Empirical Methods
Time Series Econometrics I & II
Introduction

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Time Series

A time series is a collection of observations of one or more variables ordered in time. We denote a time series by $\{x_t\}_{t \in \mathcal{T}}$, with $\mathcal{T}$ being the index set of time periods or time points.

- Typical examples of the set $\mathcal{T}$ are:
  - years: $\mathcal{T} = \{1998, 1999, \ldots, 2016\}$.
  - quarters: $\mathcal{T} = \{01/2010, 02/2010, \ldots, 04/2016\}$.
  - ...
- The chronological structure of a time series is essential and itself contains information.
- Often time series are recorded at (essentially) equidistant time points, sometimes an idealization, sometimes not tenable.
- Discrete time versus continuous time data (and models).

- As in other fields in statistics, the values of x_t can be:
  - nominal (e. g., 'red', 'blue', 'green')
  - ordinal (e. g., 'low', 'medium', 'high')
  - discrete (e. g., $x_t \in \mathbb{N}$)
  - interval data (e. g., $x_t \in [0, 1]$)
  - real or complex valued
  - univariate or multivariate

- In this course, we focus (with the exception of the discussion of spectral analysis) on real valued time series:

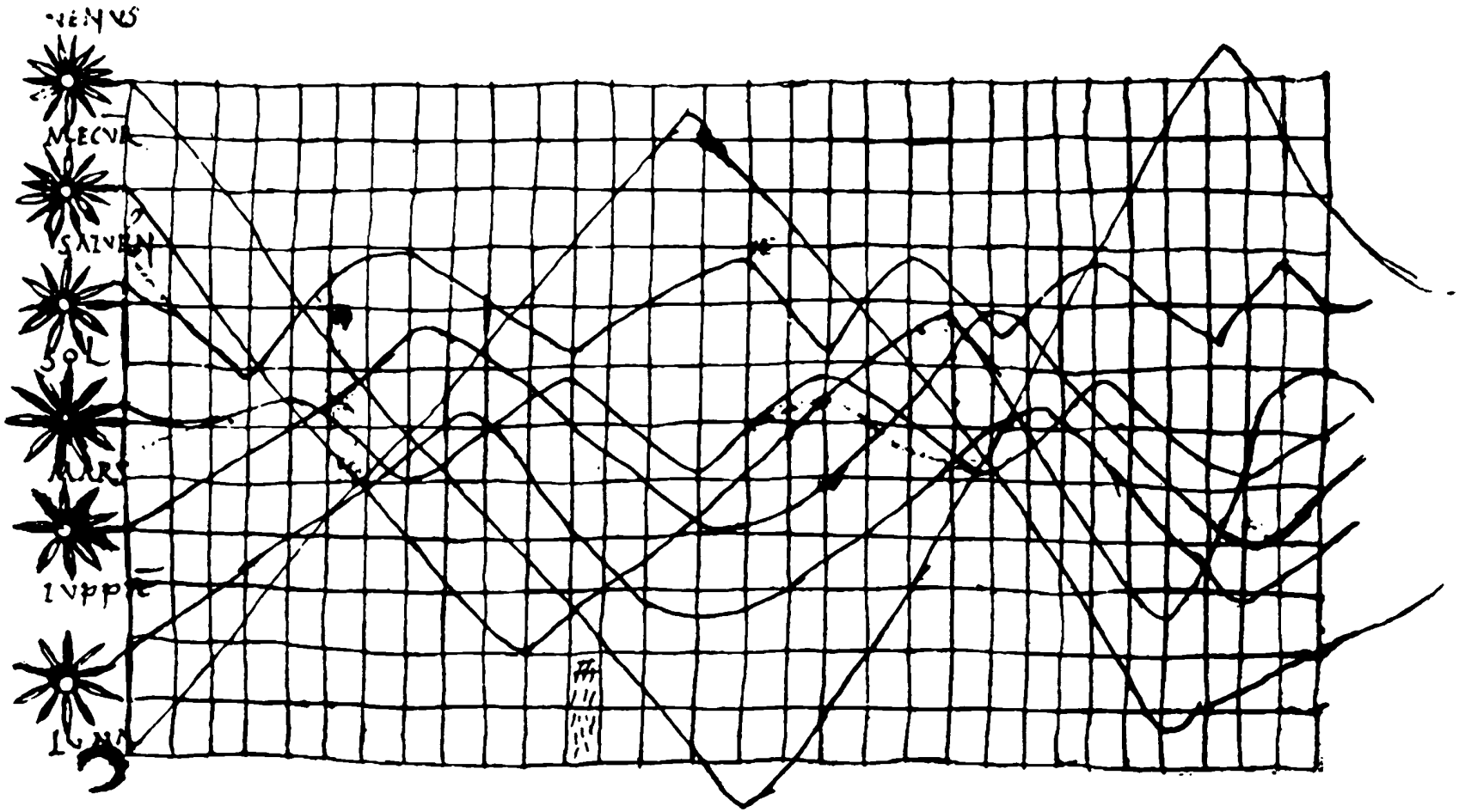
$$x_t \in \mathbb{R}^n \quad \text{and} \quad \mathcal{T} = \{1, \ldots, T\}$$

  for some $T \in \mathbb{N}$ (at least after discretization).

- For many mathematical considerations, $\mathcal{T} = \mathbb{Z}$ will be used (for simplicity or beauty).

Historical Time Series

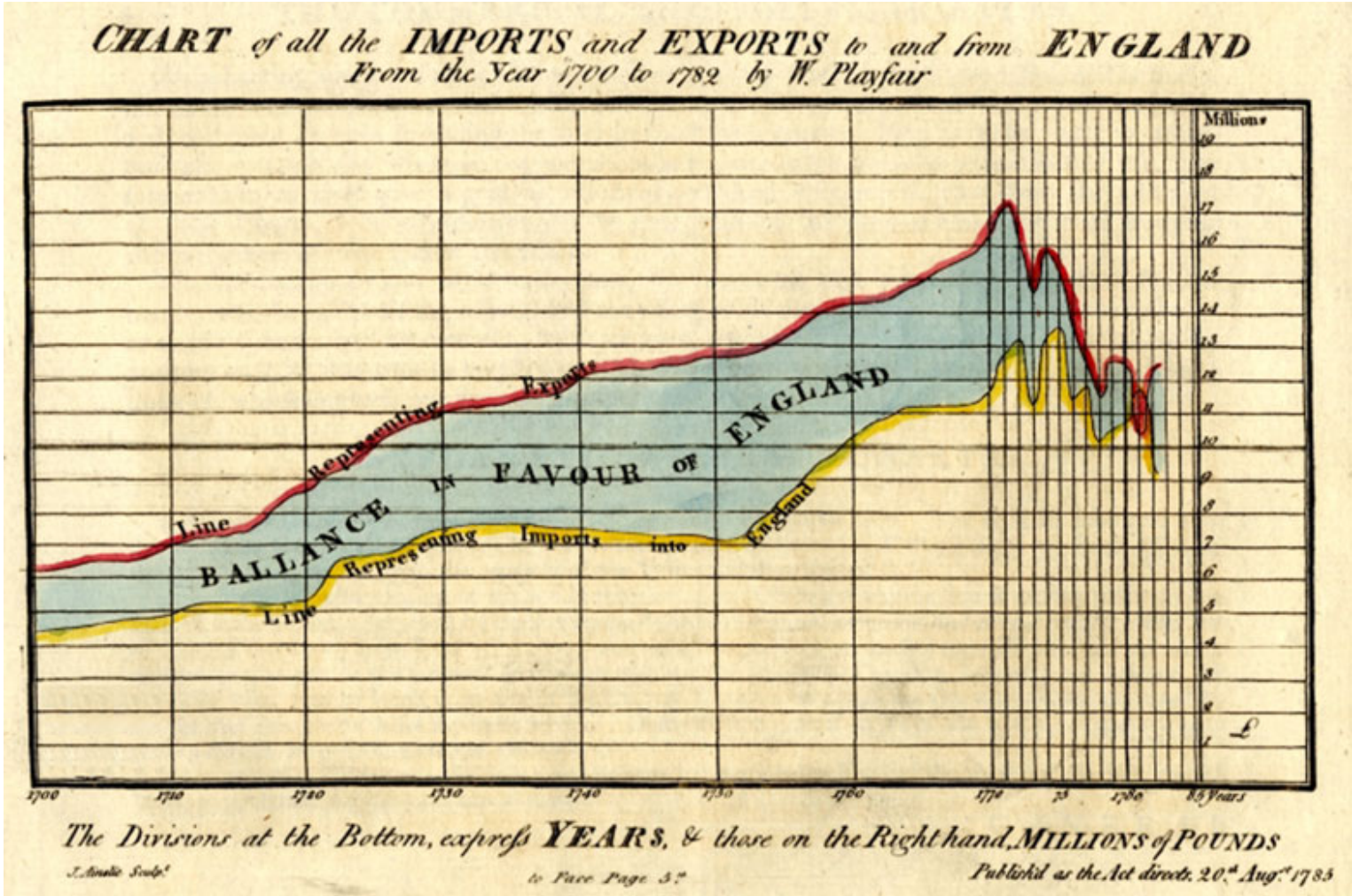
Visualization of Planetary Orbits (10th/11th Century)



Source: Funkhouser (1936)

Historical Time Series

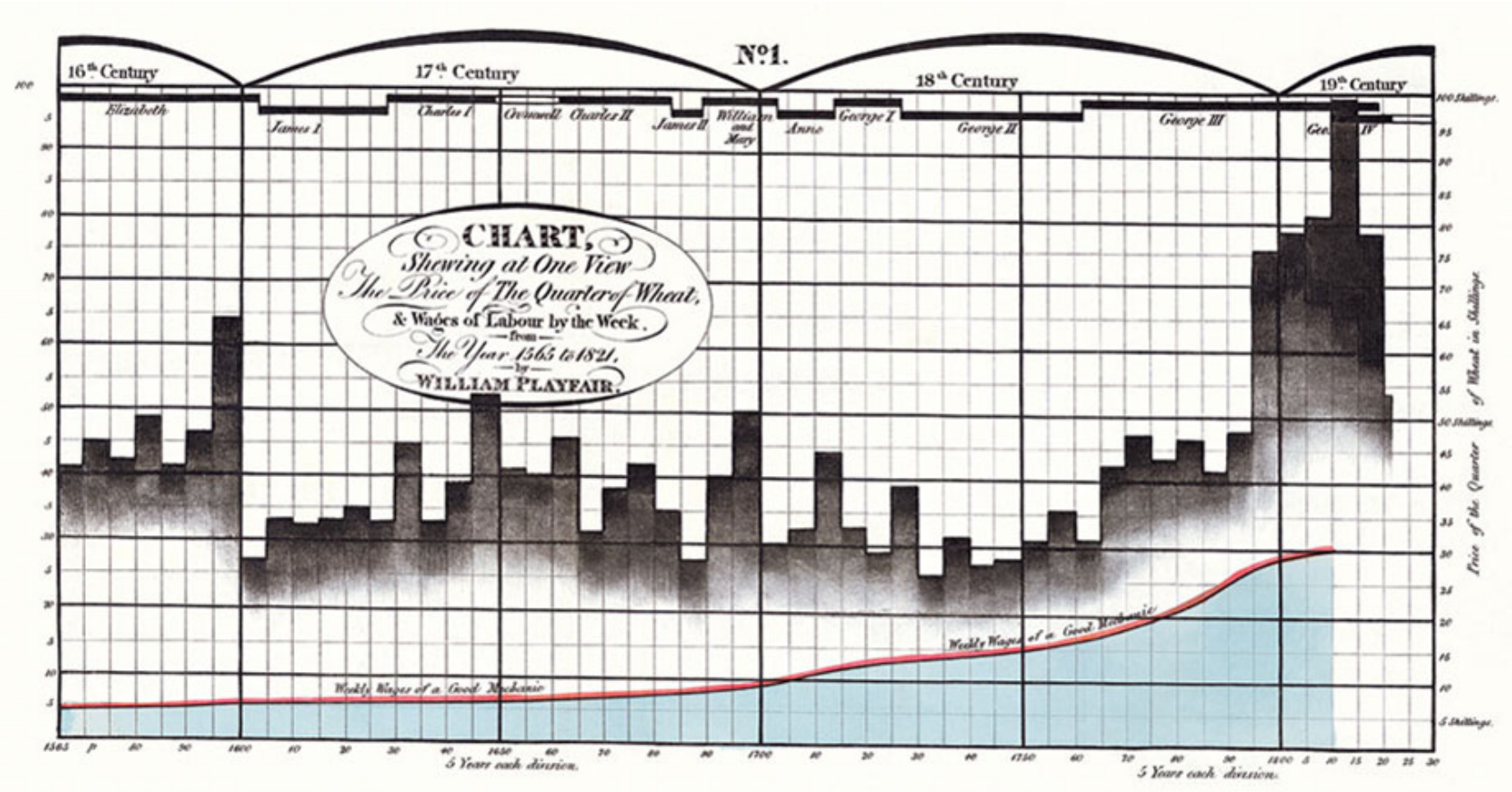
Imports and Exports to and from England (1700–1782)



