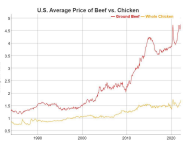
Forecasting the prices of beef and chicken in the United States

Presentation of Final Project for Statistical Consulting (STAT 684), Texas A&M University
by Ken Marciel, Spring 2022

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Introduction

- Conventional protein sources
- Escalating beef prices
- Growing popularity of chicken
- Effect of inflation on meat prices
- Effect on economy
  - Shift in consumer demand
- Effect on public policy
  - Public health
  - Environment

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Data source

- Federal Reserve Bank of St. Louis
- Economic Research
  - Average price data
  - U.S. Bureau of Labor Statistics

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Time series data sets

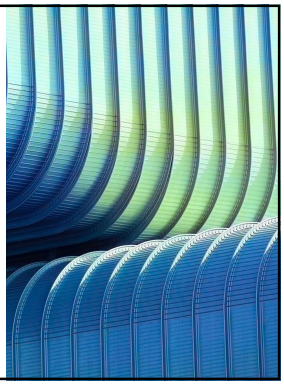
Monthly data

Average retail prices of food items in the United States

Cost in dollars per pound
- Not seasonally adjusted

100% ground beef
- January 1, 1984, to March 1, 2022
- https://fred.stlouisfed.org/series/APU0000703112

Fresh, whole chicken
- January 1, 1980, to March 1, 2022
- https://fred.stlouisfed.org/series/APU0000706111



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Partition of data sets

Forecast horizon	• 12 months
Training set	• Leave out last 12 months of data series • 447 months for beef, 495 months for chicken
Test set	• Last 12 months of data series • April 1, 2021 to March 1, 2022
Predicted value	• March 1, 2023

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Forecasting methods

Linear regression
- Coefficients estimated for predictors in equation
- Ordinary least squares (OLS) technique

Exponential smoothing
- Holt-Winters method

ARIMA
- Autoregressive Integrated Moving Average

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Evaluation metric for model comparison

- MAPE
  - Mean Absolute Percentage Error
  - Measures the average percentage of absolute error
- $MAPE = \frac{1}{n} \cdot \sum_{t=1}^{n} \left| \frac{Actual\ Price_t - Predicted\ Price_t}{Actual\ Price_t} \right| \cdot 100\%$
  - t, month in time series
  - n, number of months in time series
  - $\sum$, sum
  - $|\ |$, absolute value

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Software for data analysis

- R statistical computing software
- R software packages used
  - dplyr
  - dygraphs
  - forecast
  - imputeTS
  - lubridate
  - plotly
  - readxl
  - stats
  - TSstudio

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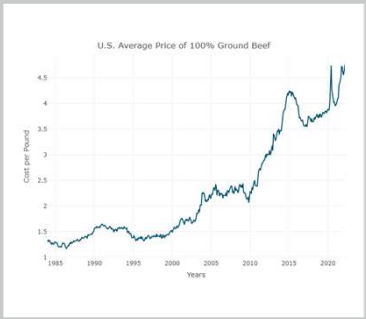
Price of beef over time

- 100% ground beef
- U.S. average monthly price
- Dollars per pound
- Time period
  - January 1, 1984
  - March 1, 2022
- 459 months
- Missing value
  - October 1, 2012
  - Imputed using linear interpolation



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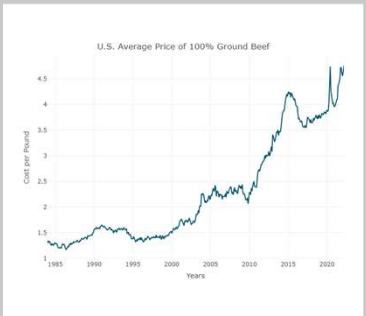
Price of beef over time

- Growing trend with embedded cycle
- Most recent cycle started in 2010
  - Near end of 2008 economic crisis
- No apparent seasonal component



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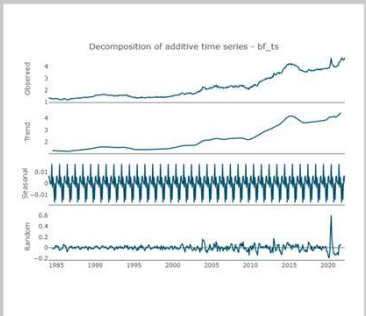
Decomposition of price series for beef

- Components
  - Trend (including cycle)
  - Seasonal
  - Random
- Impact of COVID-19 pandemic from 2020 to 2022 is conspicuous in both observed series and random component



