

# Advancing Regime-Switching Models for Macroeconomic Analysis Using the RISE Toolbox

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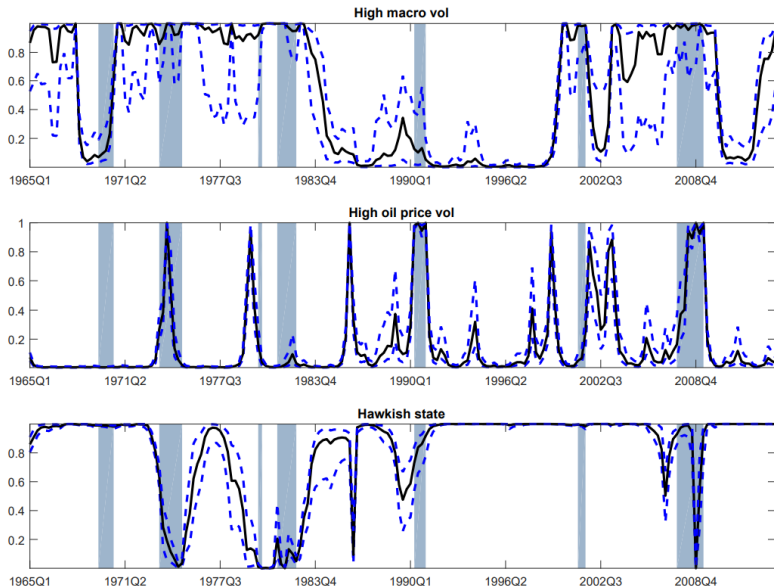
# The Need for Advanced Modeling Tools

- ▶ Policymakers rely on macroeconomic models to design frameworks for promoting stability and growth.
- ▶ But traditional models assume constant parameters and a unique steady state, designed for normal times, not well-equipped to navigate:
  - ▶ Nonlinearities and unsteady steady states.
  - ▶ Recurring natural disasters and external shocks.
  - ▶ Fragmentation of global markets and economies.
  - ▶ Financial crises, sudden stops, and occasionally-binding constraints.
  - ▶ Changes in behavior: discretionary periods and commitment in others.

# Chronology of Some Major Economic Shocks

- ▶ **1969–1970 Recession:** Tight monetary policy post-Vietnam War.
- ▶ **1973–1975 Oil Crisis:** OPEC oil embargo and energy crisis.
- ▶ **1980–1982 Recessions:** Volcker's monetary tightening to control inflation.
- ▶ **1990–1991 Recession:** Oil price spike (Gulf War) and savings & loan crisis.
- ▶ **2001 Recession:** Dot-com bubble burst and 9/11 attacks.
- ▶ **2007–2009 Great Recession:** Global financial crisis and housing market collapse.
- ▶ **2020 COVID-19 Recession:** Global pandemic disrupting demand and supply chains.

# Bjørnland, Larsen and Maih (2018)



# Hubrich & Tetlow (2015): High Stress Regime

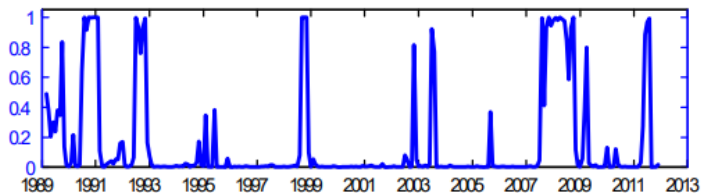


Figure 3: Probability of high-stress coefficient state, smoothed estimates,  $3v2c$  model specification