Source: Commercial and Political Atlas (Playfair and Corry, 1786)

Historical Time Series

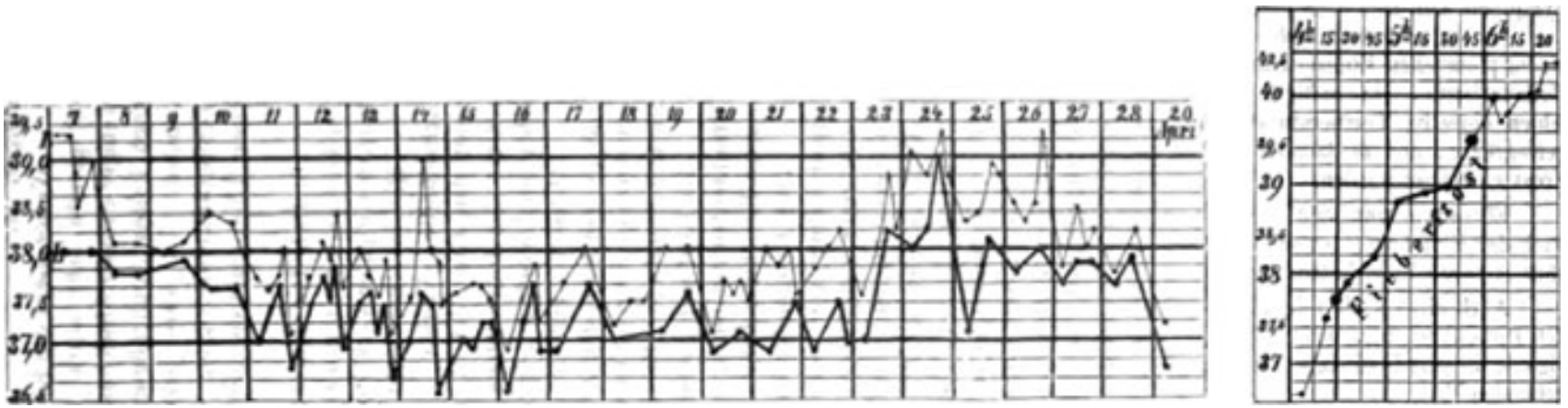
Wages and Prices in the UK 1565–1821



Source: Playfair (1981)

Historical Time Series

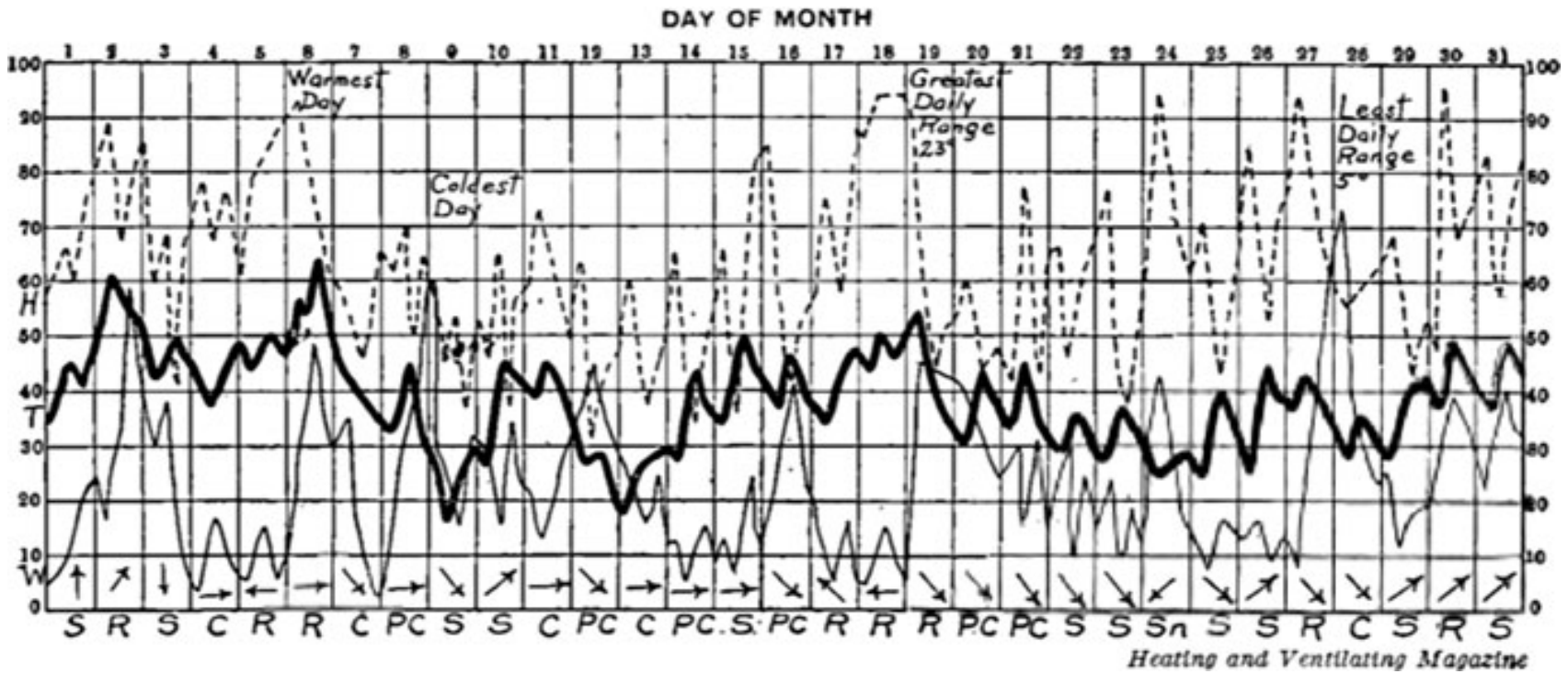
Fever Charts (19th Century)



Source: Wunderlich (1870)

Historical Time Series

Weather in New York (December 1912)



Source: Brinton (1914)

Historical Background of Time Series Analysis I

1789 Laplace searches for "secular changes" in the orbit of the planets and the moon.

1879 Stokes invents the periodogram that is used for the analysis of sunspot data (by Schuster, 1898) and for economic data (by Beveridge, 1921 & 1922).

1930–45 Cramer, Kolmogorov, Wiener and Wold develop the theory of stationary processes, including spectral theory, prediction and filtering, probability theory.

1940–50 Early heydays of econometrics: Simultaneous equation systems, identifiability and maximum likelihood estimation (Anderson, Haavelmo, Koopmans et al.).

1940–60 Spectral (estimation) theory by Tukey and (especially for economic time series) by Granger and Hatanaka.

1960 The Kalman filter and state space models.

Historical Background of Time Series Analysis II

1960–88 Asymptotic theory for stationary autoregressive and ARMA systems (Anderson, Deistler, Hannan, Walker et al.).

1971 The Box-Jenkins approach to fit ARIMA models for time series data.

1969–85 Automatic order estimation, information criteria (AIC, BIC).

1982 Autoregressive conditional heteroskedasticity (ARCH) models to describe (financial) time series that exhibit volatility clusters (Engle).

1986 Generalization of ARCH models, e. g., so-called GARCH models (Bollerslev), large zoo of variants by now.

1987 Cointegration (Engle and Granger): Analysis of multivariate integrated time series with common stochastic trends.

Some Main Uses of Time Series Analysis

- Searching for (hidden) features such as trends, cycles or (linear) dependencies
- Preprocessing of data including seasonal adjustment or the extraction of stylized facts
- Detection of structural breaks
- Prediction
- Control/Monitoring
- Estimation of parameters (which may be theoretically meaningful: structural parameters)
- Testing of (conflicting) theories
- Testing for causality

Some Main Areas of Application I

- Biology:
  - Modelling of plant growth
  - Prediction of bacteria population
- Economics:
  - Forecasting and policy simulations (e. g., macroeconomic variables like GDP, unemployment,...)
  - Estimation of parameters
  - Discrimination amongst competing theories
- Engineering:
  - Signal processing (speech processing, radar and sonar applications)
  - Control engineering (control of missiles, aeroplanes, ships, chemical or technical plants)
  - Monitoring (e. g., of oil platforms)
- Finance:
  - Analysis and forecasting of financial data (e. g., stock market prices, exchange rates, interest rates,...)

Some Main Areas of Application II

- Analysis of co-movements between prices and volatility (e. g., leverage effect)

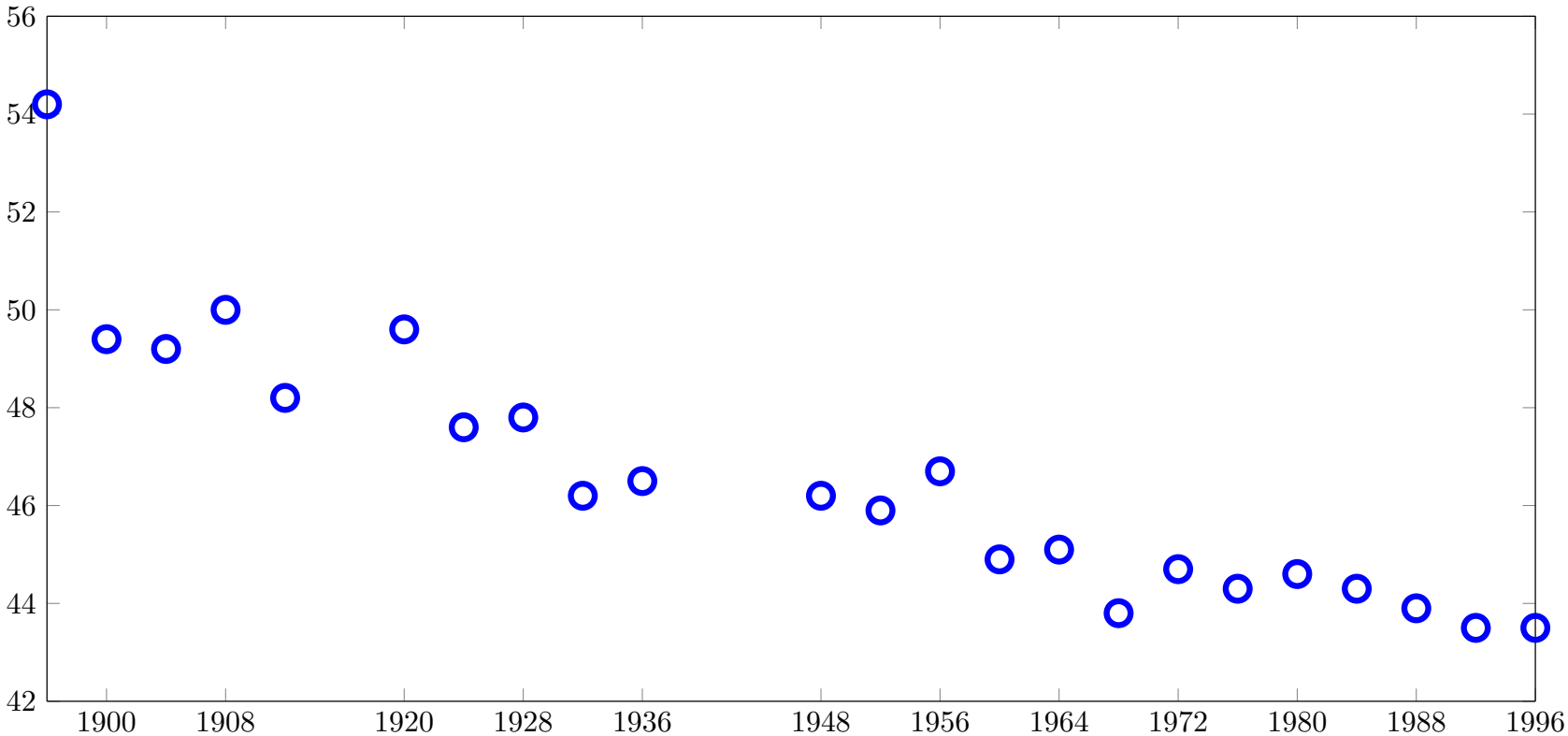
- Geophysics:
  - Exploration of natural resources (oil)
  - Prediction of earthquakes

- Medicine:
  - Analysis of EEG data
  - Estimation of intervention effects

- Meteorology and Hydrology:
  - Weather forecasting
  - Modelling stream flows of rivers
  - Prediction (and prevention) of floods

