Applying Markov Chains to replicate Fed's Monetary Policy Decisions

Francesco Mosti

Master in Data Science and Statistical Learning - UniFi
2024/2025 Edition

07/04/2025

Overview of the presentation

Monetary Policies in the economic context:

- Business cycles
- Central Banks and the importance of Monetary Policy as a *tool*

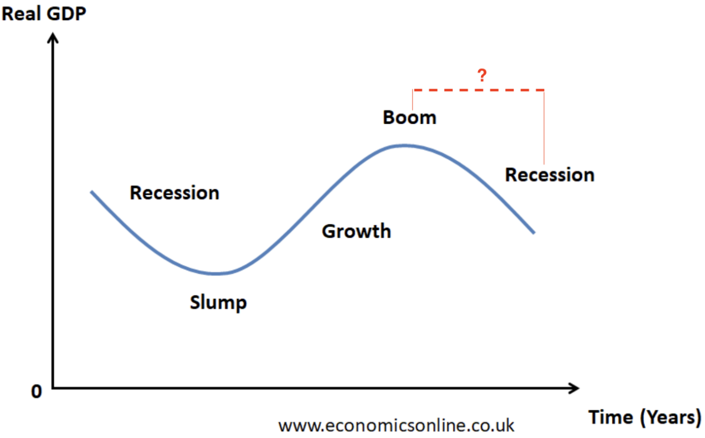
A little implementation in Python:

- Can we replicate FED's decisions with a Markov Process?
  - Chosen Economic variables
- Results: Plots, Transition Matrices, comments

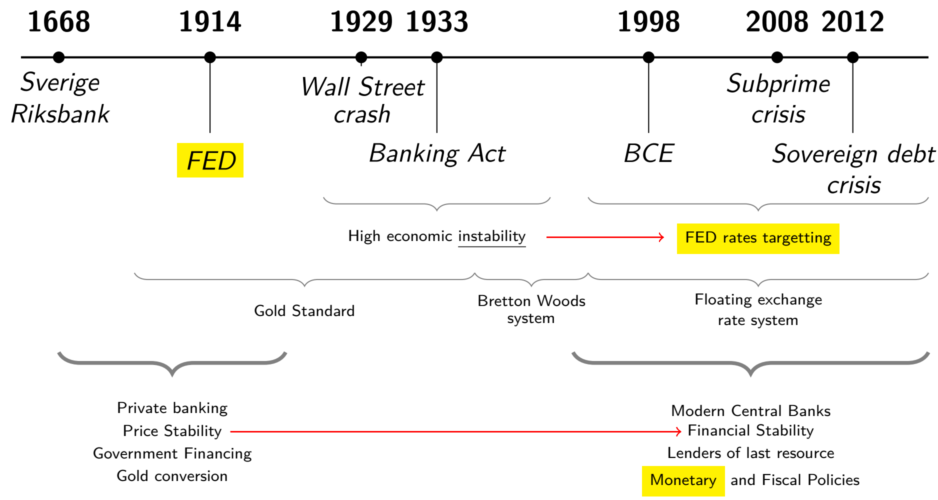
Section 1

Monetary Policies in the Economic Context

The 4 Business Cycles:



Banking over time: (in yellow our focus)



Section 2

Replicating FED's Monetary Policy Decisions with a Markov Process

Objective:

Find a set of proxies which, using the Markov Property, would allow to replicate Fed's decisions as a Markov Chain switching between 3 states:

1. Expansive Monetary Policy (Dovish)
2. Restrictive Monetary Policy (Hawkish)
3. Neutral / Stable Monetary Policy

Implementation:

- Compute transition matrices counting state transitions in the monthly historical series of three sets of variables:
  1. Federal Funds rate
  2. Inflation rate + Unemployment rate
  3. Inflation rate + Unemployment rate + % change in Real GDP
- Compare the three experiments with reality.

