The Great Inflation and the Greenbook

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The Great Inflation

The Great Inflation is the climactic monetary event of the latter part of the twentieth century. Two explanations: Federal Reserve was constrained by need to finance expansionary fiscal policy (politics view); Federal Reserve was constrained by misguided economic framework of the time (ideas view). Most evidence to date has been based on reading of narrative record, e.g., Meltzer (2005) vs. Romer (2005). Very few attempts to empirically test alternative explanations using dynamics of the macroeconomy during the Great Inflation.
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Learning and the Great Inflation

Sargent’s Conquest of American Inflation proposes that Great Inflation was caused by Federal Reserve discovering and then abandoning the Phillips curve. Sargent, Williams and Zha (2006) take the learning hypothesis to data and are remarkably successful at explaining what the Federal Reserve did. We ask whether SWZ are also able to explain why the Federal Reserve acted as it did. We use forecast data from the Greenbooks to implicitly identify the rationale behind policy.

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Summary of our results

The Federal Reserve forecasts in the estimation results of SWZ are not consistent with those published in the Greenbook. If consistency with Greenbook forecasts is imposed, then the learning hypothesis struggles to explain the dynamics of the Great Inflation. The deterioration in the dollar is robust to popular alternative specifications of the objectives of Federal Reserve policy.
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- If consistency with Greenbook forecasts is imposed then the learning hypothesis struggles to explain the dynamics of the Great Inflation.
- The deterioration in fit is robust to popular alternative specifications of the objectives of Federal Reserve policy.
A simple model for the Federal Reserve

\[ u_t = \alpha_0 t \Phi_t + \sigma w_t \Phi_t = (\pi_t \pi_t^1 u_t^1 \pi_t^2 u_t^2) \]

\( \pi_t \) is the policy instrument

\( u_t \) is the outcome of policy
A simple model for the Federal Reserve

- Federal Reserve assumed to have an approximating model of unemployment-inflation dynamics

\[ u_t = \alpha_t \Phi_t + \sigma_w w_t \quad \Phi_t = \begin{pmatrix} \pi_t & \pi_{t-1} & u_{t-1} & \pi_{t-2} & u_{t-2} & 1 \end{pmatrix} \]
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Federal Reserve learning
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- Federal Reserve believes that $\alpha_t$ follows a drifting coefficients model

\[
\begin{align*}
    u_t &= \alpha_t' \Phi_t + \sigma_w w_t \\
    \alpha_t &= \alpha_{t-1} + \Lambda_t
\end{align*}
\]

\[
\begin{align*}
    w_t &\sim N(0,1) \\
    \Lambda_t &\sim N(0,\Sigma)
\end{align*}
\]
Federal Reserve learning

- Federal Reserve believes that $\alpha_t$ follows a drifting coefficients model
  \[ u_t = \alpha'_t \Phi_t + \sigma_w w_t \quad N(0,1) \]
  \[ \alpha_t = \alpha_{t-1} + \Lambda_t \quad N(0,V) \]

- Coefficients can be estimated by recursive application of Kalman filter
  \[ \hat{\alpha}_{t+1|t} = \hat{\alpha}_{t|t-1} + \frac{P_{t|t-1} \Phi_t \left( u_t - \Phi'_t \hat{\alpha}_{t|t-1} \right)}{\sigma_w^2 + \Phi'_t P_{t|t-1} \Phi_t} \]
  \[ P_{t+1|t} = P_{t|t-1} - \frac{P_{t|t-1} \Phi_t \Phi'_t P_{t|t-1}}{\sigma_w^2 + \Phi'_t P_{t|t-1} \Phi_t} + V \]
Definition of optimal policy
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- Policy problem of Federal Reserve