Sports Data

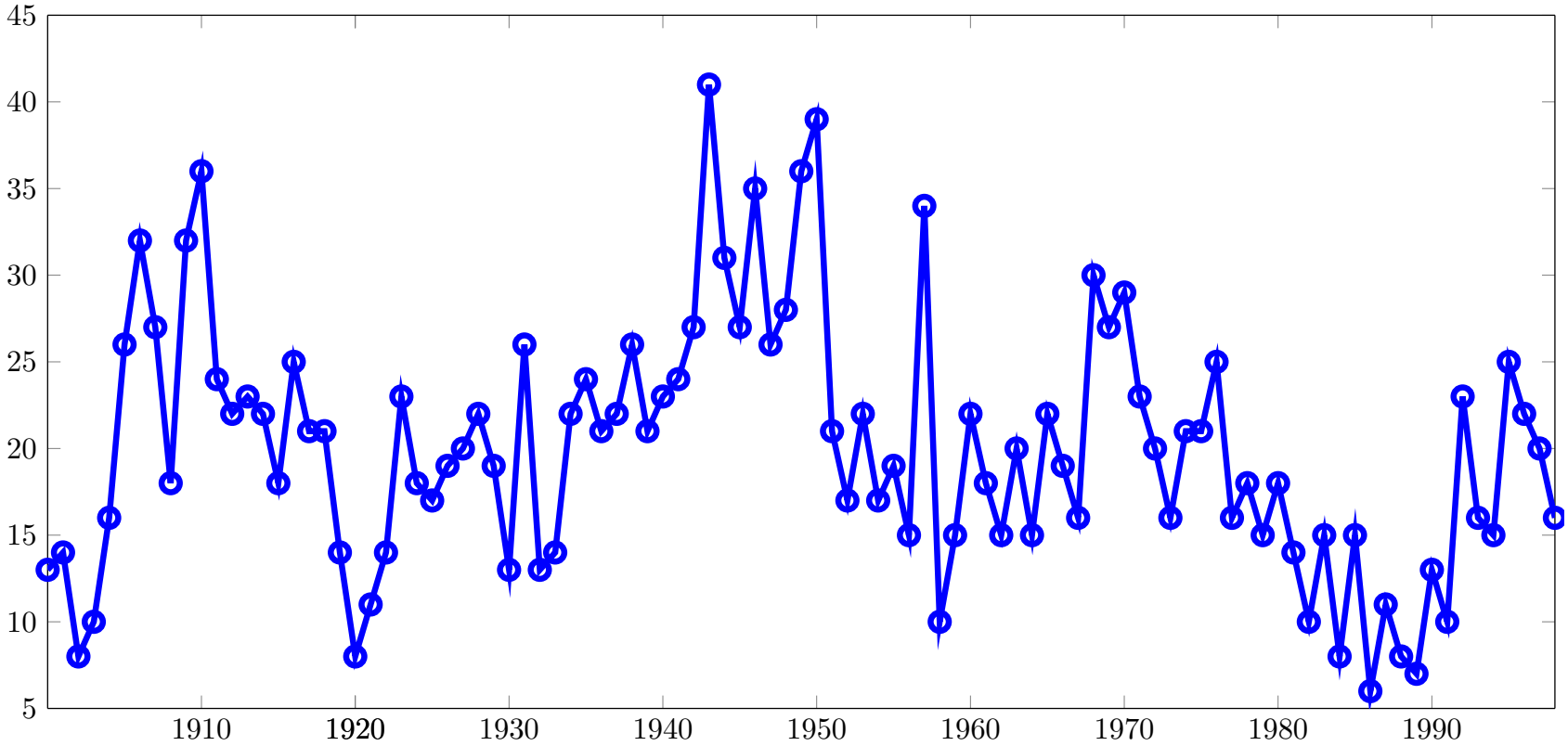
Winning Times for Men's 400m Final in the Olympic Games 1896–1996



- Missing data during WWI (1914–18) and WWII (1939–45).
- Source: https://datamarket.com

Seismological Data

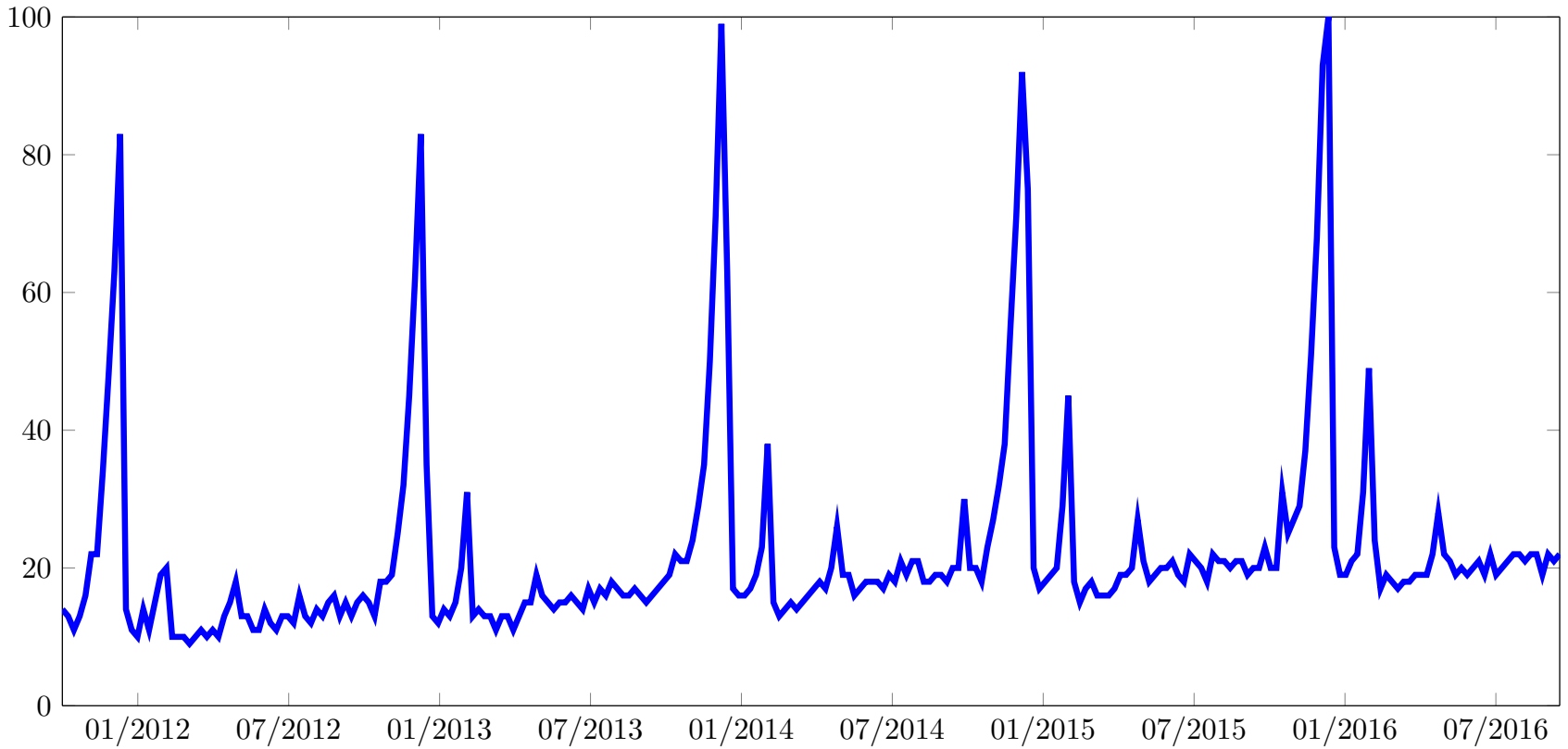
Number of Earthquakes per Year with Magnitude 7.0 or Larger (1900–1998)



- No obvious pattern (no trend, no cyclical behavior) visible.
- Source: https://datamarket.com

Google Trends Data

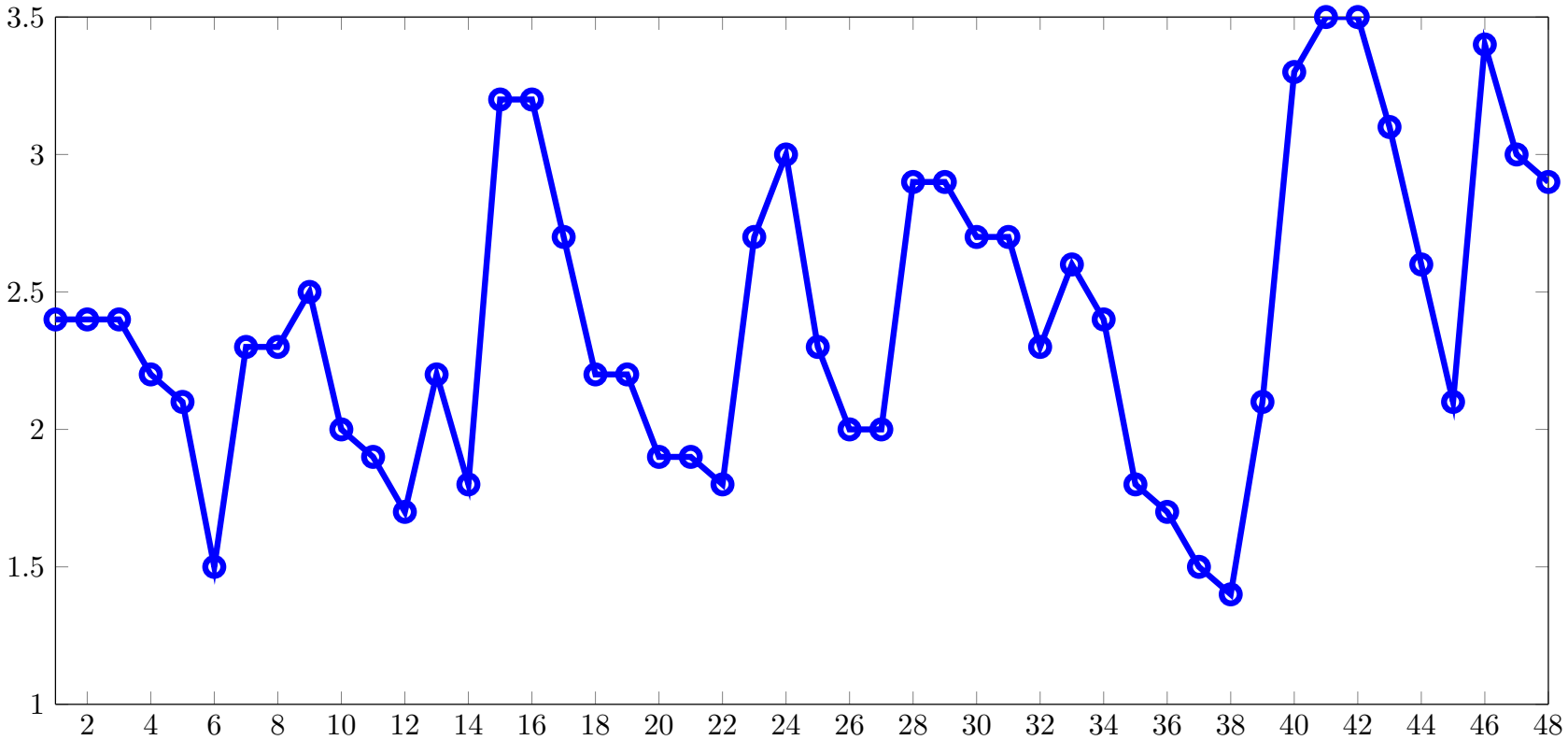
Weekly Search Volume for "gift wife"



- Indexed series: Week with highest search volume set to 100.
- Sample period from Oct. 9, 2011 to Sept. 25, 2016.