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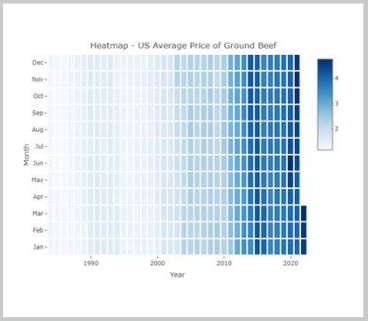
Seasonal analysis

- Heatmap
- Cyclic behavior
  - Across vertical bars
- Lack of seasonal behavior
  - Along horizontal bars



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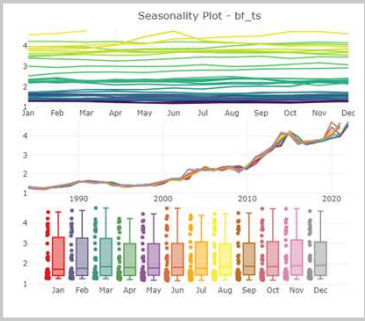
Seasonal plots

- Lack of seasonal pattern
  - Horizontal lines in standard plot
  - Rope appearance in cycle plot
  - Level pattern across box plots



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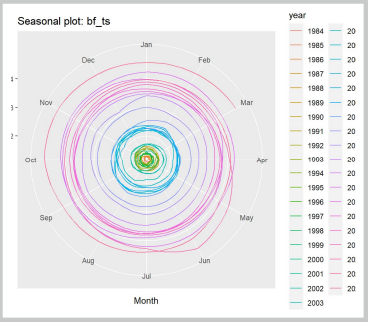
Polar plot

- Lack of seasonal behavior
  - Circular spiral pattern



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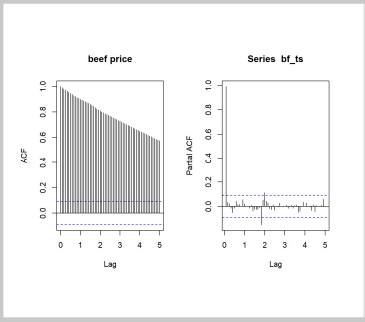
Correlation plots

- Correlation of series with lags
  - Gradual decay over time
  - No apparent seasonal component
- Lack of seasonality makes sense
  - Beef eaten year-round in U.S.



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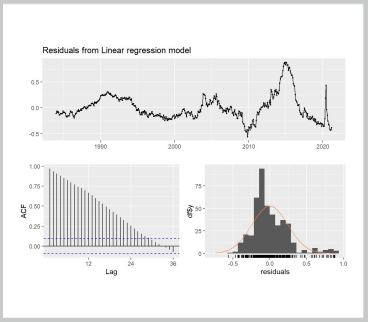
Benchmark for model selection

- Linear regression model
- $Price_t = \beta_0 + \beta_1 \cdot Trend_t + \beta_2 \cdot Trend_t^2 + \beta_3 \cdot Season_t + Irregular_t$
- Significant predictors
  - Intercept and trend
- Insignificant predictor
  - Season
- Series correlated with lags
- Not a valid forecasting model
- Useful as a benchmark
  - MAPE score = 3.07%



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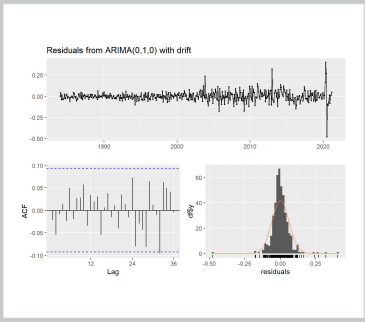
Selected forecasting model for beef prices

- ARIMA(0,1,0) with drift
  - Complex linear regression equation
    - Differences between adjacent terms
- MAPE score = 1.78%
- Valid forecasting model
- Series uncorrelated with lags
- Random component has a bell-shaped frequency distribution



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Predicted price of beef for March 1, 2023

- 100% ground beef
- U.S. average price
- Predicted price
  - **$4.19 per pound**
- Predicted price range
  - **$3.61 to $4.77 per pound**
  - 95% level of confidence

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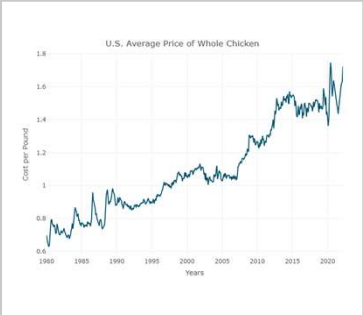
Price of chicken over time

