EXTREME EVENTS AND THE FED

by

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Extreme Value Theory

Branch of statistics concerned with extreme deviations from the median of probability distributions

Widely used in engineering, where designers seek to protect structures against infrequent, but potentially damaging, events

Economies are also subject to extreme shocks (e.g., oil shocks in the 1970s or the financial shocks in 2008)

It is important to design monetary policy with the possibility of extreme events in mind
Normal Distribution
This Paper

We study the positive and normative implications of extreme events for monetary policy

We construct and estimate a non-linear dynamic model with rigid prices and wages

Derive implications under three policies:
Taylor
Ramsey
Strict inflation targeting

Evaluate the relative contribution of model nonlinearity and shock asymmetry
One Key Issue (Svensson, 2003)

Act prudently and systematically incorporate the possibility of extreme shocks into policy (e.g., by adjusting the inflation target)

or

Follow a wait-and-see approach
Preview of the Results

Structural estimates support the view that shock innovations are drawn from asymmetric distributions.

Due to risk, there is (or there should be) a prudence motive in monetary policy making.

However, optimal (net) inflation is close to zero because inflation costs paid every period override the precautionary benefits of having a non-zero inflation target (see Coibion et al., 2012).

Under both the Taylor and Ramsey policies, the central bank responds non-linearly and asymmetrically to shocks.
Sketch of the Model

**Households**
Monopolistic competitive power over their labor supply
Face convex cost to adjust nominal wages

**Firms**
Produce differentiated goods using labor only
Monopolistic competitive power
Face convex costs to adjust nominal prices

**Monetary Authority (the Fed)**
Selects monetary policy following a Taylor-type rule
Sketch of the Model

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Monopolistic competitive power over their labor supply
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Ramsey Planner
Selects monetary policy to maximize households’ welfare
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Strict Inflation Targeter
Selects monetary policy to achieve an inflation target
Households

Household $n \in [0, 1]$ maximizes

$$E_{\tau} \sum_{t=\tau}^{\infty} \beta^{t-\tau} \left( \frac{(c^h_t)^{1-\chi}}{1-\chi} - \frac{(n^h_t)^{1+\psi}}{z_t(1+\psi)} \right)$$

where

$$c^h_t = \left( \int_{0}^{1} (c^h_{j,t})^{1/\mu} \, dj \right)^{\mu}$$

Households have monopolistic power over their labor supply and, thus, their nominal wage is a choice variable.

Labor market frictions induce a cost in the adjustment of nominal wages ($\Phi^n_t$)
Budget Constraint

Two types of financial assets: one-period nominal bonds and a complete set of Arrow-Debreu securities
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Two types of financial assets: one-period nominal bonds and a complete set of Arrow-Debreu securities

The budget constraint is

\[ c_t^h + \frac{Q_tA_t^h - A_{t-1}^h}{P_t} + \frac{B_t^h - i_{t-1}B_{t-1}^h}{P_t} = (1 - \Phi_t^h) \left( \frac{W_t^h n_t^h}{P_t} \right) + \frac{D_t^h}{P_t}, \]
Budget Constraint

Two types of financial assets: one-period nominal bonds and a complete set of Arrow-Debreu securities

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where

\[ \Phi_t^h = \left( \frac{\phi}{2} \right) \left( \frac{W_t^h}{W_{t-1}^h} - 1 \right)^2 \]
**Budget Constraint**

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where

\[ \Phi^h_t = \left( \frac{\phi}{2} \right) \left( \frac{W^h_t}{W^h_{t-1}} - 1 \right)^2 \]

and

\[ P_t = \left( \int_0^1 \left( P_{i,t} \right)^{1/(1-\mu)} \, di \right)^{1/(1-\mu)} \]

is the price index
Firms

Firm \( j \in [0, 1] \) produces a differentiated good using the technology

\[
y_{j,t} = x_t n_{j,t}^{1-\alpha}
\]

where

\[
n_{j,t} = \left( \int_{0}^{1} (n_{j,h}^t)^{1/\xi} dh \right)^{\xi}
\]