# Alstadheim, Bjørnland, Maih (2021)

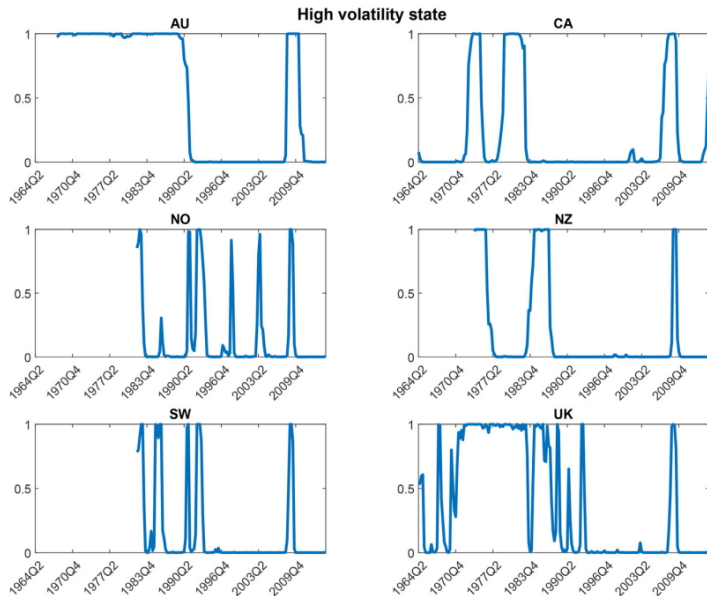


Fig. 2. Smoothed Probabilities of high volatility ( $S_t^{Vol} = \text{High}$ ).

# Why Regime-Switching Models

Models that are designed to be flexible and adaptive to changing circumstances are needed to address these challenges.

- ▶ Allow for different dynamics under various economic conditions.
- ▶ Essential for understanding behavior in crises vs normal times.

# Why RISE

- ▶ Built for regime-switching models: solution, estimation, simulations, forecasting, policy analysis.
- ▶ Enables the development of flexible models that can adapt to changing circumstances and the complex non-linear dynamics of an unstable world.
- ▶ User-friendly for macroeconomic analysis and developed in Matlab.



# Why MATLAB?

- ▶ **Numerical power:** Efficient for complex calculations.
- ▶ **Flexibility:** Ideal for solving non-linear models.
- ▶ **Wide library support:** Built-in functions for optimization and statistics.
- ▶ **User-friendly:** Fast prototyping for macroeconomic analysis.
- ▶ **Great support:** Responsive technical support for smooth implementation.

# What is RISE? I

**RISE:** Rationality in Switching Environments, a toolbox for solving, simulating and estimating regime-switching models.

## **Time Series Modeling:**

- ▶ VARs and Panel VARs
- ▶ SVARs and Proxy SVARs
- ▶ DSGE-VARs

# What is RISE? II

## **DSGE Modeling:**

- ▶ Higher-order Perturbation Solutions
- ▶ Optimal Policy: Ramsey, Discretion, Loose Commitment, Stochastic Replanning
- ▶ Tools for bounded rationality
- ▶ Occasionally binding constraints

# What is RISE? III

## **Simulation Capabilities:**

- ▶ Forecasting and Conditional Forecasting
- ▶ Perfect foresight under regime switching
- ▶ Stochastic Simulation
- ▶ Uncertainty Quantification

# What is RISE? IV

## Filtration and Estimation Capabilities:

- ▶ Nonlinear filters
- ▶ Maximum Likelihood, Bayesian Estimation, (Bayesian) Indirect Inference
- ▶ Customizable priors on parameters and model properties.

# The generic Regime-Switching Model I

$$E_t \sum_{r_{t+1}=1}^h p_{r_t, r_{t+1}} (\mathcal{I}_t) f_{r_t} (x_{t+1} (r_{t+1}), x_t (r_t), x_{t-1}, \theta_{r_t}, \theta_{r_{t+1}}, \varepsilon_t) = 0$$

- ▶  $p_{r_t, r_{t+1}} (I_t)$ : Probability of transitioning from state  $r_t$  to state  $r_{t+1}$ .
- ▶  $f_{r_t}$ : Nonlinear function representing the current regime dynamics.
- ▶  $x_t (r_t)$ : Vector of endogenous variables in regime  $r_t$ .
- ▶  $\theta_{r_t}$ : Parameters specific to regime  $r_t$ .
- ▶  $\varepsilon_t \sim N(0, I)$ : Vector of stochastic shocks.