\[
\min_{\{\pi_t\}_{t=0}^{\infty}} \hat{E} \sum_{j=0}^{\infty} \delta^j \left\{ (\pi_{t+j} - \pi^*)^2 + \lambda (u_{t+j} - u^*)^2 \right\} \\
\text{s.t.} \\
u_{t+j} = \alpha'_{t+j} \Phi_{t+j} + \sigma_w w_{t+j} \\
\hat{\alpha}_{t+j+1|t+j} = \hat{\alpha}_{t+j|t+j-1} + \frac{P_{t+j|t+j-1} \Phi_{t+j} (u_{t+j} - \Phi'_{t+j} \hat{\alpha}_{t+j|t+j-1})}{\sigma_w^2 + \Phi'_t + \hat{\alpha}_{t+j|t+j-1} \Phi_{t+j}} \\
P_{t+j+1|t+j} = P_{t+j|t+j-1} - \frac{P_{t+j|t+j-1} \Phi_{t+j} \Phi'_{t+j} P_{t+j|t+j-1}}{\sigma_w^2 + \Phi'_t + \hat{\alpha}_{t+j|t+j-1} \Phi_{t+j}} + \nabla
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s.t.

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u_{t+j} = \alpha'_{t+j} \Phi_{t+j} + \sigma_w w_{t+j}
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\]

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P_{t+j+1|t+j} = P_{t+j|t+j-1} - \frac{P_{t+j|t+j-1} \Phi_{t+j} \Phi'_{t+j} P_{t+j|t+j-1} \Phi_{t+j}}{\sigma_w^2 + \Phi'_{t+j} P_{t+j|t+j-1} \Phi_{t+j}} + V
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- Assume Federal Reserve uses ‘anticipated utility’ (Kreps (1998)) as decision criterion. Federal Reserve then projects forward using current parameter estimates and approximating model
Optimal ‘anticipated utility’ policy
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- Standard linear-quadratic problem

\[
\min_{\{\pi_t\}_{t=0}^{\infty}} \mathbb{E} \sum_{j=0}^{\infty} \delta^j \left\{ (\pi_{t+j} - \pi^*)^2 + \lambda (\tilde{u}_{t+j} - u^*)^2 \right\}
\]

s.t.

\[
\tilde{u}_{t+j} = \hat{\alpha}'_{t|t-1} \hat{\Phi}_{t+j}
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\]

- Solution is a best-response policy function

\[
\pi_t = h(\hat{\alpha}_{t|t-1})' \phi_t \quad \phi_t = (\pi_{t-1} \ u_{t-1} \ \pi_{t-2} \ u_{t-2} \ 1)
\]
Estimation without Greenbook data

Best-response policy function is an approximation of Federal Reserve behaviour

\[ \pi_t = h(\hat{\alpha}_t^j t^1) \phi_t + \sigma_2 w^2 t \hat{\alpha}_t^j + j + 1 \]

This model can be estimated from data on inflation and unemployment.
Estimation without Greenbook data

- Best-response policy function is an approximation of Federal Reserve behaviour

$$\pi_t = h(\hat{\alpha}_{t|t-1})' \phi_t + \sigma_2 w_{2t}$$

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- This model can be estimated from data on inflation and unemployment

- Free parameters \( \left( \sigma_2 \delta \lambda u^* \pi^* \sigma_w \nu \hat{\alpha}'_1 P_{1|0} \right) \)
Avoiding overparameterisation

4 parameters are calibrated from macro studies

\[ \delta = 0.9936 \]

\[ \lambda = 1 \pi \]

\[ \mu = 1 \]

Initial values \( \hat{\alpha}_j \) for Kalman filter from training sample 1948:1-1959:12

\[ \sigma_w \] not identified so normalised

\[ \Xi = \sigma^2_P \]

parameters left to estimate
Avoiding overparameterisation

- 4 parameters are calibrated from macro studies

\[ \delta = 0.9936 \quad \lambda = 1 \quad \pi^* = 2 \quad u^* = 1 \]
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- \( \Xi = \begin{pmatrix} \sigma_2 & P_{1|0} & V \end{pmatrix} \) parameters left to estimate
Estimation strategy

$$\xi = \left( \frac{\sigma^2}{\sigma_j^2} \right)_{\phi}$$

Factorise joint distribution and apply Gibbs sampler to draw successively from conditional distributions

$\sigma^2$ has conjugate inverse-gamma prior

$\phi$ has no suitable conjugate prior, so Metropolis algorithm used to generate draws for Gibbs sampler