Medical Data

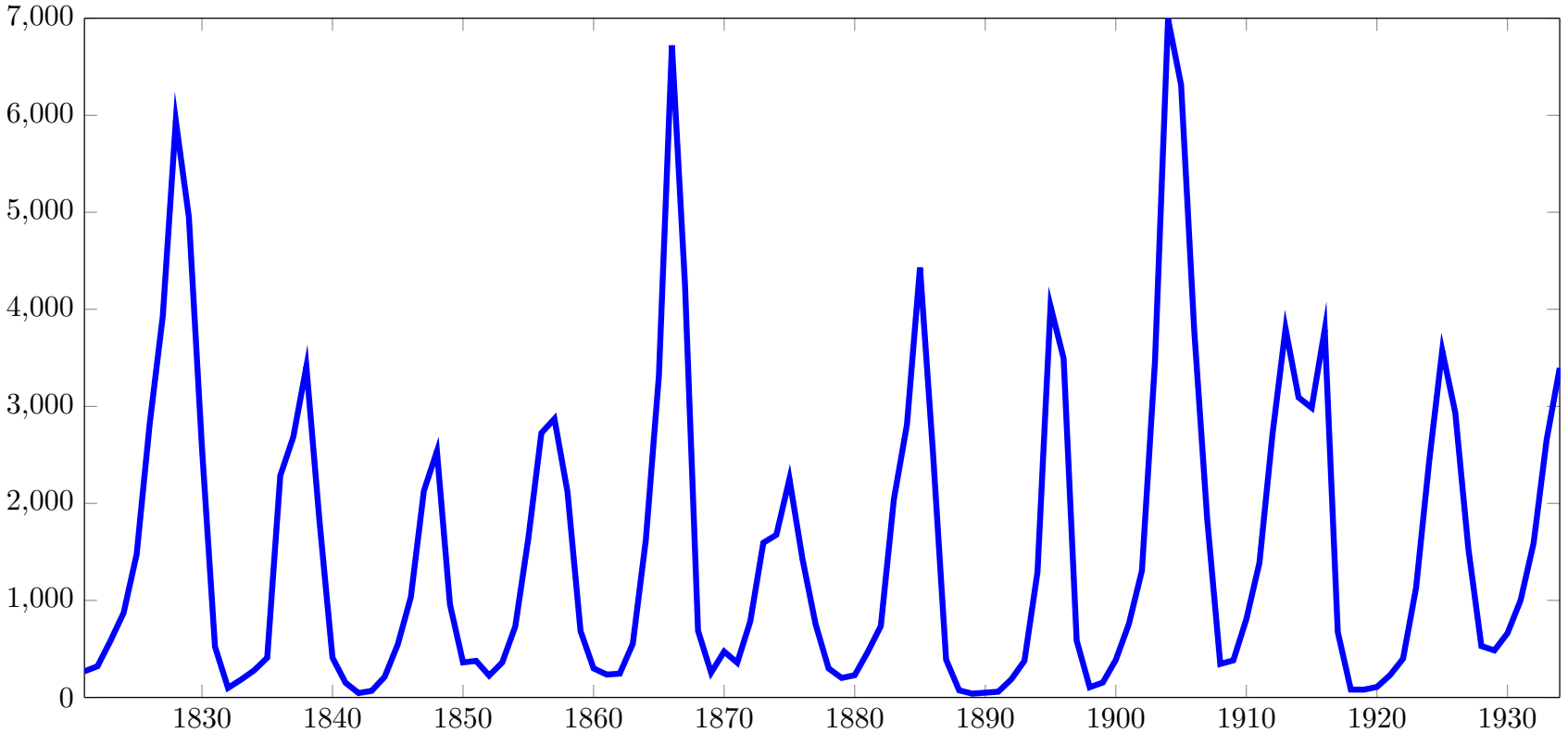
Luteinizing Hormone (Triggers Ovulation) in Blood



- Series shows 48 LH levels (blood samples from a human female) taken at 10 min intervals.
- Source: R datasets

Ecological Data

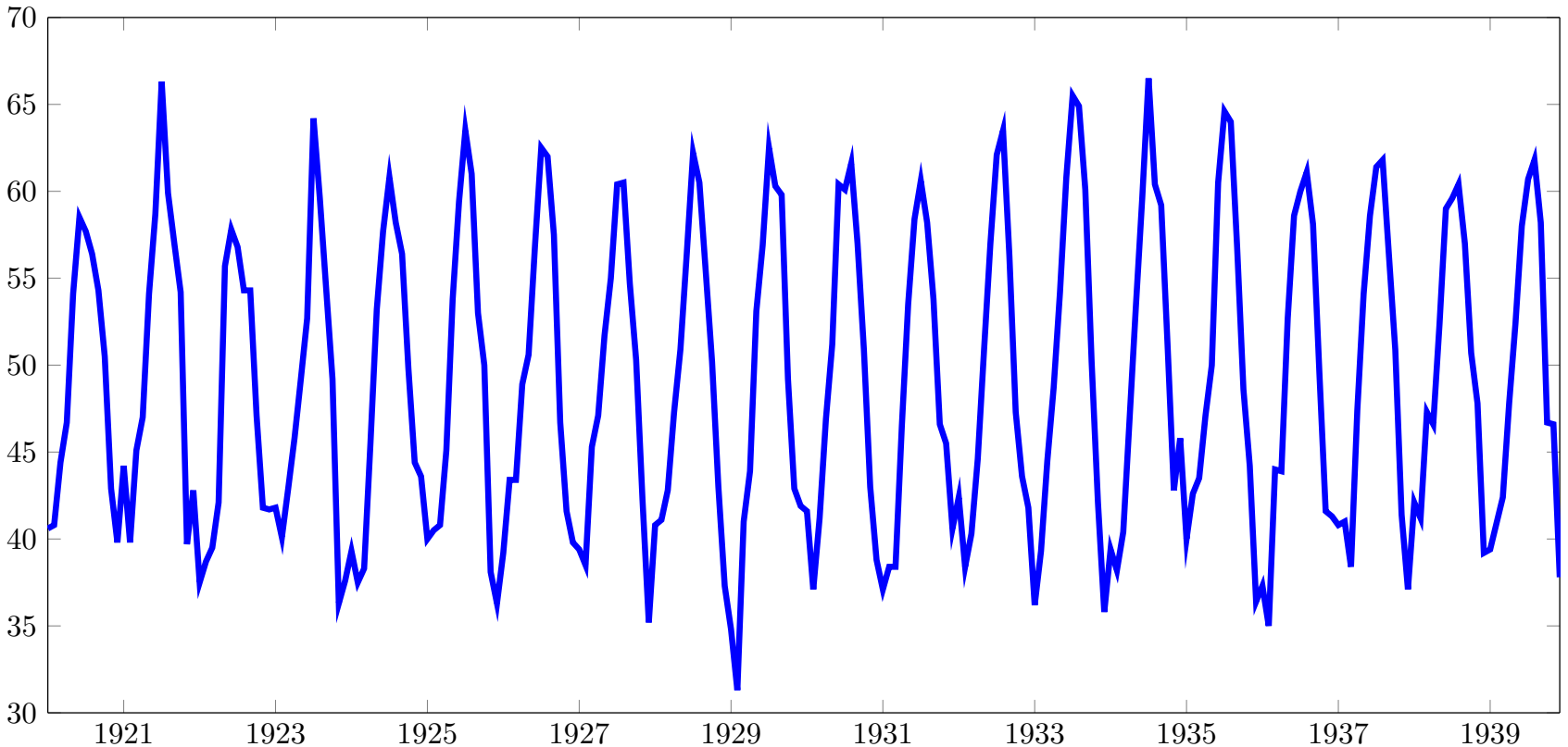
Number of Lynx Trapped in McKenzie River District in Northwest Canada



- Annual data for the period 1821–1934: Some form of cyclical behavior is visible.
- Source: https://datamarket.com

Meteorological Data

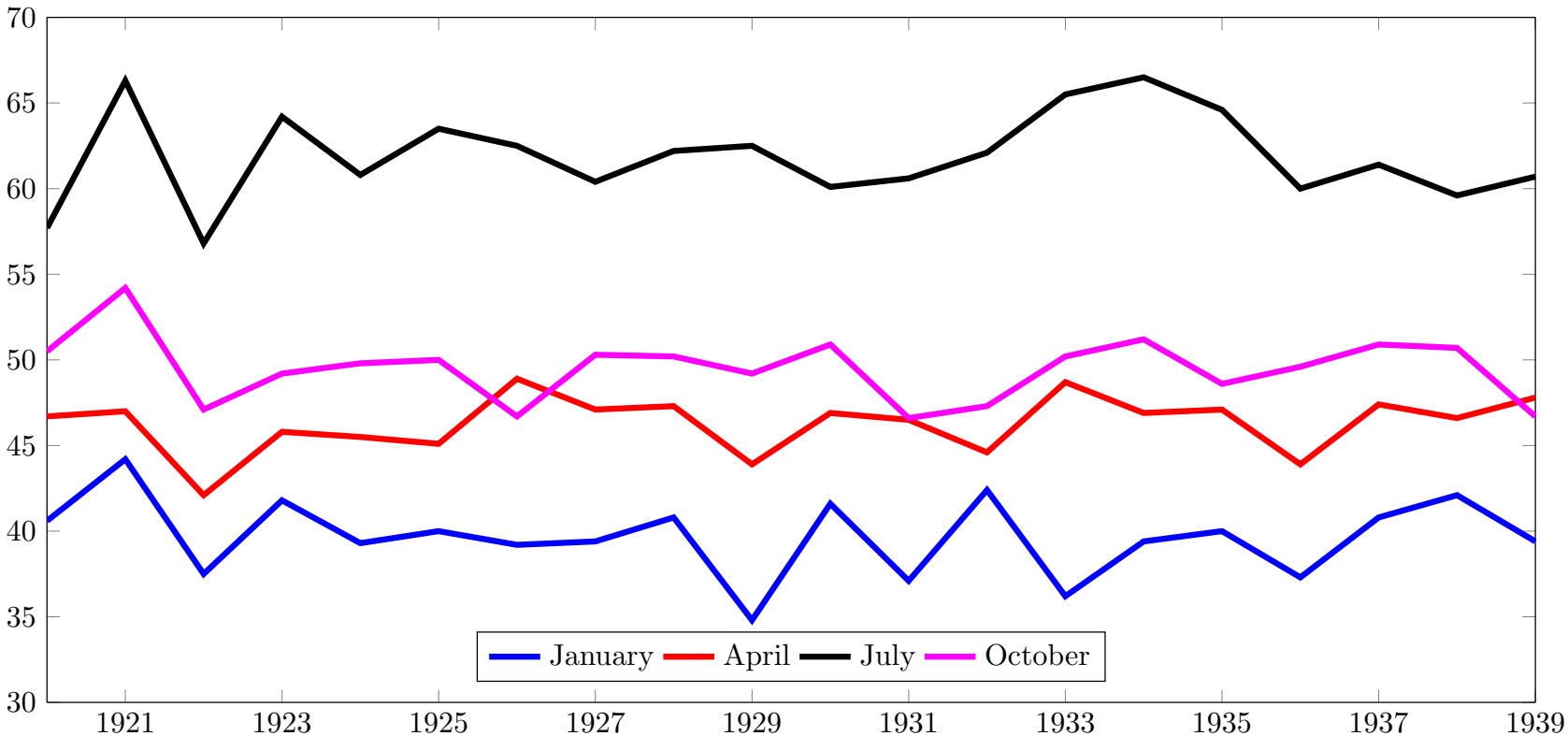
Average Monthly Temperature (in ^oF) in Nottingham



- The sample period is Jan 1920 – Dec 1939: Clearly visible seasonal pattern.
- Source: R datasets

Meteorological Data

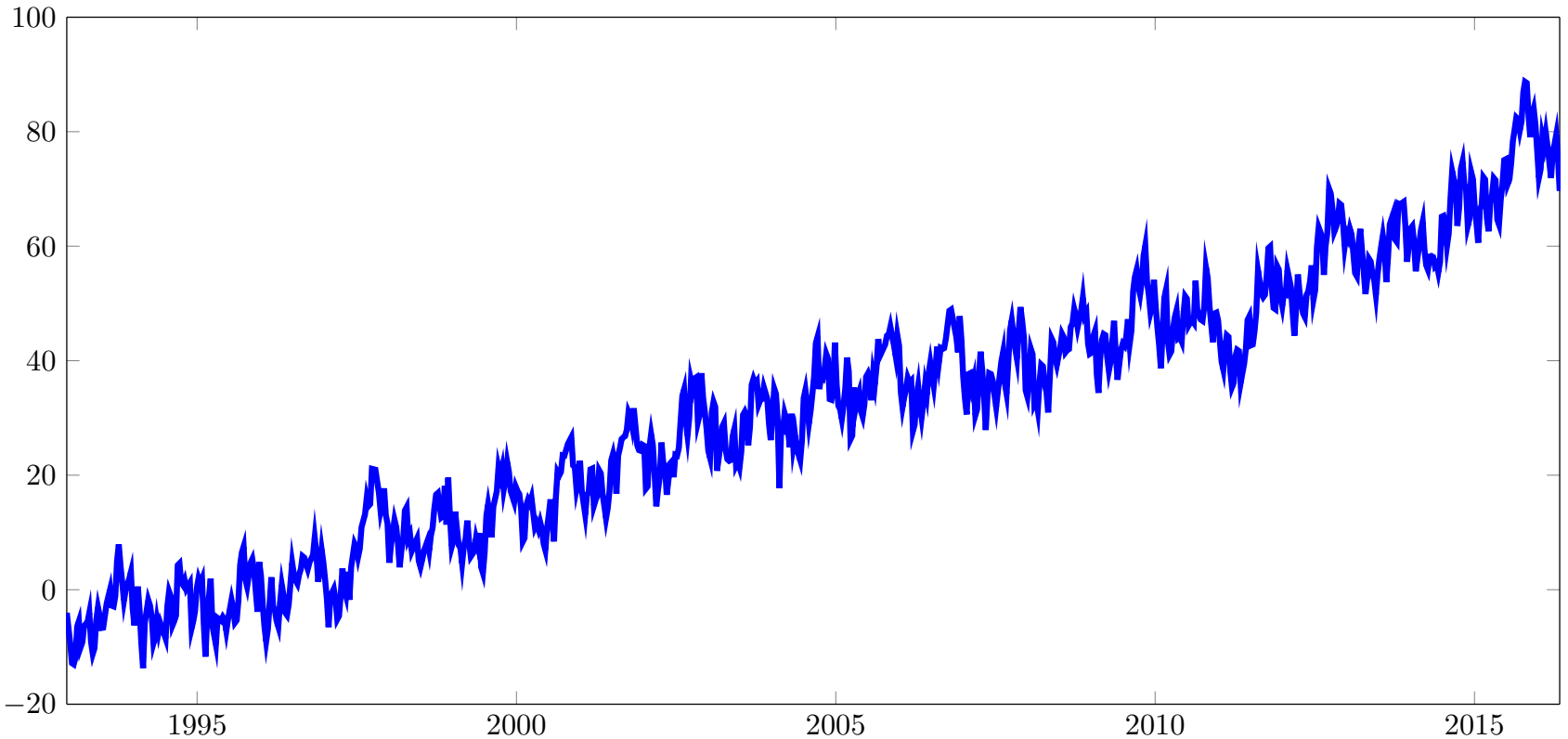
Average Monthly Temperature (in ^oF) in Nottingham



- Skip plot: annual time series for (four) individual months.
- No seasonal pattern visible.