1. Federal Funds Rate

Imposing transition criteria on Fed's Fund Rate:

- Before mid-1990s:

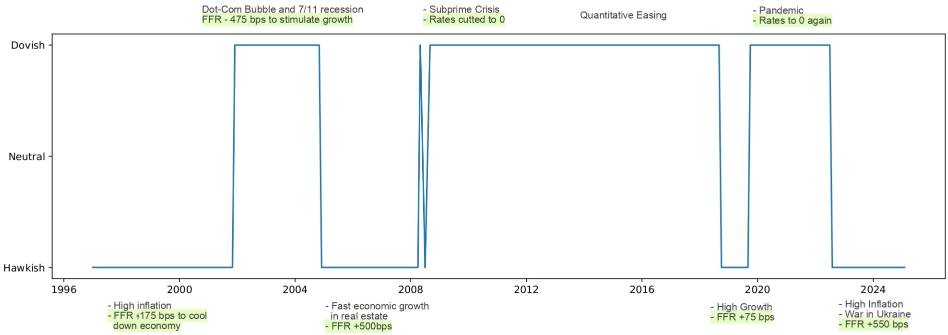
```
def type_policy_simple(curr_fed_fund,prev_fed_fund,multiplier =
    0.97):
    if curr_fed_fund < prev_fed_fund * multiplier:
        return "Dovish"
    elif curr_fed_fund > prev_fed_fund / multiplier:
        return "Hawkish"
    else:
        return "Neutral"
```

- After mid-1990s (FED transitions to inflation targetting):

```
def type_policy_target(curr_fed_fund,prev_fed_fund,
    inflation_target=2):

    if curr_fed_fund < inflation_target:
        return "Dovish"
    elif curr_fed_fund > inflation_target:
        return "Hawkish"
    else:
        return "Neutral"
```

Here we try to associate empirical states, obtained via **FFR proxy**, with true business cycles fluctuations during the past 30 years:
(Hawkish = Restrictive, Dovish = Expansive).



- ✓ Comparing only the latest state for FFR with the inflation target, we are able to capture most of the biggest economic fluctuations.
- ✓ This is relatively easy to find, since Federal Funds Rates are **directly imposed by the FED** as their main Monetary Policy tool.
- ✗ Problem: Looking at the plot we don't see intermediate transitions to neutral state.. this differs highly from reality!

2. Inflation + Unemployment

Quick look:

Inflation and Unemployment: Phillips Curve *(..flattening)*.

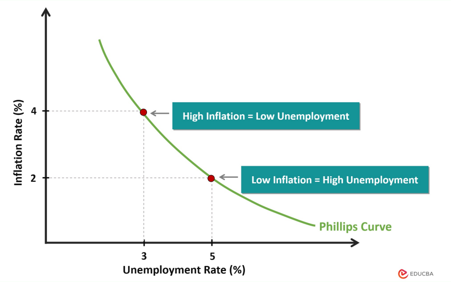


Figure: Original Phillips Curve (1958)

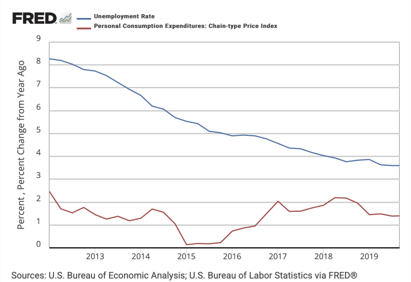


Figure: Phillips Curve today

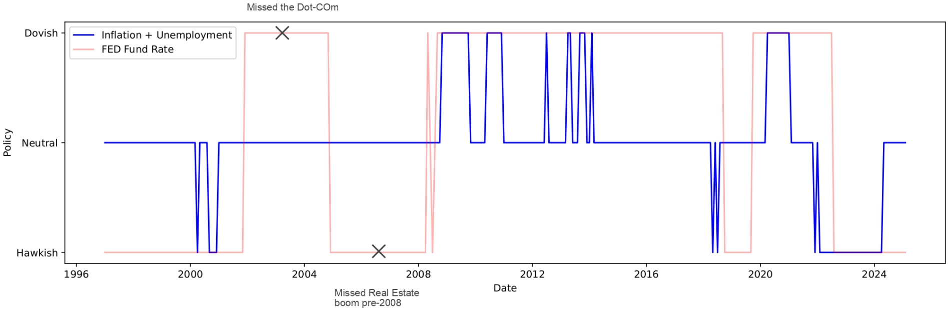
Imposing transition criteria on Unemployment and Inflation..