# The generic Regime-Switching Model II

## Uncertainty Comes from:

- ▶ Structural shocks.
- ▶ Behavioral changes governed by switching processes (exogenous and endogenous).

## Takeaways:

- ▶ These shocks and regime switches induce nonlinearity, generating real-world instability.
- ▶ All models mentioned earlier are special cases of this framework

# A Simple Regime-Switching DSGE Model I

## Model Overview:

- ▶ Two regimes: Dovish vs Hawkish monetary policy.
- ▶ Regime-switching governed by a Markov process.

<b>Endogenous Variables</b>	<b>Exogenous Variables</b>
$\pi_t$ : Inflation	$\varepsilon_{z,t}$ : Demand shock
$y_t$ : Output	$\varepsilon_{r,t}$ : Monetary policy shock
$r_t$ : Interest rate	$\varepsilon_{\eta,t}$ : Cost-push shock
$\pi_{z,t}$ : Demand	
$\eta_t$ : Cost-push process	



# A Simple Regime-Switching DSGE Model II

## Model Equations (Part 1)

### 1. Euler Equation

$$y_t = E_t y_{t+1} - E_t(r_t - \pi_{t+1}) + E_t \pi_{z,t+1}$$

### 2. New Keynesian Phillips Curve

$$\begin{aligned}(\pi_t - \alpha \cdot \pi_{t-1}) &= \frac{(\eta - 1) \cdot (1 + \chi)}{\kappa \cdot \pi_\star^2} \cdot y_t \\ &+ \beta \cdot E_t(\pi_{t+1} - \alpha \cdot \pi_t) - \frac{1}{\kappa \cdot \pi_\star^2} \cdot \eta_t\end{aligned}$$

### 3. Interest Rate Rule

$$r_t = \rho \cdot r_{t-1} + (1 - \rho) \cdot \psi_{\text{regime}} \cdot \pi_t + \sigma_r \cdot \varepsilon_{r,t}$$

# A Simple Regime-Switching DSGE Model III

## Model Equations (Part 2)

### 4. Cost-push process

$$\eta_t = \rho_\eta \cdot \eta_{t-1} + \sigma_\eta \cdot \varepsilon_{\eta,t}$$

### 5. Demand process

$$\pi_{z,t} = \rho_z \cdot \pi_{z,t-1} + \sigma_z \cdot \varepsilon_{z,t}$$

# A Simple Regime-Switching DSGE Model IV

Parameter	Value	Description
$\beta$	0.99	Discount factor
$\kappa$	161	Price adjustment cost coefficient
$\pi_{ss}$	$1.02^{0.25}$	Steady-state inflation
$\alpha$	0.5	Indexation to past inflation
$\eta$	6	Elasticity of substitution
$\chi$	0.7	Inverse Frisch elasticity
$\rho$	0.7	Interest rate smoothing
$\rho_z$	0.75	Persistence of technology shock
$\rho_\eta$	0.75	Persistence of cost-push shock
$\sigma_z$	0.05	Std. dev. of demand shock
$\sigma_\eta$	0.05	Std. dev. of cost-push shock
$\sigma_r$	0.05	Std. dev. of monetary policy shock
$pol\_tp\_1\_2$	0.05	Transition prob. regime 1 to 2
$pol\_tp\_2\_1$	0.1	Transition prob. regime 2 to 1
$\psi(pol, 1)$	2.5	Policy reaction to inflation (regime 1)
$\psi(pol, 2)$	0.9	Policy reaction to inflation (regime 2)

# RISE Implementation I

## Declarations

```
%% Log-Linearized New Keynesian DSGE model
```

```
@endogenous Y "Output", R "Interest rate", PAI "Inflation", ETA "Cost-push",  
PI_Z "Technology"
```

```
@exogenous EPS_R "Monetary Policy shock", EPS_Z "Demand shock", EPS_ETA "Cost-push shock"
```

```
@parameters alpha "Price indexation on past inflation", beta "discount factor",  
kappa "price adjustment cost coeff.", eta "steady-state elast. of subst. across goods",  
chi "inverse Frisch elast. of substitution", rho "interest rate smoothing",  
psi "policy reaction to inflation", sigma_r "std: monetary policy shock",  
sigma_eta "std: cost-push shock", sigma_z "std: demand shock",  
rho_eta "persistence: cost-push", rho_z "persistence: demand",  
paiss "steady-state inflation"
```