Climate Science Data

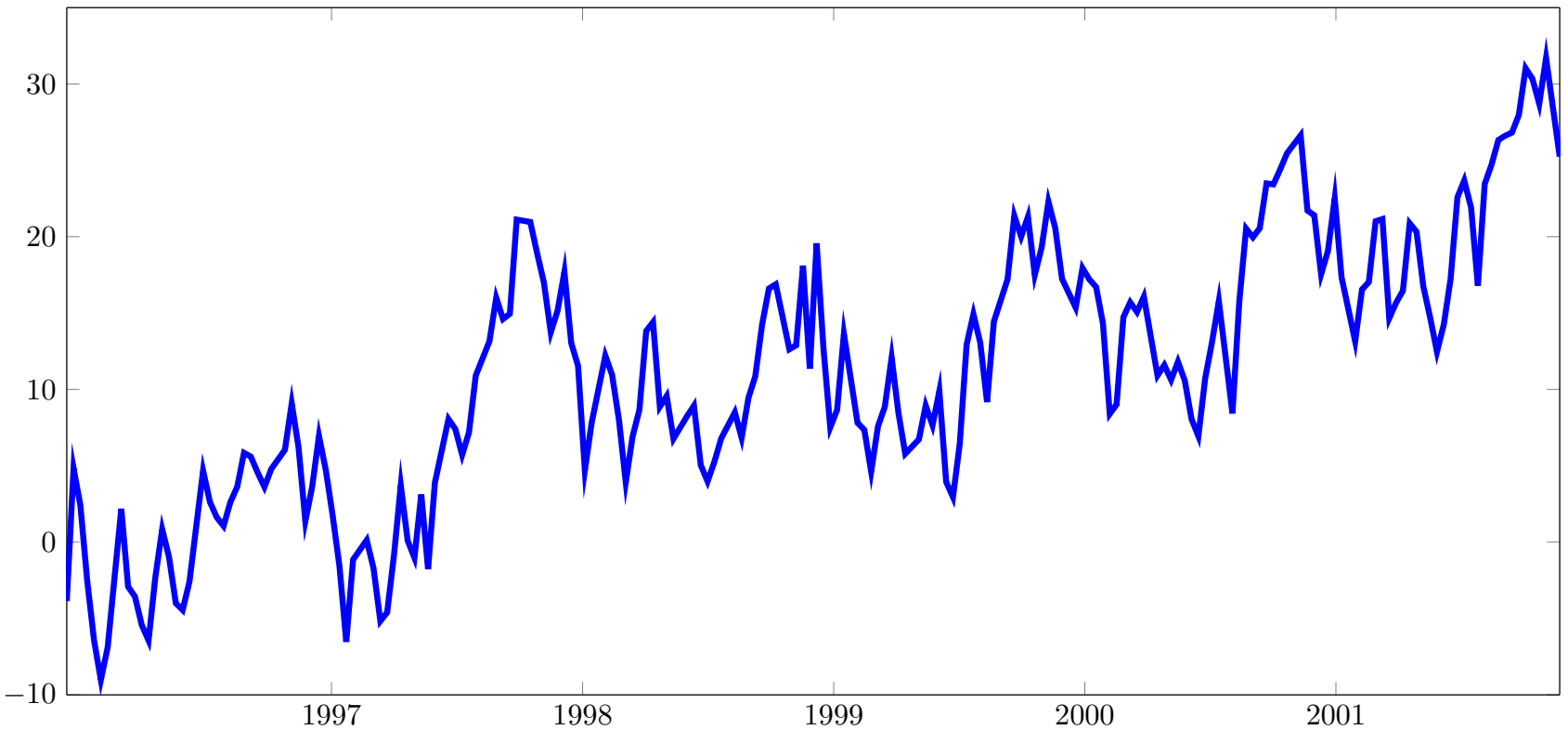
Increase in Global Mean Sea Level (in mm) from 1992–2016



- Time series contains both trend and cyclical/seasonal component.
- Source: University of Colorado

Climate Science Data

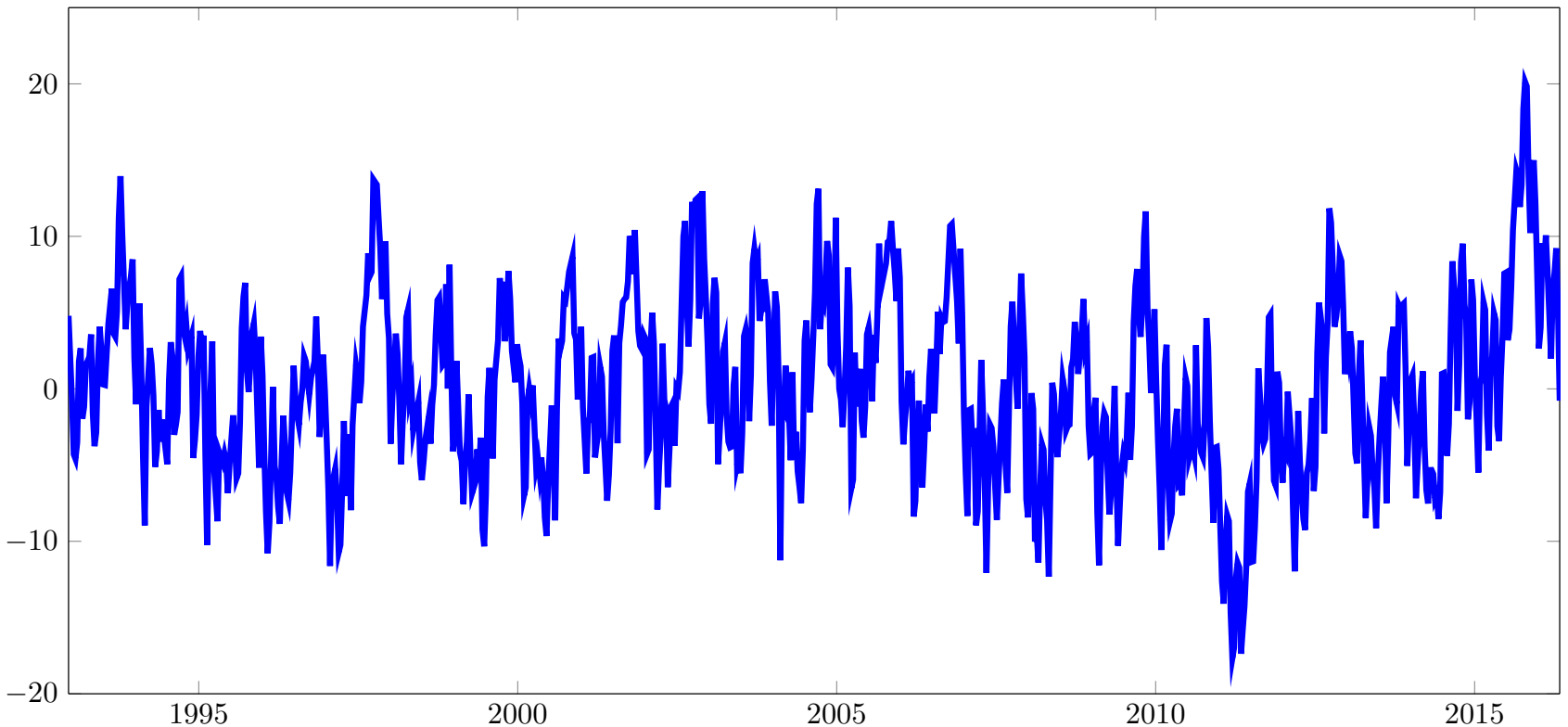
Increase in Global Mean Sea Level (in mm) – zoomed in



- Looking at the previous series more closely for 300 observations.

Climate Science Data

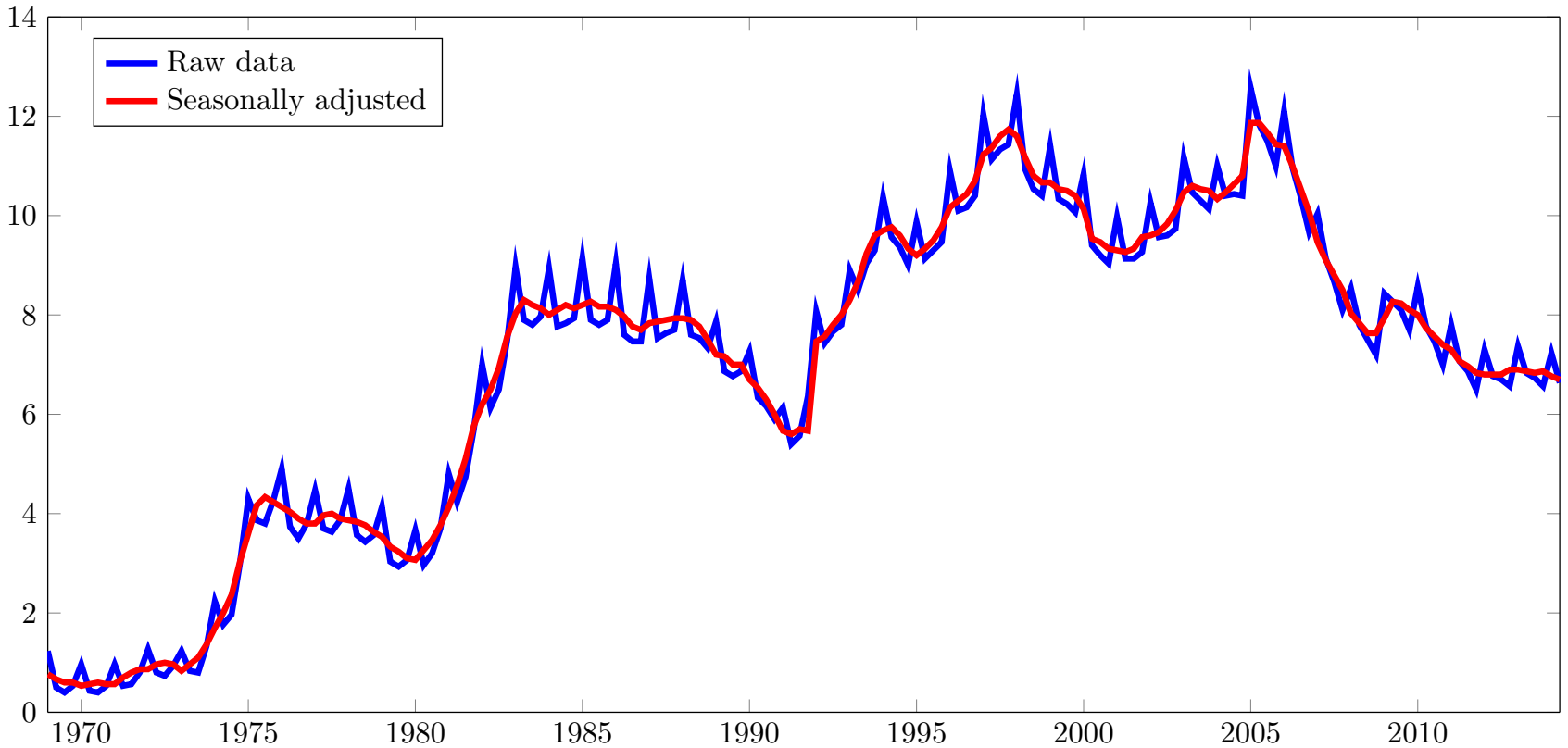
Increase in Global Mean Sea Level – Detrended (Constant and Linear Trend)



- Detrended time series: Intercept and linear trend removed.
- Maybe not the "right" trend?