- Here we consider the entire series by imposing **arbitrary** intervals of "intensity" for the two variables, based on practicioners:

```python
def my_policy(inflation, unemployment, h_inf = 2.75, l_inf = 1.5,
    h_un = 6, l_un = 4):

    if inflation < l_inf and unemployment > h_un:
        return "Dovish"
    elif inflation > h_inf and unemployment < l_un:
        return "Hawkish"
    else:
        return "Neutral"
```

Here we try to associate empirical states, obtained via **Unemployment rate and Inflation proxy**, with true business cycles fluctuations during the past 30 years:
(Hawkish = Restrictive, Dovish = Expansive).



- ✗ The Chain is not able to capture every economic cycles fluctuation, and is less stable than the previous.
- ✓ The biggest cycles are replicated correctly and, as it happens in practice, there are intermediate transitions to the Stable state.

Fed Funds Rates

	Dovish	Neutral	Hawkish
Dovish	0.9792	0.0052	0.0156
Neutral	0.5	0.0	0.5
Hawkish	0.0210	0.0070	0.9720

- ✓ $|E| < \infty$ and Irreducible chain $\rightarrow$ Unique stationary distribution.
- ✗ Persistence in the Neutral state has 0 probability, and transitions to it too little. Not coherent with practice.
- ✓ More "sticky" in two states. Coherent with reality, since non-neutral monetary policies do not fluctuate much.
- ✓ Direct transitions from Hawkish to Dovish (and back) have small probabilities.

Inflation + Unemployment

	Dovish	Neutral	Hawkish
Dovish	0.7978	0.2022	0.0
Neutral	0.0183	0.9644	0.0173
Hawkish	0.0	0.1504	0.8496

- ✓ $|E| < \infty$ and Irreducible chain $\rightarrow$ Unique stationary distribution.
- ✓ It allows persistence in the Neutral State and transitions to it have higher probabilities, coherently with practice.
- ✗ Less stable, more frequent fluctuations in non-neutral periods.
- ✗ Does not allow direct transitions in both directions from Hawkish to Dovish. Not coherent, it could (rarely) happen.

- FED uses a **smooth** transition between Policies, and it cannot be zero as in the second case. *Dov to Haw* $>$ *Haw to Dov* is coherent with the first, in practice.
- For this reason, Neutral state is better represented in the second case.

Finding Stationary Distributions example: Second Case

We want to solve the system:

$$\begin{cases} \pi_d = 0.7978\,\pi_d + 0.0183\,\pi_n + 0 \cdot \pi_h \\ \pi_n = 0.2022\,\pi_d + 0.9644\,\pi_n + 0.1504\,\pi_h \\ \pi_h = 0 \cdot \pi_d + 0.0173\,\pi_n + 0.8496\,\pi_h \\ \pi_d + \pi_n + \pi_h = 1 \end{cases} \Rightarrow \begin{cases} \pi_d(1 - 0.7978) = 0.0183\,\pi_n \\ \pi_h(1 - 0.8496) = 0.0173\,\pi_n \\ \pi_d + \pi_n + \pi_h = 1 \end{cases}$$

$$\begin{cases} \pi_d = 0.0905\,\pi_n \\ \pi_h = 0.115\,\pi_n \\ 0.0905\,\pi_d + \pi_n + 0.115\,\pi_h = 1 \end{cases} \Rightarrow \begin{cases} \pi_d \simeq 0.0751 \\ \pi_n \simeq 0.8295 \\ \pi_h \simeq 0.0954 \end{cases}$$

To verify stationarity, we need to test: $\pi\,\mathrm{P} = \pi$.