Firms have monopolistic power and, thus, their nominal price is a choice variable

Good market frictions induce a cost in the adjustment of nominal prices:

\[
\Gamma^j_t = \left( \frac{\gamma}{2} \right) \left( \frac{P_{j,t}}{P_{j,t-1}} - 1 \right)^2,
\]
Equilibrium

Symmetric equilibrium: all households and firms are identical \textit{ex-post}

Arrow-Debreu securities and bonds are not held

Economy-wide resource constraint

\[ c_t = y_t - (y_t \Gamma_t + w_t n_t \Phi_t) \]
The Fed

Sets the interest rate following the Taylor-type rule

\[ \ln(i_t/i) = \eta_1 \ln(i_{t-1}/i) + \eta_2 \ln(\Pi_t/\Pi) + \eta_3 \ln(n_t/n) + e_t, \]

where \( \eta_1 \in (-1, 1) \), \( \eta_2 \) and \( \eta_3 \) are parameters.
Shocks

Define

\[ \xi_t = [\ln(z_t) \ln(x_t) \ln(e_t)]' \]

Then

\[ \xi_t = \rho \xi_{t-1} + \epsilon_t \]

where

\[ \rho = \begin{bmatrix}
\rho_z & 0 & 0 \\
0 & \rho_x & 0 \\
0 & 0 & \rho_e \\
\end{bmatrix} \]

and \( \epsilon_t = [\epsilon_{z,t} \epsilon_{x,t} \epsilon_{e,t}]' \) is a vector of i.i.d. innovations

Innovations are a generalized extreme value (GEV) distribution
GEV Distribution

According to the Fisher-Tippett (1928) theorem, the maximum of an i.i.d. series converges in distribution to either the Gumbel, Fréchet or Weibull distributions.

Jenkinson (1955) shows that these three distributions can be represented in a unified way using the GEV distribution.

Three parameters: location, scale, and shape.

The shape parameter controls the thickness of the tail of the distribution.

Positive or negative skewness.

Mean (variance) is not defined when shape parameter is larger than 1 (0.5).
GEV Distribution

Frechet

Weibull

Gumbel
Solution Method

Third-order approximation to policy functions (Jin and Judd, 2002)

In tensor notation

$$[f(x_t, \sigma)]^j = [f(x, 0)]^j + [f_x(x, 0)]_a^j [(x_t - x)^a$$

$$+ (1/2)[f_{xx}(x, 0)]_{ab}^j [(x_t - x)^a [(x_t - x)^b$$

$$+ (1/6)[f_{xxx}(x, 0)]_{abc}^j [(x_t - x)^a [(x_t - x)^b [(x_t - x)^c$$

$$+ (1/2)[f_{\sigma\sigma}(x, 0)]^j[\sigma][\sigma$$

$$+ (1/2)[f_{x\sigma\sigma}(x, 0)]_a^j [(x_t - x)^a[\sigma][\sigma$$

$$+ (1/6)[f_{\sigma\sigma\sigma}(x, 0)]^j[\sigma][\sigma][\sigma]$$

where $x_t$ is a vector with the state variables

If innovation distributions are symmetric, $(1/6)[f_{\sigma\sigma\sigma}(x, 0)]^j[\sigma][\sigma][\sigma] = 0$
Estimation

Simulated Method of Moments (SMM)

\[
\hat{\theta} = \arg\min_{\theta} M(\theta)'W M(\theta)
\]

where

\[
M(\theta) = \frac{1}{T} \sum_{t=1}^{T} m_t - \frac{1}{\lambda T} \sum_{t=1}^{\lambda T} m_t(\theta)
\]

\(T\) is the sample size, \(\lambda\) is a positive constant and \(W\) is a weighting matrix
Asymptotic Distribution