Economics

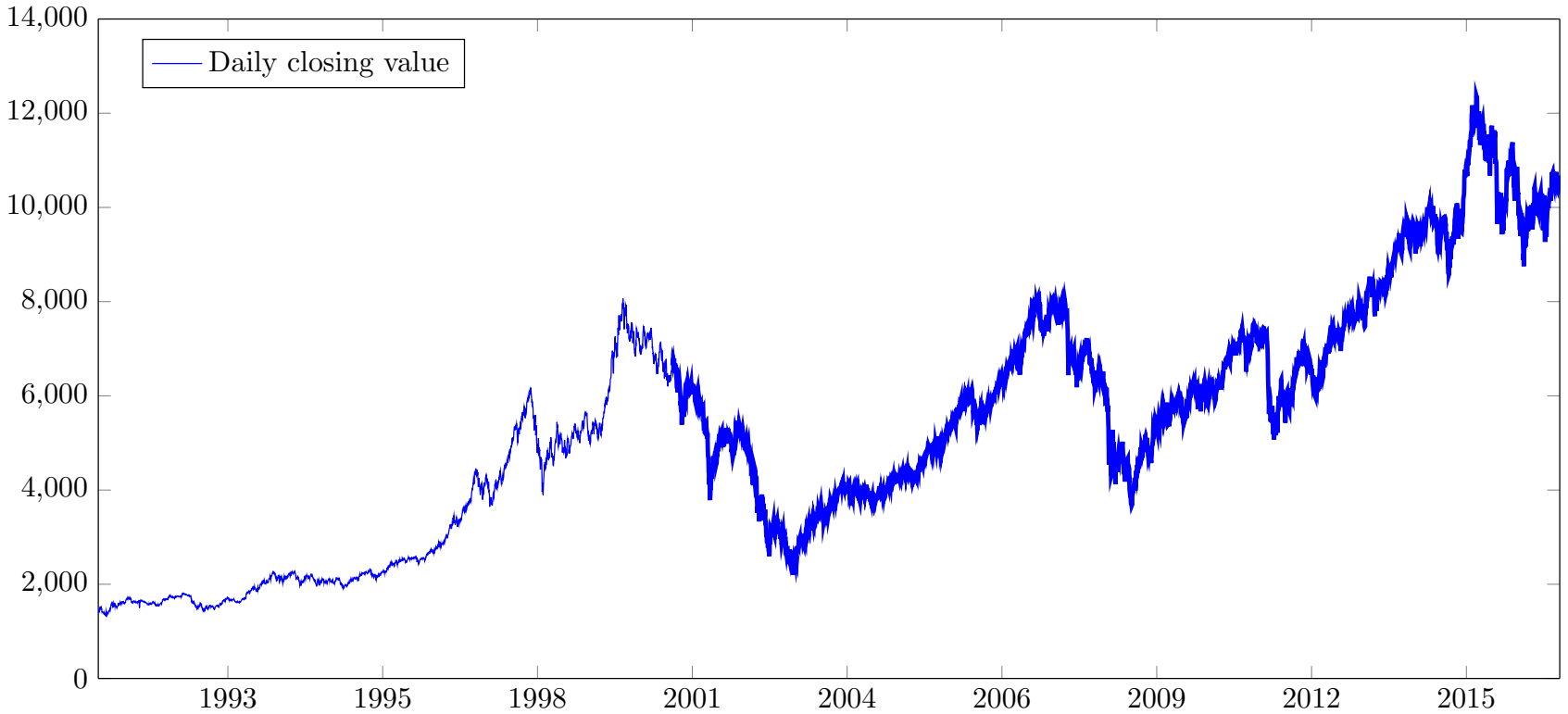
Unemployment Rate in Germany, Quarterly Data, 1969(1)–2014(2)



- Deseasonalized with X12-ARIMA or X13-ARIMA filter.
- Source: St. Louis FED

Finance

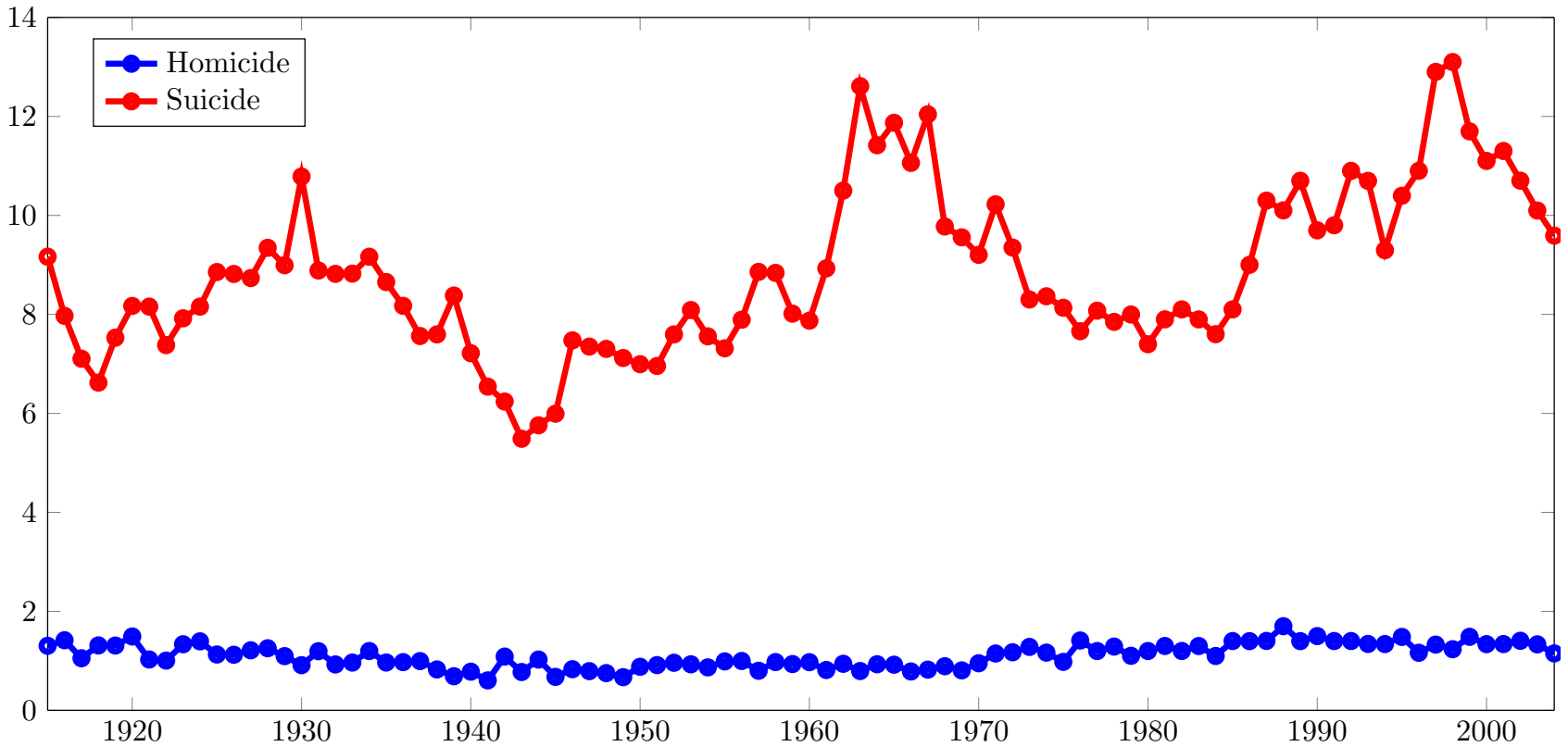
German Stock Market Index DAX: Nov. 27, 1990 – Sept. 30, 2016



- Different crashes clearly visible: Dotcom bubble (2002), global financial crisis (2007), euro crisis (2011).
- Source: Yahoo finance

Crime Statistics Data

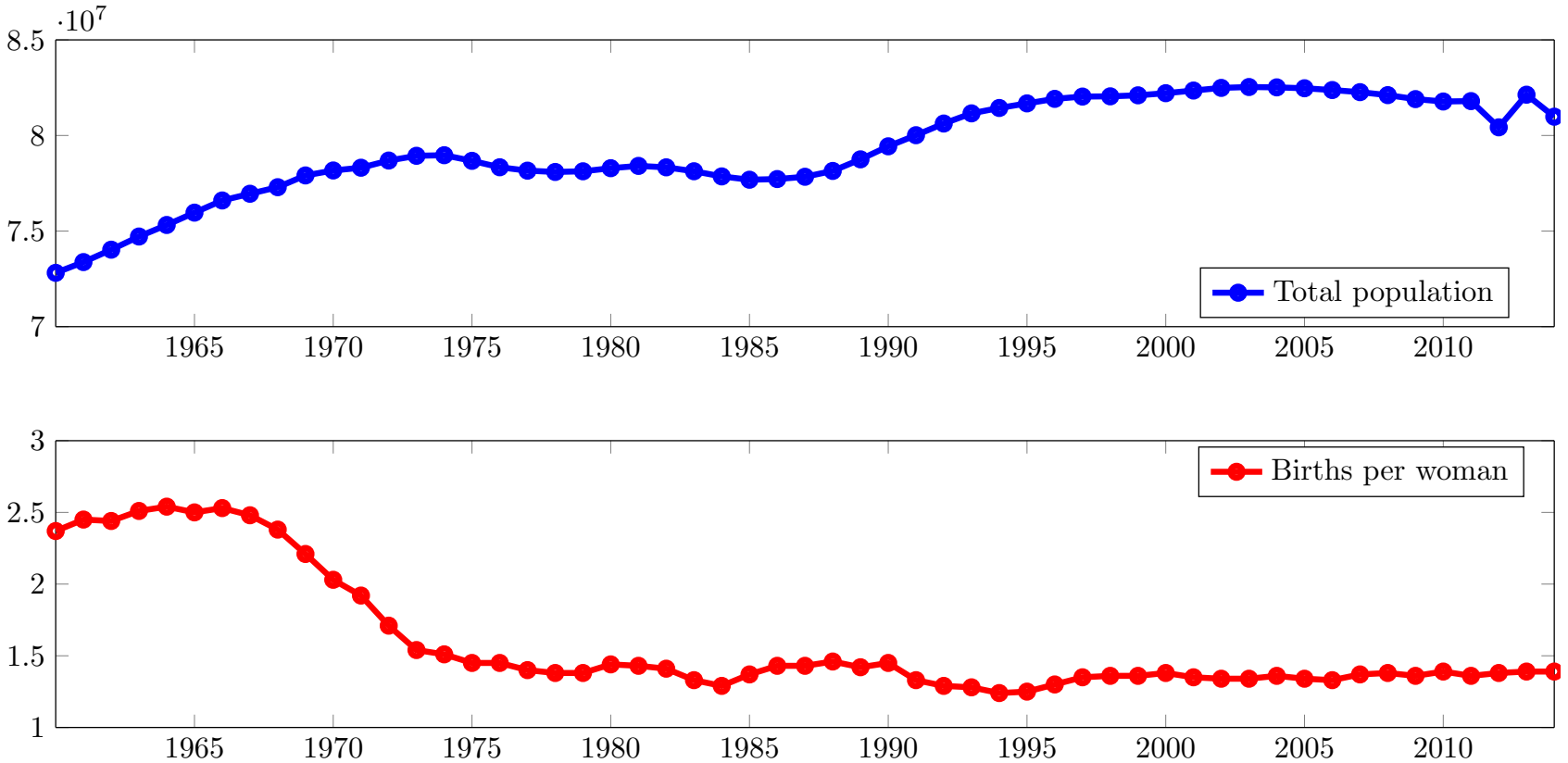
Deaths in Australia by Suicide and Homicide (Deaths per 100,000)