- Fresh, whole chicken
- U.S. average monthly price
- Dollars per pound
- Time period
  - January 1, 1980
  - March 1, 2022
- 507 months
- Missing value
  - May 1, 2020
  - Imputed using linear interpolation



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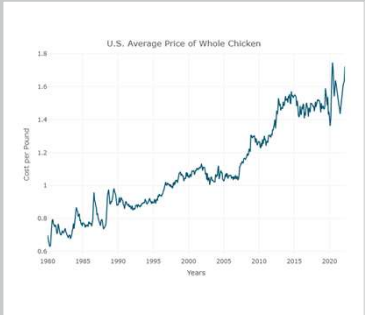

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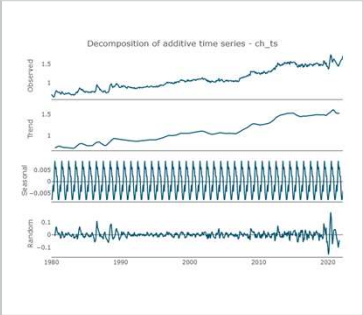

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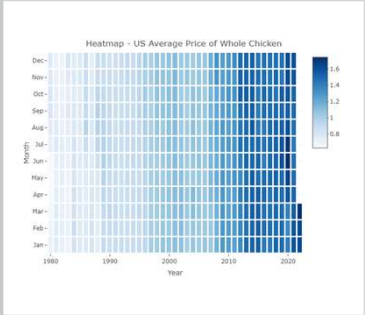

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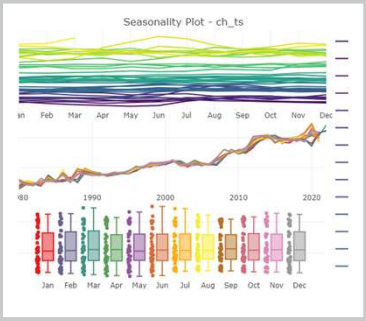

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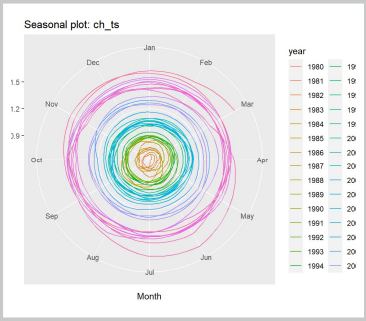

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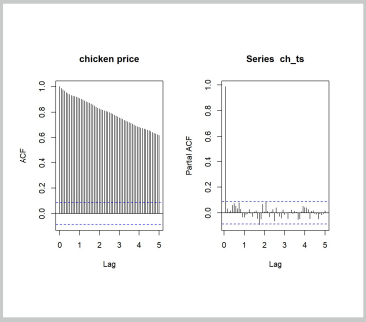

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- Significant predictors
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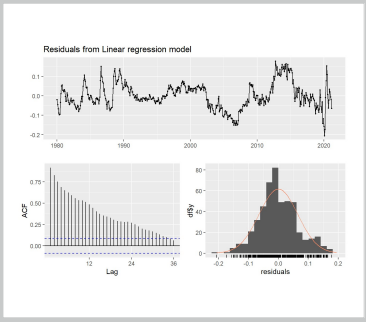
- Insignificant predictor
  - Season
- Series correlated with lags
- Not a valid forecasting model
- Useful as a benchmark
  - MAPE score = 6.51%



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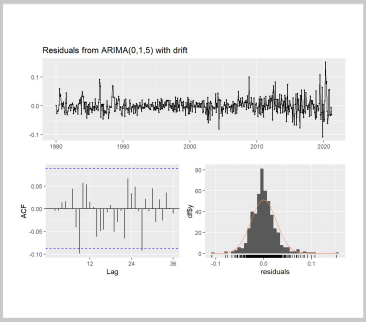
Selected forecasting model for chicken prices

- ARIMA(0,1,5) with drift
  - Complex linear regression equation
    - Differences between adjacent terms
    - Moving average of white noise
- MAPE score = 1.78%
- Valid forecasting model
- Series uncorrelated with lags
  - Verified by Ljung-Box test
- Random component has a bell-shaped frequency distribution



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Predicted price of chicken for March 1, 2023

- Fresh, whole chicken
- U.S. average price
- Predicted price
  - **$1.62 per pound**
- Predicted price range
  - **$1.46 to $1.78 per pound**
  - 95% level of confidence

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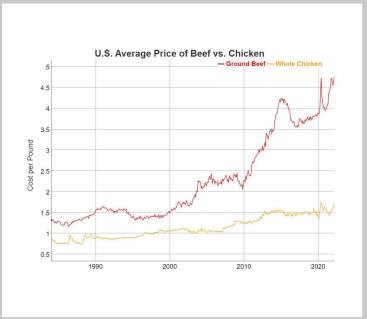
Price difference between beef and chicken

