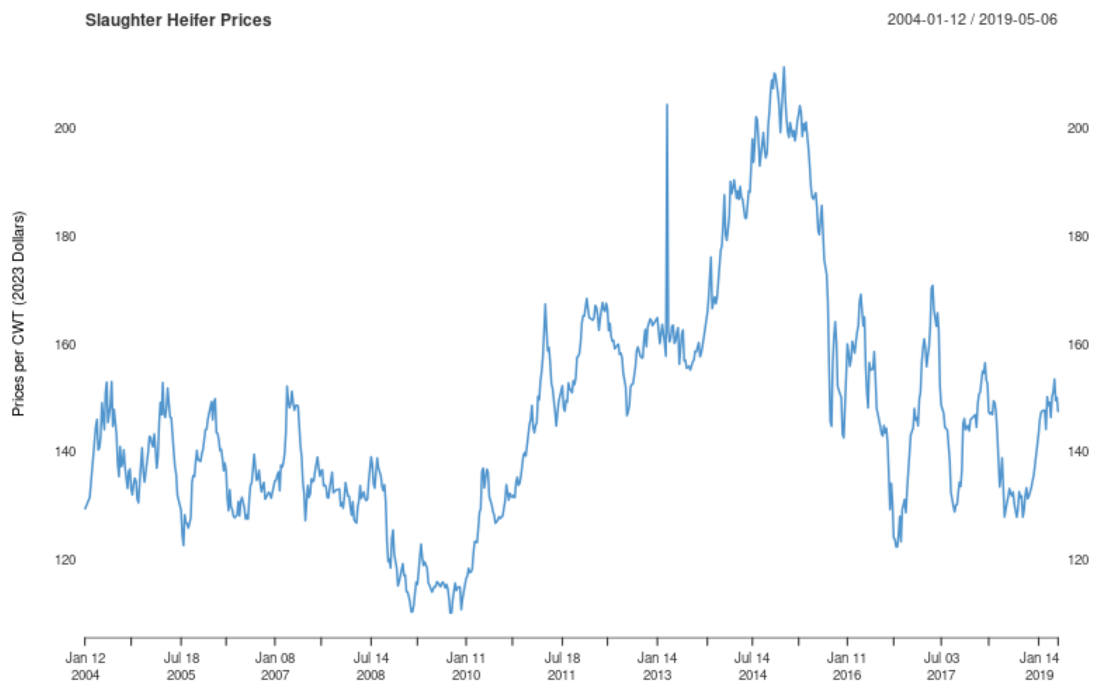


Figure 18: Time Series of Heifer Real Prices

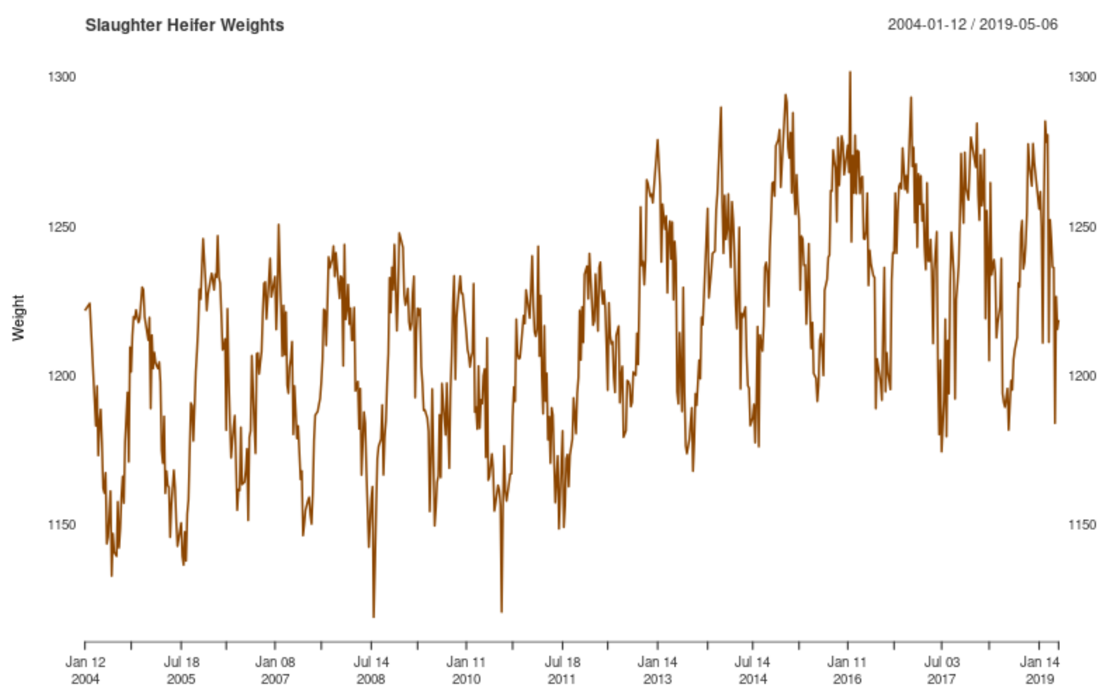


Figure 19: Time Series of Heifer Weights