- Annual data for 1915–2004.
- Source: https://datamarket.com

Demographic Data

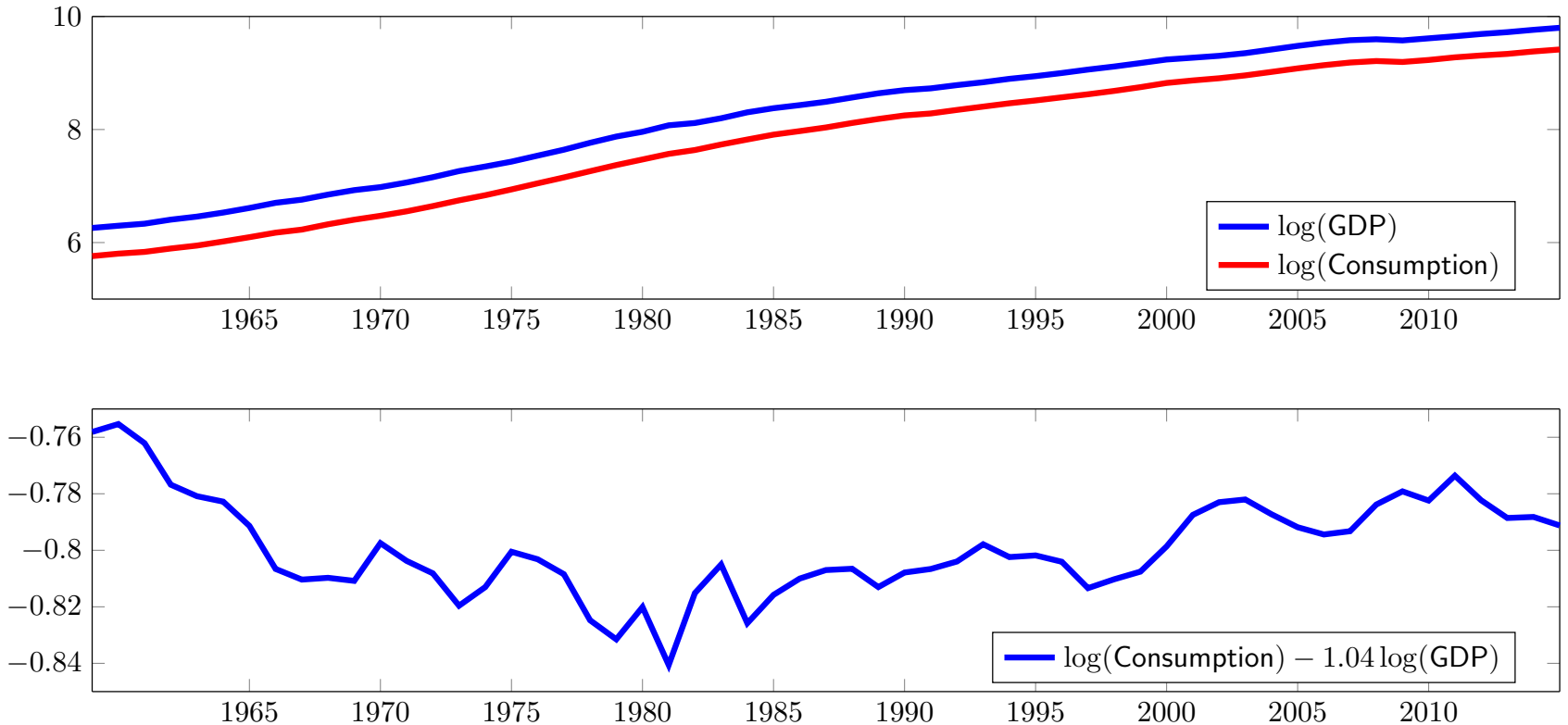
Total Population and Fertility in Germany (Annual Data 1960–2014)



- Source: St. Louis FED

Macroeconomic Data

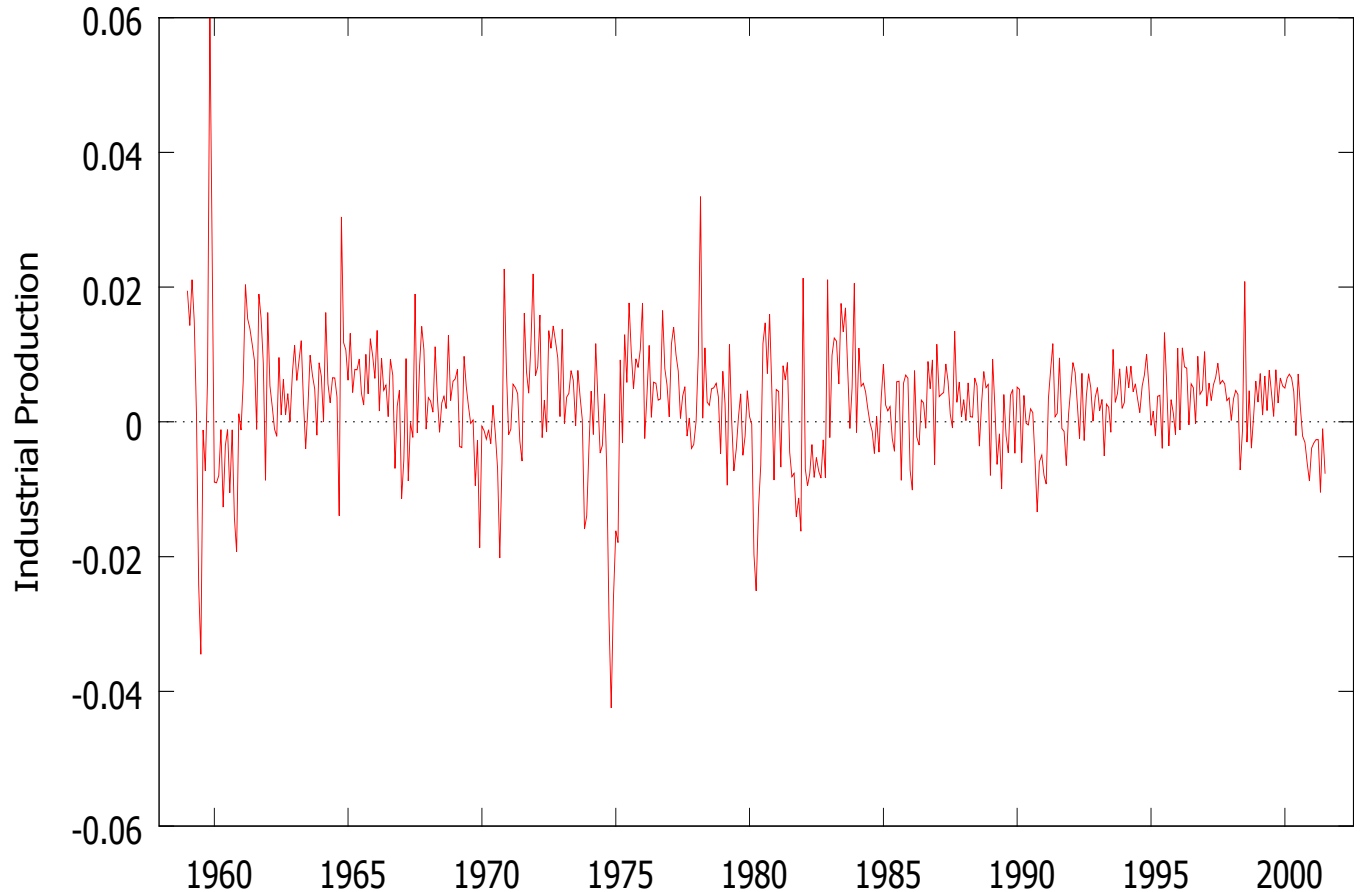
US Real Gross Domestic Product and Personal Consumption Expenditures



- Annual data from 1929–2015 in billions of USD.
- Source: St. Louis FED

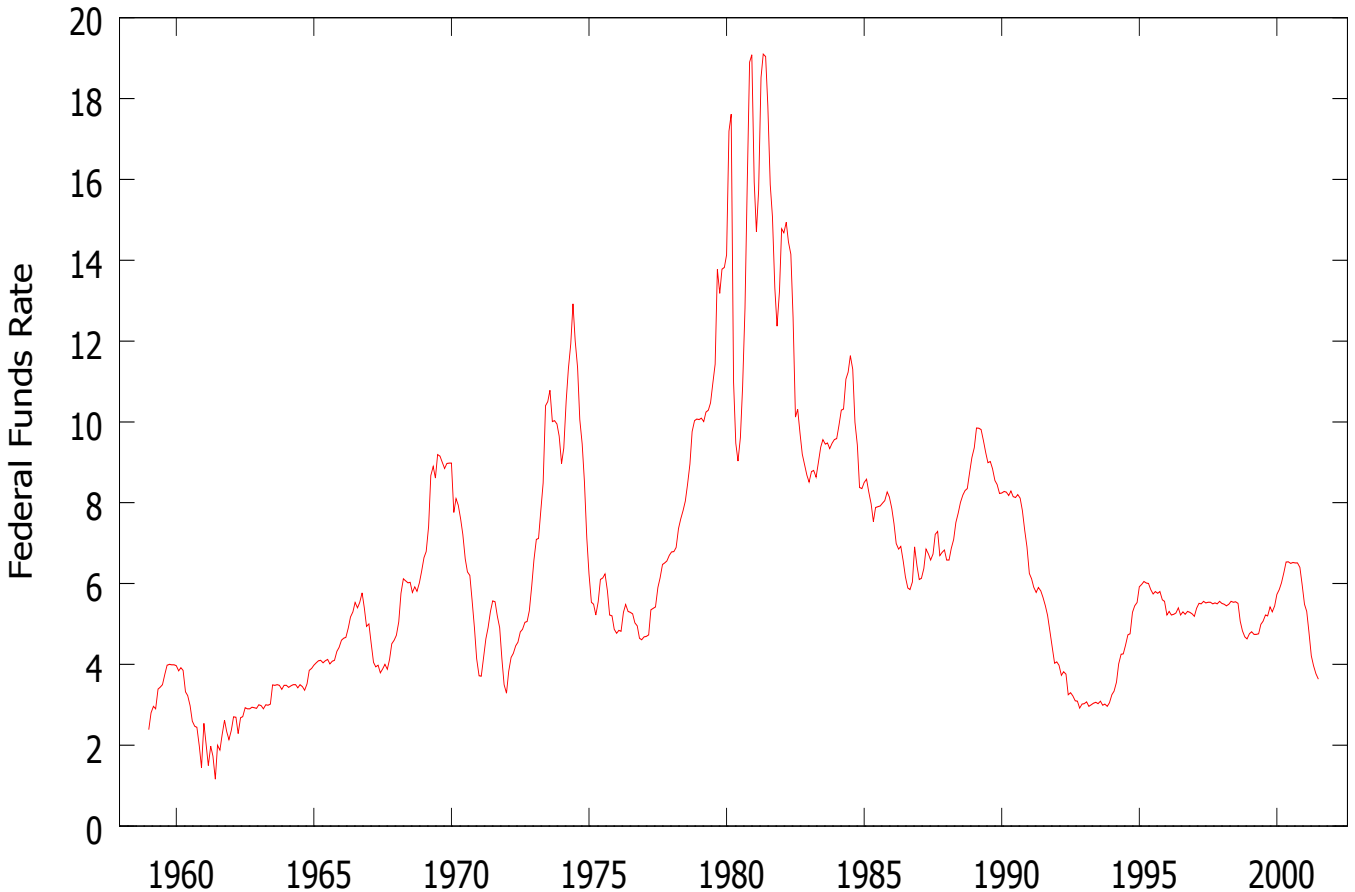
US Macro Data

Industrial Production (Growth Rates)