$$\begin{aligned} \pi_d P_{11} + \pi_n P_{21} + \pi_h P_{31} &= 0.7978\,(0.0751) + 0.0183\,(0.8925) + 0 = \mathbf{0.0751} \\ \pi_d P_{12} + \pi_n P_{22} + \pi_h P_{32} &= 0.2022\,(0.0751) + 0.9644\,(0.8295) + 0.1504\,(0.0954) = \mathbf{0.8925} \qquad \checkmark \\ \pi_d P_{13} + \pi_n P_{23} + \pi_h P_{33} &= 0 + 0.0173\,(0.8295) + 0.8496\,(0.0954) = \mathbf{0.0954} \end{aligned}$$

With the same procedure, in the first case we get:

$$\begin{aligned} \pi_d &\simeq 0.5704 \\ \pi_n &\simeq \color{red}{0.0059} \\ \pi_h &\simeq 0.4237 \end{aligned}$$

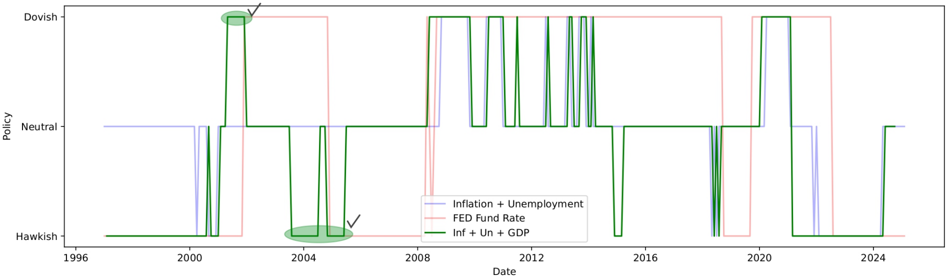
3. Inflation + Unemployment + change in Real GDP

Imposing transition criteria on Unemployment + Inflation + GDP..

```
def my_policy3(inflation, unemployment, gdp_growth, h_inf=2.75, l_inf
    =1.5, h_un=6, l_un=4, h_gdp=3.5, l_gdp=1.0):

    if (inflation < l_inf and unemployment > h_un) or gdp_growth <
        l_gdp:
        return "Dovish"
    elif (inflation > h_inf and unemployment < l_un) or gdp_growth >
        h_gdp:
        return "Hawkish"
    else:
        return "Neutral"
```

..What if we add to the second set of variables the % change in GDP?



	Dovish	Neutral	Hawkish
Dovish	0.8418	0.1448	0.0135
Neutral	0.0311	0.9391	0.0298
Hawkish	0.0016	0.0763	0.9221

Exp 1

$\pi_d \simeq 0.5704$
$\pi_n \simeq 0.0059$
$\pi_h \simeq 0.4237$

Exp 2

$\pi_d \simeq 0.0751$
$\pi_n \simeq 0.8295$
$\pi_h \simeq 0.0954$

$\boxed{\textbf{Exp 3}}$

$\pi_d \simeq 0.1241$
$\pi_n \simeq 0.6181$
$\pi_h \simeq 0.2578$

Best of both.. ?

- ✓ We are able to capture the two missing cycles.
- ✓ Neutral state treated correctly, with a scaled probability.
- ✓ Much more similar to reality.
- ✗ In some cases, still unwanted fluctuations.

Conclusions

1. We tried to model a sequence of Monetary Policy periods as a Markov Chain, for three sets of proxies.
   Each set of variables has its own pros and cons:
   - Capacity of capturing economic booms/downturns
   - Stable pattern
   - Smooth transitions (passing through Neutral state)
2. Once obtained a satisfactory transition matrix one could use it to **simulate** future scenarios.
3. These were very simple examples.
   Markov Chain are a research topic in Macroeconomics, especially in forecasting, but **their use in Policy Making is limited** and supported by a vastity of other analysis.
   - Simplicistic approach to economic regimes.
   - Dependence only on the latest state (e.g. not true if we introduce future **Expectations**)
   - Fixed transition matrices (e.g in the last 30y is different form before).