- Same measurement unit
  - dollars per pound
- Same frequency
  - First day of month
- Common endpoint
  - March 1, 2022
- Earliest common point
  - January 1, 1984
  - Start of beef price series



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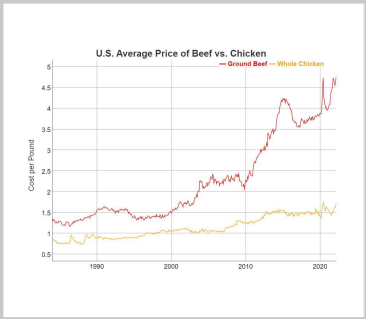
Price difference between beef and chicken

- 1984 to 2000
  - Mostly horizontal trend
  - Slight upward movement
  - Mostly parallel series
  - Roughly constant difference
- After January 1, 2000
  - Steeper incline for beef
  - Growing price disparity



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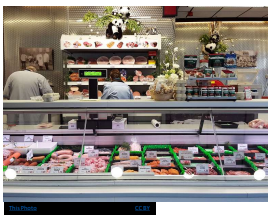
Predicted price difference for March 1, 2023

- U.S. average price
  - 100% ground beef
  - Fresh, whole chicken
- Predicted price difference
  - **$2.57 per pound**
- Predicted range of price difference
  - **$2.14 to $2.99 per pound**
  - 95% level of confidence



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Conclusion

	March 1, 2022	March 1, 2023 (forecast)
Price of 100% ground beef	$4.76 per pound	**$4.19 per pound**
95% prediction interval		$3.61 to $4.77 per pound
Price of fresh, whole chicken	$1.72 per pound	**$1.62 per pound**
95% prediction interval		$1.46 to $1.78 per pound
Price difference	$3.04 per pound	**$2.57 per pound**
95% prediction interval		$2.14 to $2.99 per pound

- Predictions are based on the forecasting models selected from this investigation
  - ARIMA(0,1,0) with drift, MAPE score of 1.78%, for prices of 100% ground beef
  - ARIMA(0,1,5) with drift, MAPE score of 1.73%, for prices of fresh whole chicken

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Future research

Longer forecast horizon

5 years into the future

Machine learning models

Random Forest

Gradient Boosting Machine

To obtain low error rates for longer forecast horizons

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Discussion

- In 12 months from March 1, 2022, on March 1, 2023
  - Price per pound for 100% ground beef not expected to increase by more than $0.01 per pound
  - Price per pound for fresh, whole chicken not expected to increase by more than $0.06 per pound
  - Price difference expected to decrease by at least $0.05 per pound

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Effect on Economy

- No major increase expected for U.S. beef and chicken prices
- Relief for consumers grocery shopping during current inflationary period
- Consumers may continue to enjoy favorite beef and chicken dishes at restaurants
- Restaurants may maintain current volume of business and work hours for employees
- Producers of beef and chicken may not have to raise prices beyond normal inflation adjustment
- Positive indicator of health of economy on March 1, 2023
- Perhaps a lower risk of entering next recession by then

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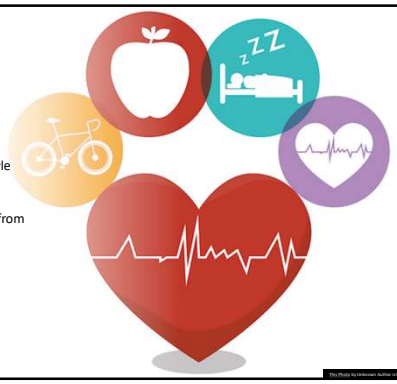
Effect on Public Health

- Cost of healthcare
  - Burden of chronic lifestyle diseases
    - Meat consumption
- Antibiotic resistant bacteria from industrial animal agriculture
- Zoonotic pandemic risk from intensive animal agriculture



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Effect on Environment

- Price stability may sustain current level of consumption of beef and chicken
- Livestock produce more emissions than all forms of transportation combined
- Amount of land, grain, and water required for livestock production
- Waste and agricultural runoff from industrial animal agriculture

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References

Krispin, R. (2019), *Hands-On Time Series Analysis with R*, Birmingham, UK: Packt Publishing Ltd.

Shumway, R. H., and Stoffer, D. S. (2017), *Time Series Analysis and Its Applications* (4th ed.), Cham, CH: Springer International Publishing AG.

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