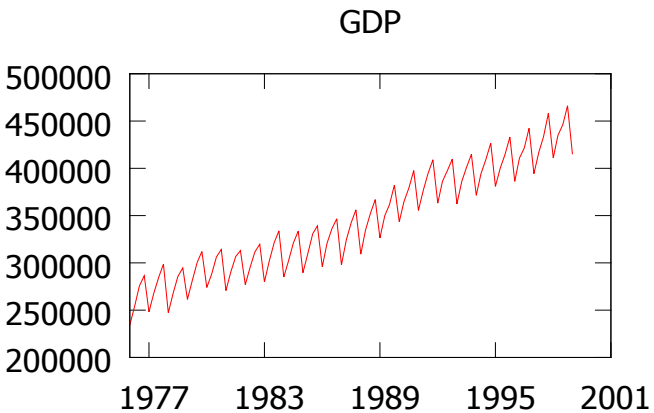
US Macro Data

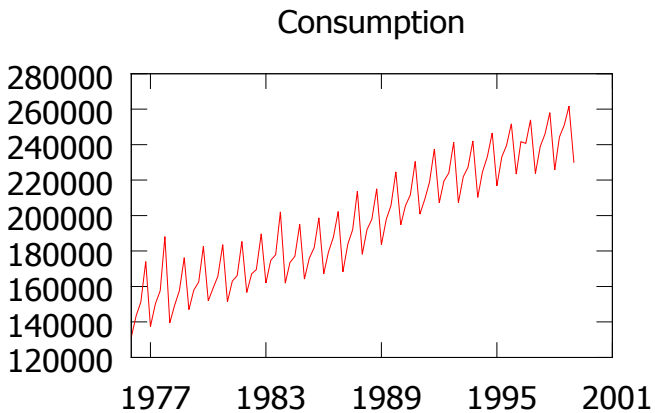
Federal Funds Rate

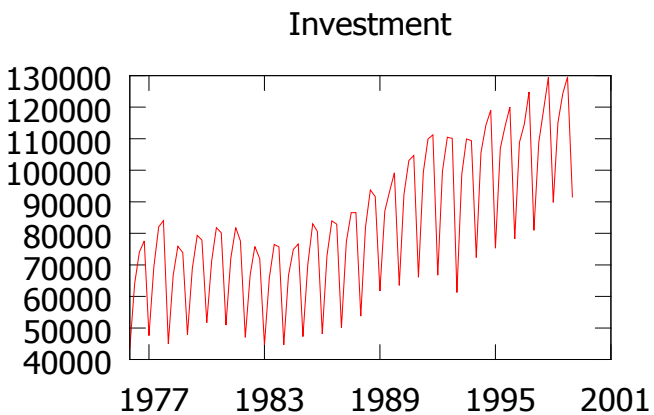


Austrian Macro Data

GDP, Consumption and Investment

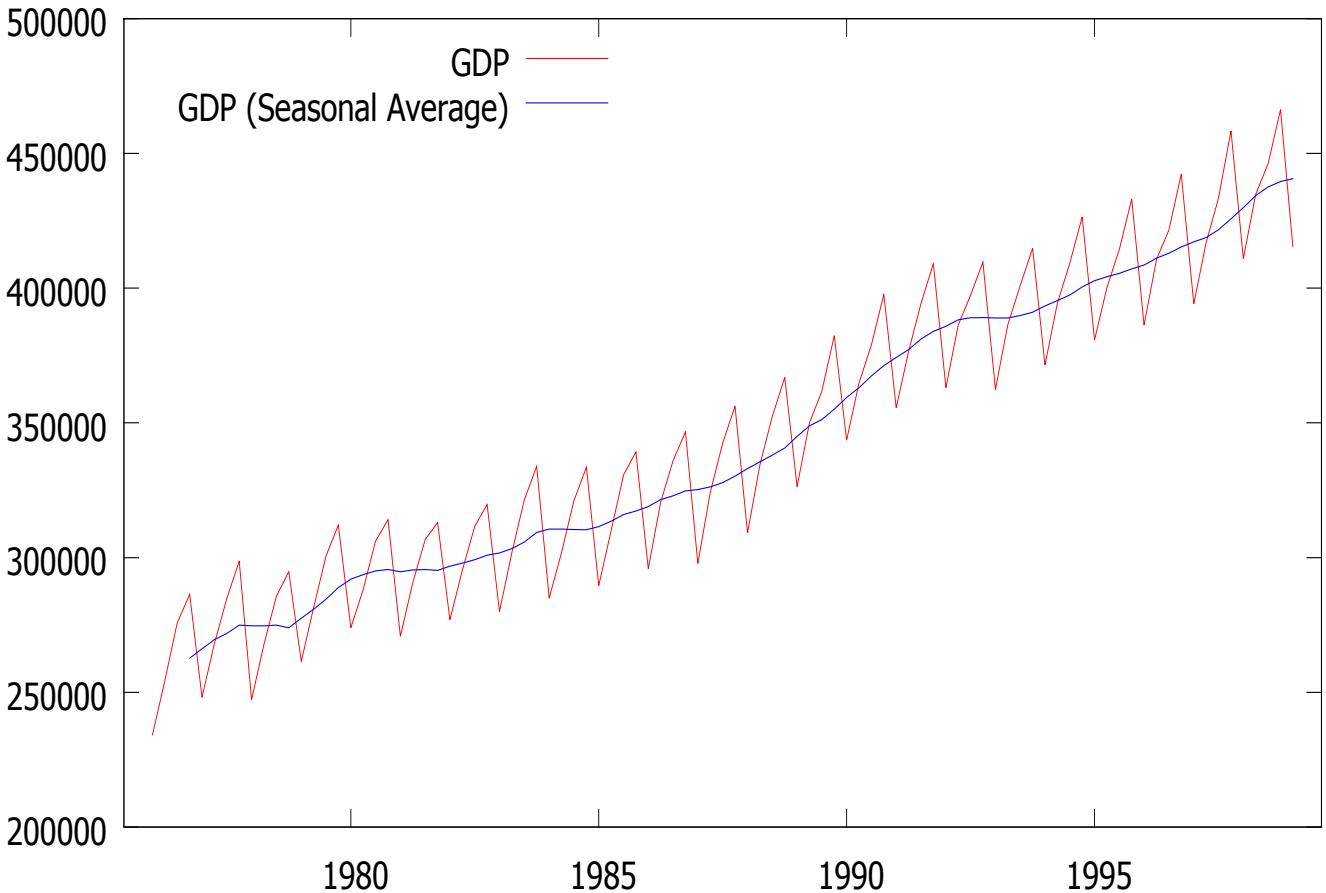






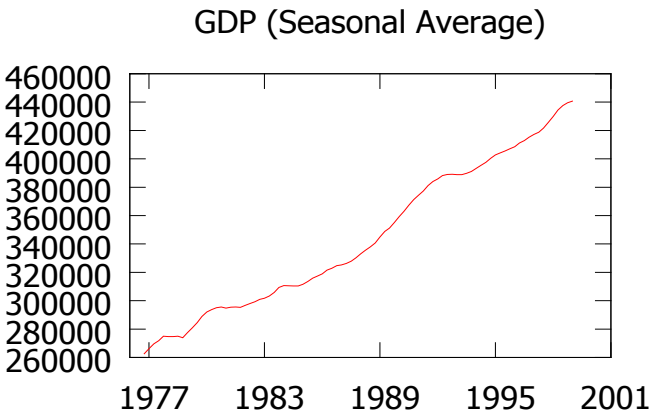
Austrian Macro Data

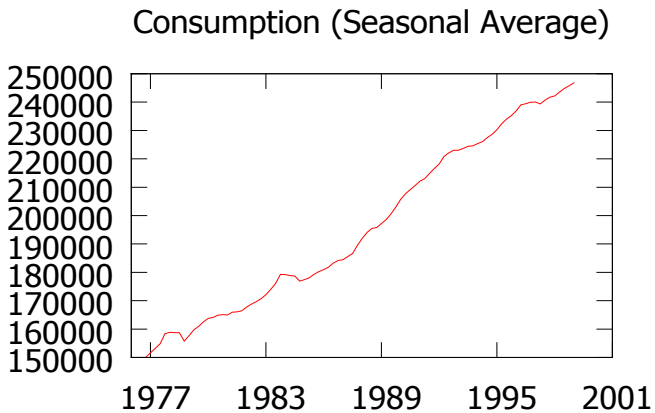
GDP: Raw Data and Seasonally Averaged

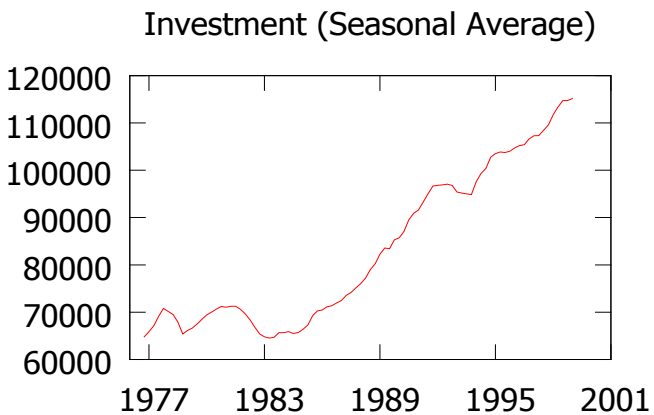


Austrian Macro Data

GDP, Consumption and Investment: Seasonally Averaged

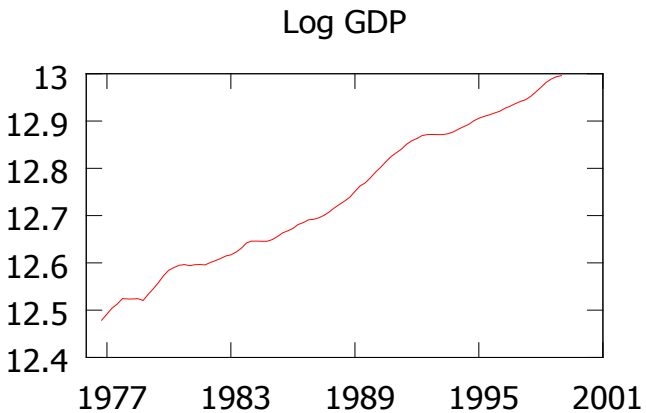


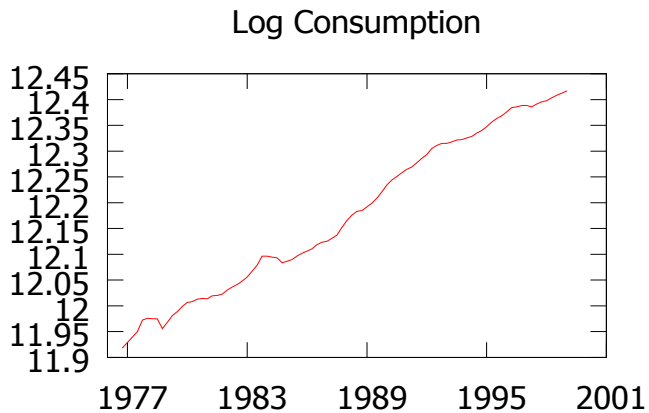


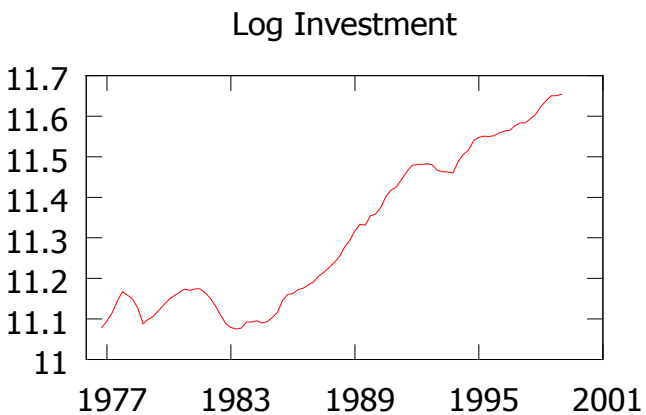


Austrian Macro Data

GDP, Consumption and Investment: Logarithms

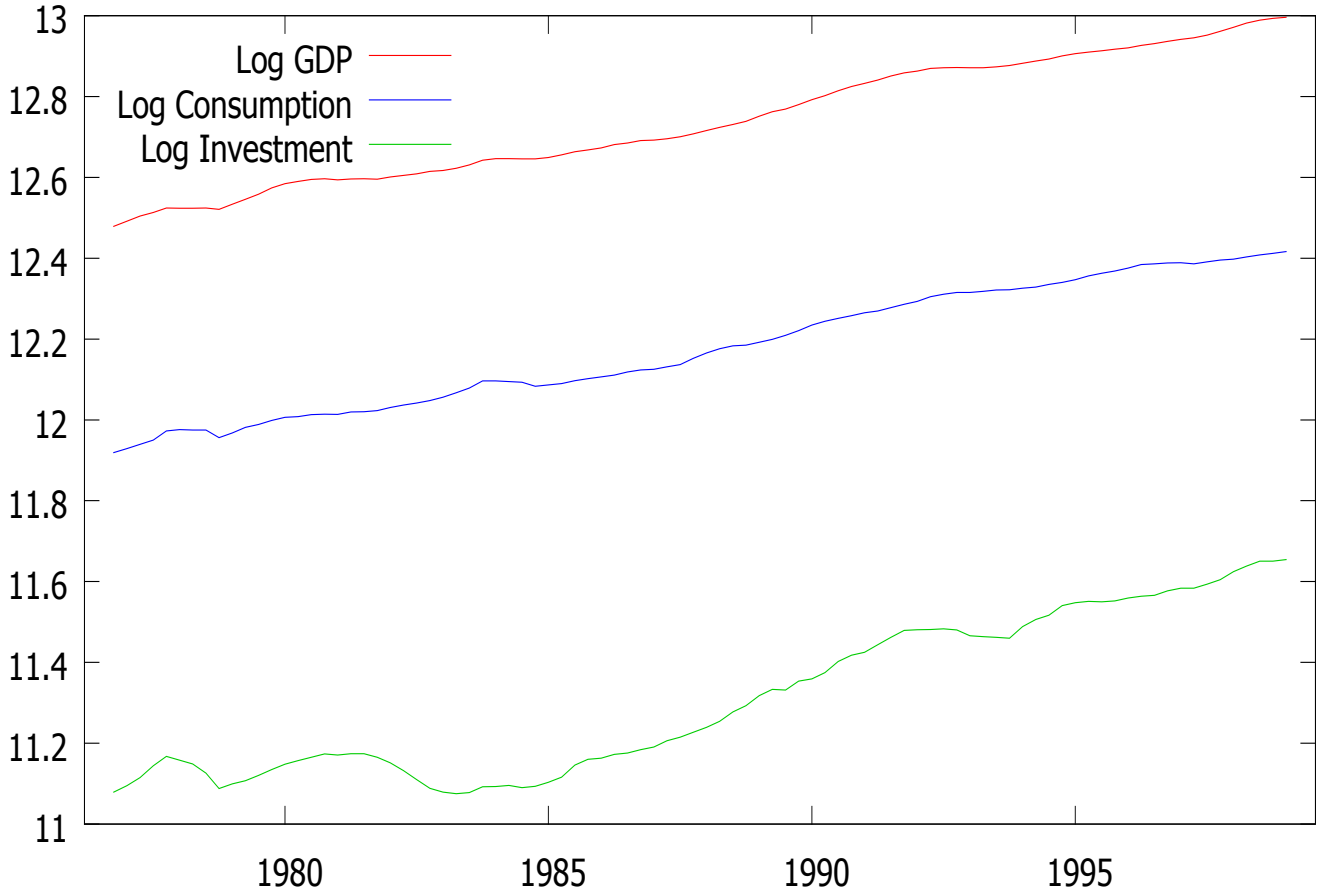






Austrian Macro Data

GDP, Consumption and Investment: Logarithms



Austrian Macro Data

GDP, Consumption and Investment: Growth Rates