Priors loose as is SWZ

Data 1960:1 - 2003:12 annual PCE inflation and civilian unemployment rate
Estimation strategy

\[ \Xi = \left( \begin{array}{c} \sigma_2 \\ P_{1|0} \\ V \\ 1/\sigma_2 \\ \varphi \end{array} \right) \]

Factorise joint distribution and apply Gibbs sampler to draw successively from conditional distributions. \( \sigma_2 \) has conjugate inverse-gamma prior. \( \varphi \) has no suitable conjugate prior, so Metropolis algorithm used to generate draws for Gibbs sampler. Priors loose as is SWZ. Data 1960:1 - 2003:12 annual PCE in‡ation and civilian unemployment rate.
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\[ \Xi = (\sigma_2, P_{1|0}, V) \]

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\[ \frac{1}{\sigma_2}, \phi \]

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- Priors loose as is SWZ
- Data 1960:1 - 2003:12 annual PCE inflation and civilian unemployment rate
Inflation without Greenbook data

\[ \sigma^2 = 0.23 \]

- This fit is the source of SWZ claim that the learning hypothesis can explain the Great Inflation.
The Phillips curve without Greenbook data
The Phillips curve without Greenbook data

- Evolution of perceived Phillips curve trade-off, as measured by sum of coefficients on inflation in Federal Reserve’s approximating model of unemployment-inflation dynamics

![Graph showing the evolution of the sum of Phillips curve coefficients over time from 1960 to 2005. The graph indicates a decline in the 1960s and early 1970s, followed by a more stable period, and a recent increase towards the end of the period.]
The Phillips curve without Greenbook data

- Evolution of perceived Phillips curve trade-off, as measured by sum of coefficients on inflation in Federal Reserve’s approximating model of unemployment-inflation dynamics

- Clear evidence of discovery and abandonment of Phillips curve
Unemployment forecasts

Federal Reserve approximating model

$$\begin{align*}
\gamma_t &= \alpha_0 t \Phi_t + \sigma_w w_t \\
\Phi_t &= (\pi_t \pi_t)^1 u_t^1 \pi_t^2 u_t^2^1)
\end{align*}$$

Best-response policy function

$$\pi_t = h(\hat{\alpha}_t j_t^1)$$

These can be compared to unemployment forecasts published in the Greenbooks.
Unemployment forecasts

- Federal Reserve approximating model

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Unemployment forecasts

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- Together these imply unemployment forecasts of the form

\[ \hat{E}(u_t) = g(\hat{\alpha}_{t|t-1})' \phi_t \]
Unemployment forecasts

- Federal Reserve approximating model
  \[ u_t = \alpha_t^' \Phi_t + \sigma_w w_t \quad \Phi_t = (\pi_t \, \pi_{t-1} \, u_{t-1} \, \pi_{t-2} \, u_{t-2} \, 1) \]

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- Together these imply unemployment forecasts of the form
  \[ \hat{E}(u_t) = g(\hat{\alpha}_{t|t-1})'\phi_t \]

- These can be compared to unemployment forecasts published in the Greenbooks
Unemployment forecasts without Greenbook data

Unemployment forecasts are much too volatile in the estimated model Change forecasts \( \hat{E}(u_{t+1}) \) are completely uncorrelated with Greenbook forecasts. Actual and fitted forecasts are not consistent.
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Unemployment forecasts are much too volatile in the estimated model.

Change forecasts $\hat{\mathbb{E}}(u_t - u_{t-1})$ are completely uncorrelated with Greenbook forecasts. Actual and fitted forecasts are not consistent.
Estimation with Greenbook data

πₜ = \( h(\hat{\alpha}_t j t + 1) \) + \( \phi_t + \sigma^2 w^2_t \)

\( \hat{\alpha}_t j t + 1 + p_t j t + 1 + \Phi_t + \Phi_0 t + p_t j t + 1 + \Phi_t + \Phi_0 t + \sigma^2 w + \Phi_0 t + p_t j t + 1 + \Phi_t + \Phi_0 t = P_t + j P_t + 1 j t + \Phi_t + \Phi_0 t + p_t j t + 1 + \Phi_t + \Phi_0 t + \sigma^2 w + \Phi_0 t + p_t j t + 1 + \Phi_t + \Phi_0 t \)