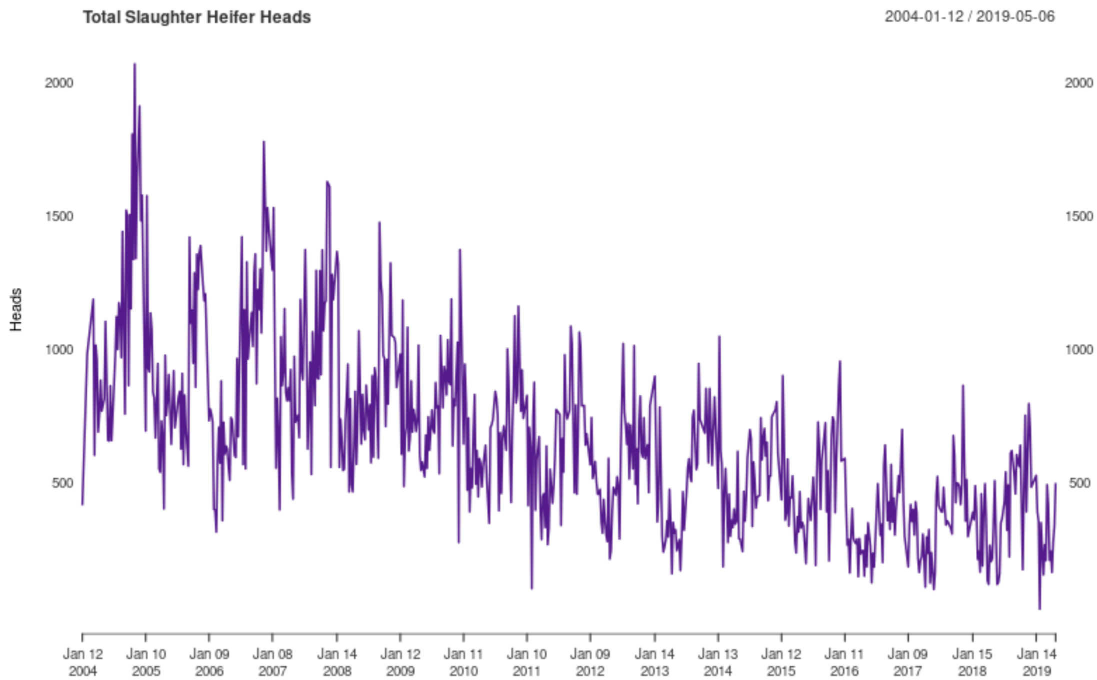


Figure 20: Time Series of Heifer Head Sold

Figure 21: Time Series of Steer Real Prices

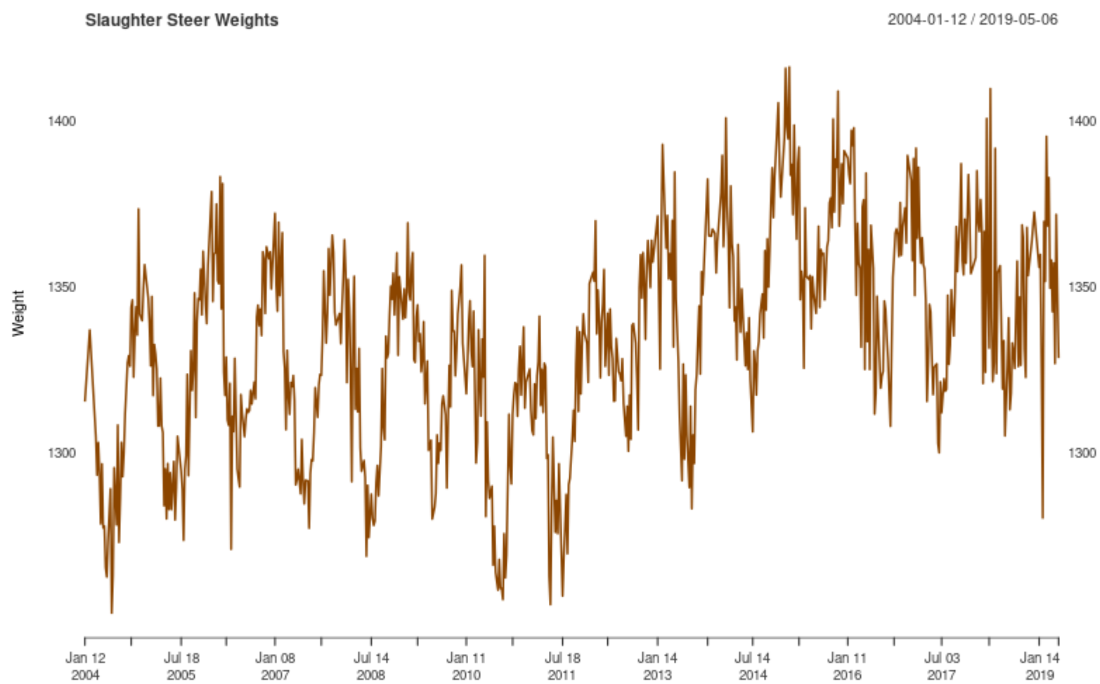