# RISE Implementation II

## Model Equations

@model

"First Order Condition for Bonds"

$$Y\{t\} = Y\{t+1\} - (R\{t\} - \text{PAI}\{t+1\}) + \text{PI\_Z}\{t+1\};$$

"New Keynesian Phillips Curve"

$$\text{PAI}\{t\} - \alpha * \text{PAI}\{t-1\} = (\eta - 1) * (1 + \chi) / (\kappa * \text{paiss}^2) * Y\{t\} \dots \\ + \beta * (\text{PAI}\{t+1\} - \alpha * \text{PAI}\{t\}) - (1 / (\kappa * \text{paiss}^2)) * \text{ETA}\{t\};$$

"Interest Rate Rule"

$$R\{t\} = \rho * R\{t-1\} + (1 - \rho) * \psi * \text{PAI}\{t\} + \sigma_r * \text{EPS\_R}\{t\};$$

"Cost-push Shock Process"

$$\text{ETA}\{t\} = \rho_{\eta} * \text{ETA}\{t-1\} - \sigma_{\eta} * \text{EPS\_ETA}\{t\};$$

"Technology Shock Process"

$$\text{PI\_Z}\{t\} = \rho_z * \text{PI\_Z}\{t-1\} + \sigma_z * \text{EPS\_Z}\{t\};$$

# Model Solution I

## MODEL SOLUTION #1/1

SOLVER :: mfi

Regime 1 : const = 1 & Hawkish

	ETA	R	PAI	PI_Z	Y
ETA{-1}	0.75	-0.0042389	-0.0056519	0	0.036397
R{-1}	0	0.58954	-0.14728	0	-1.5034
PAI{-1}	0	0.27214	0.36285	0	-0.92156
PI_Z{-1}	0	0.10809	0.14412	0.75	1.3219
EPS_ETA	-0.05	0.0002826	0.00037679	0	-0.0024265
EPS_R	0	0.04211	-0.01052	0	-0.10739
EPS_Z	0	0.0072062	0.0096082	0.05	0.088125

ETA R PAI PI\_Z Y

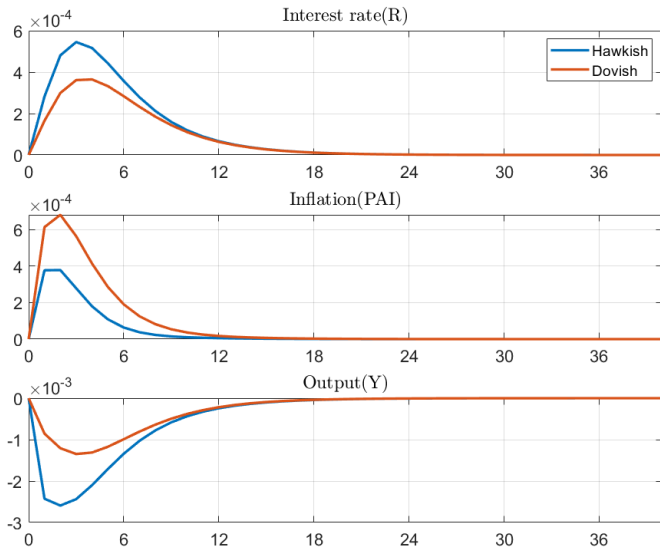
Regime 2 : const = 1 & Dovish

	ETA	R	PAI	PI_Z	Y
ETA{-1}	0.75	-0.002482	-0.0091927	0	0.012837
R{-1}	0	0.63887	-0.22641	0	-2.0524
PAI{-1}	0	0.11358	0.42068	0	-0.36936
PI_Z{-1}	0	0.063292	0.23441	0.75	1.9227
EPS_ETA	-0.05	0.00016547	0.00061285	0	-0.00085581
EPS_R	0	0.045634	-0.016172	0	-0.1466
EPS_Z	0	0.0042194	0.015628	0.05	0.12818