Under the regularity conditions in Duffie and Singleton (1993)

$$\sqrt{T}(\hat{\theta} - \theta) \to N(0, (1 + 1/\lambda)(J'W^{-1}J)^{-1}J'W^{-1}SW^{-1}J(J'W^{-1}J)^{-1})$$

where

$$S = \lim_{T \to \infty} Var\left( \left( \frac{1}{\sqrt{T}} \right) \sum_{t=1}^{T} m_t \right)$$

and

$$J = E\left( \frac{\partial m_t(\theta)}{\partial \theta} \right)$$

is a finite Jacobian matrix of full column rank.
Data

Sample Period and Frequency
Quarterly from 1964Q2 to 2012Q4
Data

Sample Period and Frequency
Quarterly from 1964Q2 to 2012Q4

Series
Real per-capita consumption
Hours worked
Price inflation rate
Wage inflation rate
Nominal interest rate
Data

Sample Period and Frequency
Quarterly from 1964Q2 to 2012Q4

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Real per-capita consumption
Hours worked
Price inflation rate
Wage inflation rate
Nominal interest rate

Moments
Variances, covariances, autocovariances and skewness of all data series
## SMM Estimates: Nominal Rigidity

<table>
<thead>
<tr>
<th>Model</th>
<th>Nonlinear</th>
<th>Linear</th>
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<tr>
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<td>Normal</td>
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<tr>
<td>Parameter</td>
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<tr>
<td>Wages</td>
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<tr>
<td>Prices</td>
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**Note:** s.e. are standard errors computed using a $k$-step block bootstrap with 5 steps and 19 replications. During the estimation $\beta = 0.995$, $\alpha = 1/3$, $\Pi = 1$, $\mu = 1.1$ and $\zeta = 1.4$. 
## SMM Estimates: Productivity Shock

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<td>s.e.</td>
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<td>0.899</td>
<td>0.227</td>
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<td>–</td>
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<td></td>
<td>(-1.204)</td>
<td>0.055</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Standard deviation ( \times 10^{-2} )</td>
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<td>0.999</td>
<td>0.230</td>
<td>1.502</td>
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<td>(-2.655)</td>
<td>0.182</td>
<td>0</td>
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Figure 1: Estimated Cumulative Distribution Function of Productivity Shock

- Nolinear GEV
- Nonlinear Normal
- Linear GEV
## SMM Estimates: Labor Supply Shock

<table>
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<tr>
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<td>s.e.</td>
<td>Estimate</td>
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<td>Autoregressive coefficient</td>
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<td>0.011</td>
<td>0.968</td>
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<td>0.996</td>
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<tr>
<td>Scale ($\times 10^{-4}$)</td>
<td>0.418</td>
<td>0.615</td>
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<td>0.715</td>
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<td>Shape</td>
<td>−3.755</td>
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<td>–</td>
<td>−4.881</td>
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<tr>
<td>Standard deviation ($\times 10^{-2}$)</td>
<td>0.132</td>
<td>0.106</td>
<td>0.758</td>
<td>0.401</td>
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<td>Skewness</td>
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<td>3.252</td>
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<td>−165.6</td>
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Figure 2: Estimated Cumulative Distribution Function of Labor Supply Shock
## SMM Estimates: Taylor Rule

<table>
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<td>GEV</td>
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<tr>
<td></td>
<td>Estimate</td>
<td>s.e.</td>
<td>Estimate</td>
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<td>Smoothing</td>
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<tr>
<td>Inflation</td>
<td>0.384</td>
<td>0.077</td>
<td>0.385</td>
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<td>Output</td>
<td>0.143</td>
<td>0.037</td>
<td>0.137</td>
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<tr>
<td>Scale (&lt;10⁻²)</td>
<td>0.420</td>
<td>0.098</td>
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<tr>
<td>Shape (&lt;10⁻¹)</td>
<td>0.917</td>
<td>1.887</td>
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<tr>
<td>Standard deviation (&lt;10⁻²)</td>
<td>0.532</td>
<td>0.133</td>
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<tr>
<td>Skewness</td>
<td>1.086</td>
<td>1.881</td>
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</table>
Figure 3: Estimated Cumulative Distribution Function of Monetary Policy Shock