Figure 22: Time Series of Steer Weights

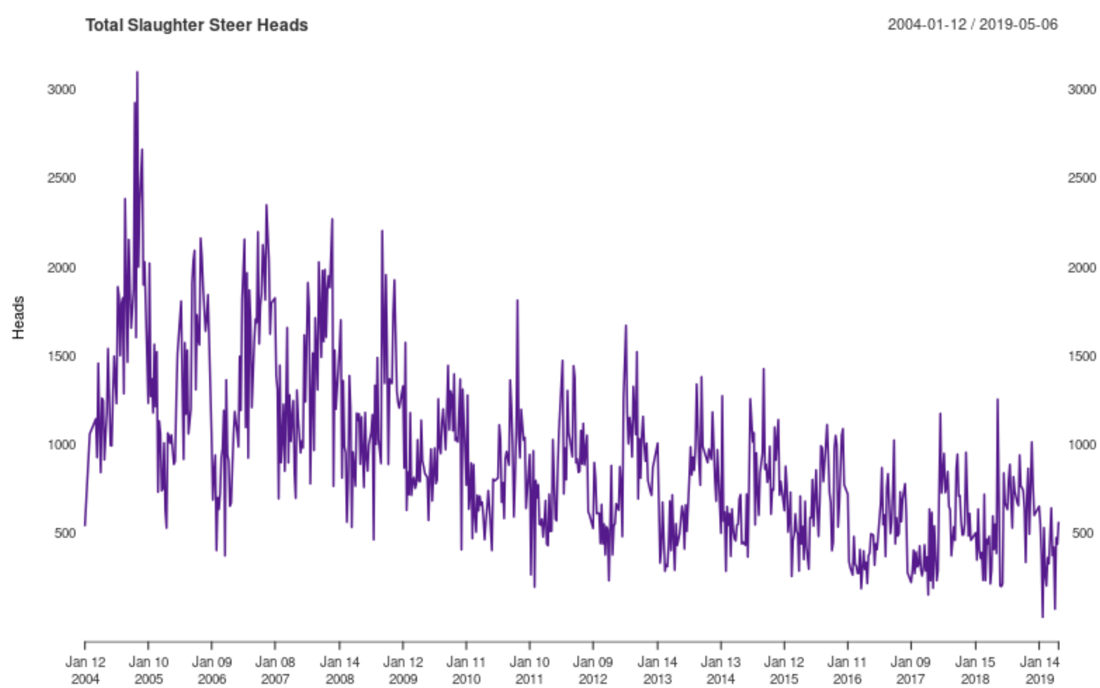


Figure 23: Time Series of Steer Head Sold

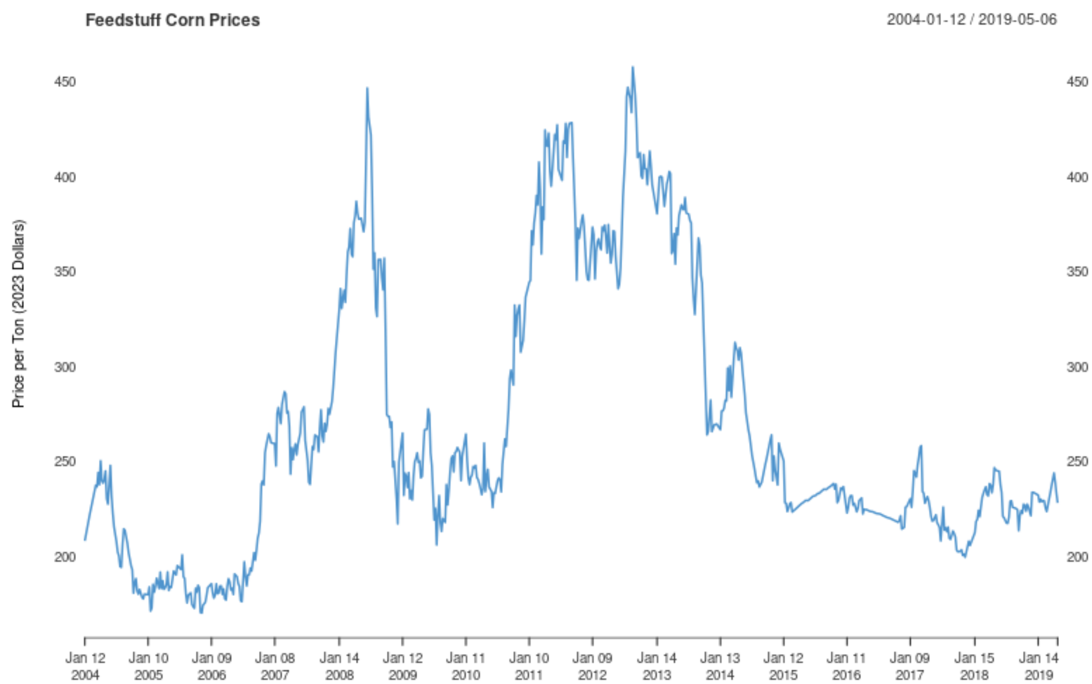


Figure 24: Time Series of Corn Real Prices