\( h() \) and \( g() \) are functions of the same structural parameters
Estimation with Greenbook data

- Inconsistence suggests model should be estimated using both aggregate data and Greenbook forecasts

\[ \pi_t = h(\hat{\alpha}_{t|t-1})' \phi_t + \sigma_2 w_{2t} \]

\[ E^{GB}(u_t) = g(\hat{\alpha}_{t|t-1})' \phi_t + \sigma_3 w_{3t} \]

\[ \hat{\alpha}_{t+j+1|t+j} = \hat{\alpha}_{t+j|t+j-1} + \frac{P_{t+j|t+j-1} \Phi_{t+j}}{\sigma_2^{2} + \Phi_{t+j}'} P_{t+j|t+j-1} \Phi_{t+j} \]

\[ P_{t+j+1|t+j} = P_{t+j|t+j-1} - \frac{P_{t+j|t+j-1} \Phi_{t+j} \Phi_{t+j}'}{\sigma_2^{2} + \Phi_{t+j}'} P_{t+j|t+j-1} \Phi_{t+j} + V \]
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- \( h(\cdot) \) and \( g(\cdot) \) are functions of the same structural parameters
- ‘Irrational Expectations Econometrics’ because we estimate according to a cross-equation restriction
Estimation with Greenbook data

- Inconsistence suggests model should be estimated using both aggregate data and Greenbook forecasts

\[ \pi_t = h(\hat{\alpha}_{t|t-1})' \phi_t + \sigma_2 w_{2t} \]

\[ E^{GB}(u_t) = g(\hat{\alpha}_{t|t-1})' \phi_t + \sigma_3 w_{3t} \]

\[ \hat{\alpha}_{t+j+1|t+j} = \hat{\alpha}_{t+j|t+j-1} + \frac{P_{t+j|t+j-1} \Phi_{t+j} (u_{t+j} - \Phi'_{t+j} \hat{\alpha}_{t+j|t+j-1})}{\sigma^2_w + \Phi'_t \Phi_t \Phi'_{t+j} P_{t+j|t+j-1} \Phi_{t+j}} \]

\[ P_{t+j+1|t+j} = P_{t+j|t+j-1} - \frac{P_{t+j|t+j-1} \Phi_{t+j} \Phi'_{t+j} P_{t+j|t+j-1} \Phi'_{t+j} P_{t+j|t+j-1} \Phi_{t+j}}{\sigma^2_w + \Phi'_t \Phi_t \Phi'_{t+j} P_{t+j|t+j-1} \Phi_{t+j}} + V \]

- \( h(\cdot) \) and \( g(\cdot) \) are functions of the same structural parameters
- ‘Irrational Expectations Econometrics’ because we estimate according to a cross-equation restriction
- Extra parameter \( \sigma_3 \) implies minor changes to estimation algorithm
Inflation with Greenbook data

\[ \sigma^2 = 0.52 \]

Fit to inflation now worse than before (when \( \sigma^2 = 0.23 \)).

Consistency learning hypothesis has trouble explaining the Great Inflation.
Inflation with Greenbook data

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How much of the learning story is left?
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![Graph showing sum of π coefficients](chart.png)
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- Imposing consistency means Federal Reserve perceives coefficients as drifting less.
- Reduced coefficient drift is reflected in evolution of perceived Phillips curve trade-off.

- Discovery and abandonment of Phillips curve less dramatic than before.
Unemployment forecasts with Greenbook data

As expected, the fit to Greenbook forecasts has improved. Change forecasts $\hat{E}(u_t - u_{t-1})$ are now significantly correlated.