Nonlinear GEV

Nonlinear Normal

Linear GEV
## Skewness

<table>
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<tr>
<th></th>
<th>U.S. Data</th>
<th>Model</th>
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<tr>
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<tr>
<td>Consumption</td>
<td>-0.874</td>
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<tr>
<td>Hours</td>
<td>-0.580</td>
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</tr>
<tr>
<td>Price inflation</td>
<td>0.656</td>
<td></td>
</tr>
<tr>
<td>Wage inflation</td>
<td>1.023</td>
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<tr>
<td>Nominal interest rate</td>
<td>0.641</td>
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</table>
Figure 4: Asymmetry of U.S. Macroeconomic Data
## Skewness

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## Kurtosis

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## Jarque-Bera Test

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Dynamics

Since model is nonlinear, impulse responses depend on sign, size, and timing (see Gallant, Rossi and Tauchen, 1993, and Koop, Pesaran, and Potter, 1996)

Consider innovations in the 1st and 99th percentiles

Innovations take place when system is at the stochastic steady state
Figure 8: Interest Rate Policy Function

Productivity Shock

Labor Supply Shock

Monetary Shock

- Linear
- Nonlinear
Figure 5: Responses to Extreme Productivity Shocks under Taylor Rule Policy
Figure 6: Responses to Extreme Labor Supply Shocks under Taylor Rule Policy
Figure 7: Responses to Extreme Monetary Shocks under Taylor Rule Policy
Ramsey Policy

A benevolent central bank chooses \( \{c_t, h_t, w_t, i_t, \Omega_t, \Pi_t\}_{t=\tau}^{\infty} \) to maximize the households welfare subject to:

The social resource constraint

First-order conditions of firms and

First-order conditions of households
Dynamics

Consider innovations in the 1st and 99th percentiles

Innovations take place when system is at the stochastic steady state
Figure 11: Optimal Interest Rate Policy Function

Productivity Shock

Labor Supply Shock

- Linear
- Nonlinear
Figure 9: Optimal Responses to Extreme Productivity Shocks

- Consumption
- Hours
- Interest Rate
- Price Inflation
- Wage Inflation
- Real Wage
Figure 10: Optimal Responses to Extreme Labor Supply Shocks

- **Consumption**
- **Hours**
- **Interest Rate**
- **Price Inflation**
- **Wage Inflation**
- **Real Wage**

Legend:
- 1st GEV
- 1st Normal
- 99th Normal
- 99th GEV
- SS (set to 0)
Optimal Inflation

In the deterministic steady state, (gross) optimal inflation = 1.0

In the stochastic steady state, (gross) optimal inflation = 1.001
Comparison with Strict Inflation Targeting

Inflation targeter has less knowledge and flexibility than Ramsey

Optimal inflation may be different from that under Ramsey

In the stochastic steady state, (gross) optimal inflation $\approx 1.0$
Optimal Inflation Rate under Strict Inflation Targeting
Summary

In an economy where extreme events can occasionally happen:

There is (or there should be) a prudence motive in monetary policy making
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In an economy where extreme events can occasionally happen:

There is (or there should be) a prudence motive in monetary policy making

However, optimal (net) inflation is close to zero because inflation costs paid every period override the precautionary benefits of having a non-zero inflation target
Summary

In an economy where extreme events can occasionally happen:

There is (or there should be) a prudence motive in monetary policy making

However, optimal (net) inflation is close to zero because inflation costs paid every period override the precautionary benefits of having a non-zero inflation target

Under both the Taylor and Ramsey policies, the central bank responds non-linearly and asymmetrically to shocks