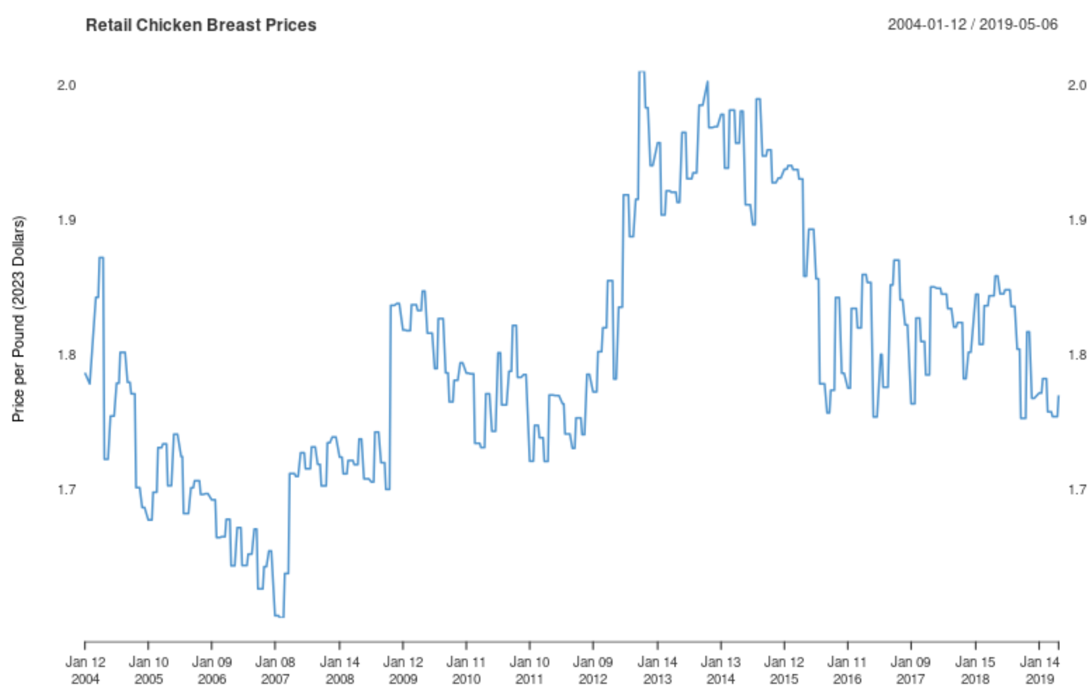


Figure 25: Time Series of Chicken Breast Real Prices

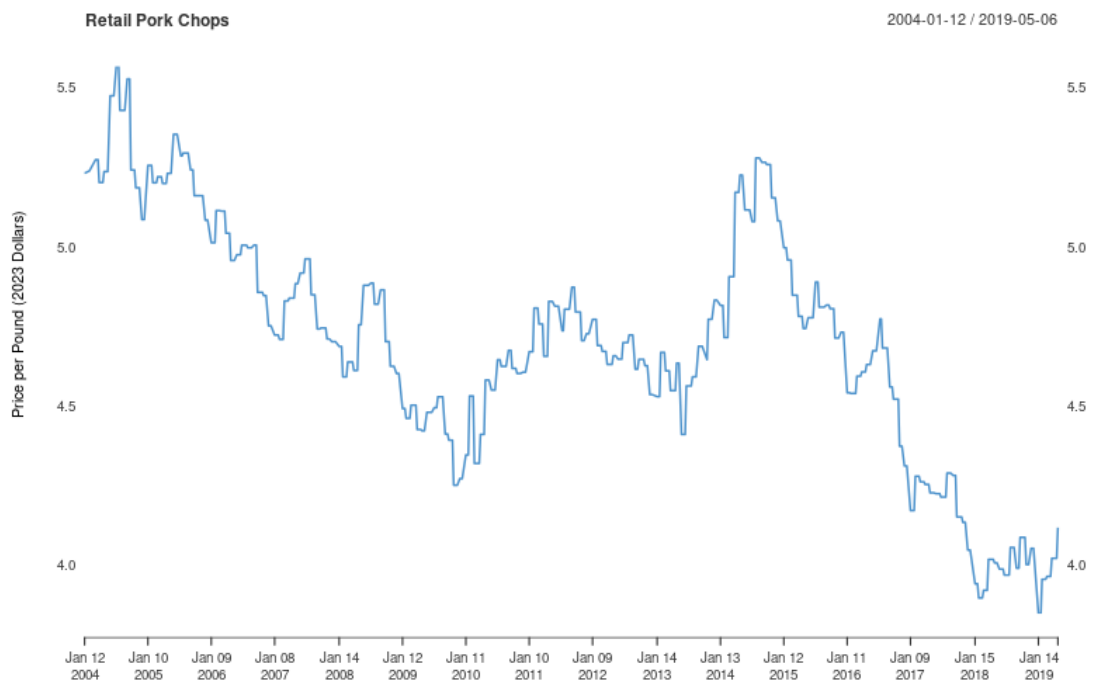