But this is only at cost of worse fit to dynamics of Great Inflation.
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Two robustness exercises

1. Parameter uncertainty
   - Relax anticipated utility assumption that Federal Reserve ignores uncertainty when setting policy
   - Potentially important as uncertainty is pervasive, e.g. in perceived Phillips curve

2. Policy smoothing
   - Introduce additional motivation to smooth policy, e.g. to reduce risk of financial instability
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Parameter uncertainty

Generalised objective for policy

\[ \min_{\pi_{\mathbf{t}}} \sum_{j=0}^{\infty} \delta^j n \left( \pi_{\mathbf{t}} + j \right) + \lambda \left( \tilde{u}_{\mathbf{t}} + j \right)^2 + \text{var} \left( u_{\mathbf{t}} + j \right) \]

Project bias term forward using Kreps (1998) 'anticipated utility' as before

\[ \tilde{u}_{\mathbf{t}} + j = \hat{\alpha}_0 t + j \hat{\phi}_t \]

Project variance term forward using Sack (2000) approximation

\[ \text{var} \left( u_{\mathbf{t}} + j \right) = \tilde{\phi}_0 t + j P_t + j \tilde{\phi}_t \]

Best-response policy function

\[ \pi_{\mathbf{t}} = h \left( \hat{\alpha}_0 t + j ; P_t + j \right) \]

Policy now depends on current parameter estimates \( \hat{\alpha}_0 t + j \) and precision with which they are estimated \( P_t + j \).
Parameter uncertainty

- Generalised objective for policy

\[
\min_{\{\pi_t\}_{t=0}^{\infty}} \hat{E} \sum_{j=0}^{\infty} \delta^j \left\{ (\pi_{t+j} - \pi^*)^2 + \lambda((\tilde{u}_{t+j} - u^*)^2 + \text{var}(u_{t+j})) \right\}
\]
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- Project bias term forward using Kreps (1998) ‘anticipated utility’ as before

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\tilde{u}_{t+j} = \hat{\alpha}'_{t|t-1} \hat{\Phi}_{t+j}
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Parameter uncertainty

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\[
\text{var}(u_{t+j}) = \tilde{\Phi}'_{t+j} P_{t|t-1} \tilde{\Phi}_{t+j}
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Parameter uncertainty

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\min_{\{\pi_t\}^\infty_{t=0}} \hat{E} \sum_{j=0}^\infty \delta^j \left\{ (\pi_{t+j} - \pi^*)^2 + \lambda((\tilde{u}_{t+j} - u^*)^2 + \text{var}(u_{t+j})) \right\}
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Results with parameter uncertainty

Parameter Baseline model Parameter uncertainty

\[ \sigma_2 \quad 0.52 \quad 0.57 \]

\[ \sigma_3 \quad 0.31 \quad 0.26 \]

log-likelihood

\[ 258.1 \quad 208.3 \]
Results with parameter uncertainty

- Significant improvement in statistical fit of model

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- No change in economic fit of model
Policy smoothing

\[
\min_{\pi_t} \sum_{j=0}^{\infty} \delta_j n(\pi_t + j \pi_t)^2 + \lambda (\tilde{u}_t + j u_t)^2 + 0.5 (\Delta \pi_t + j)^2
\]

Results

Parameter | Baseline model | Policy smoothing
\hline
\(\sigma^2\) | 0.52 | 0.49
\(\sigma^3\) | 0.31 | 0.27
log-likelihood | 258.1 | 152.2

Smoothing does improve the fit of the model in a statistical sense, but not in an economic sense.
Policy smoothing

- Policy objective under smoothing

\[
\min_{\{\pi_t\}_{t=0}^{\infty}} \hat{E} \sum_{j=0}^{\infty} \delta^j \left\{ (\pi_{t+j} - \pi^*)^2 + \lambda (\tilde{u}_{t+j} - u^*)^2 + 0.5(\Delta \pi_{t+j})^2 \right\}
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Conclusions

1. Estimation results of SWZ are predicated on the Federal Reserve making very volatile forecasts of unemployment.

2. SWZ explain what the Federal Reserve did, but their explanation for why the Federal Reserve acted in this way is inconsistent with forecasts published in the Greenbooks.

3. Requiring model forecasts to be consistent with Greenbooks makes the learning hypothesis struggle to explain the dynamics of the Great Inflation. The deterioration is robust to other popular objectives for Federal Reserve policy.

4. The door is open to alternative explanations of the Great Inflation.

Giacomo Carboni and Martin Ellison

The Great Inflation and the Greenbook

October 2007
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