Figure 26: Time Series of Pork Chop Real Prices

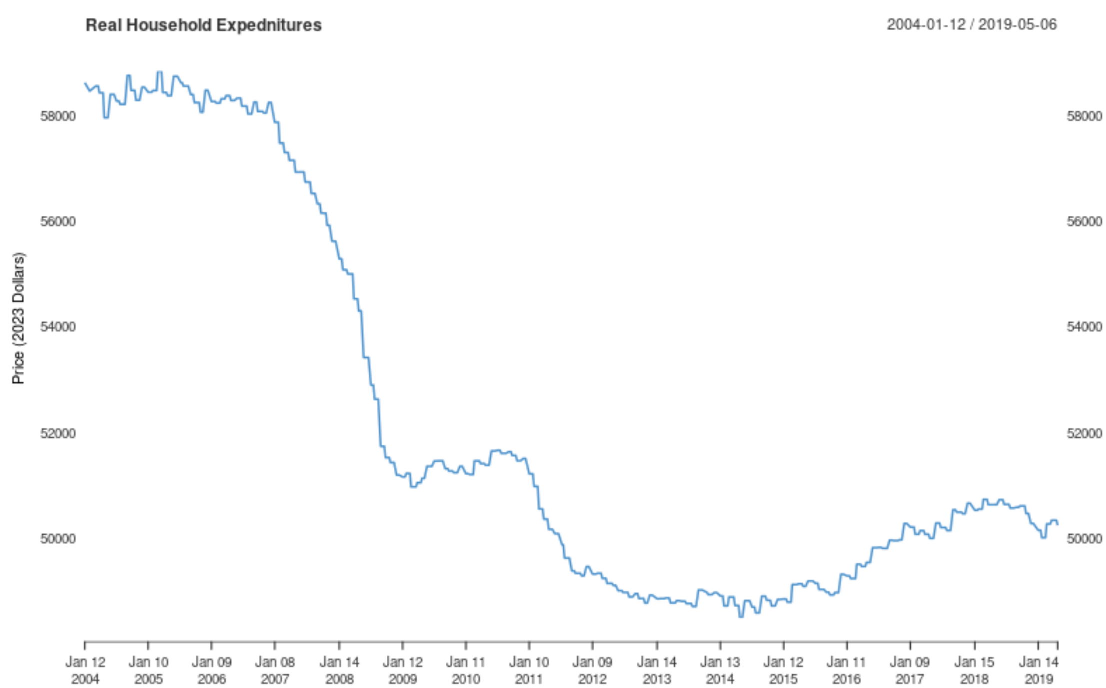


Figure 27: Time Series of Household Real Expenditures

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