# Model Solution II

State Var	Variable	Hawkish	Dovish	Difference
ETA{-1}	Y	0.03640	0.01284	<b>+0.02356</b>
	R	-0.00424	-0.00248	<b>-0.00176</b>
	PAI	-0.00565	-0.00919	<b>+0.00354</b>
R{-1}	Y	-1.50340	-2.05240	<b>+0.549</b>
	R	0.58954	0.63887	<b>-0.04933</b>
	PAI	-0.14728	-0.22641	<b>+0.07913</b>
PAI{-1}	Y	-0.92156	-0.36936	<b>-0.5522</b>
	R	0.27214	0.11358	<b>+0.15856</b>
	PAI	0.36285	0.42068	<b>-0.05783</b>
PI_Z{-1}	Y	1.32190	1.92270	<b>-0.6008</b>
	R	0.10809	0.06329	<b>+0.0448</b>
	PAI	0.14412	0.23441	<b>-0.09029</b>
EPS_ETA	Y	-0.00243	-0.00086	<b>-0.00157</b>
	R	0.00028	0.00017	<b>+0.00011</b>
	PAI	0.00038	0.00061	<b>-0.00023</b>
EPS_R	Y	-0.10739	-0.14660	<b>+0.03921</b>
	R	0.04211	0.04563	<b>-0.00352</b>
	PAI	-0.01052	-0.01617	<b>+0.00565</b>
EPS_Z	Y	0.08813	0.12818	<b>-0.04005</b>
	R	0.00721	0.00422	<b>+0.00299</b>
	PAI	0.00961	0.01563	<b>-0.00602</b>

# IRF: Cost-Push Shock





# Conclusion

## Advancing Macroeconomic Analysis with RISE

- ▶ **Flexible Modeling:** Captures dynamics in both normal and crisis periods with regime-switching models.
- ▶ **Policy Analysis:** Powerful tools for forecasting, estimation, and simulation under uncertainty.
- ▶ **User-Friendly:** Easily solves complex models in MATLAB with precision.
- ▶ **Driving Insightful Policy Decisions:** Helps design frameworks to navigate today's unstable and fragmented global economy.

*“We have not succeeded in answering all our  
problems.*

*The answers we have found only serve to raise a  
whole set of new questions.*

*In some ways we feel we are as confused as ever,  
but we believe we are confused on a higher level and  
about more important things.”*

— Earl C. Kelley

# Thank You!

For more information, feel free to reach out:  
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Explore the RISE Toolbox at:  
[https://github.com/jmaih/RISE\\_toolbox](https://github.com/jmaih/RISE_toolbox)

I look forward to your feedback and collaboration!






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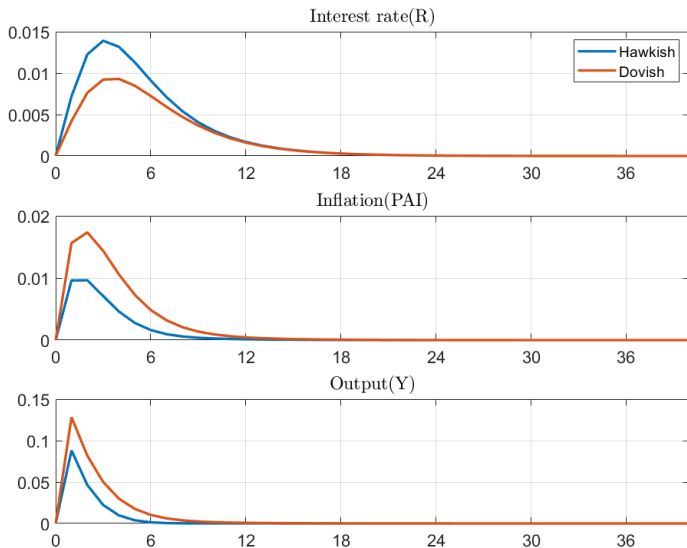
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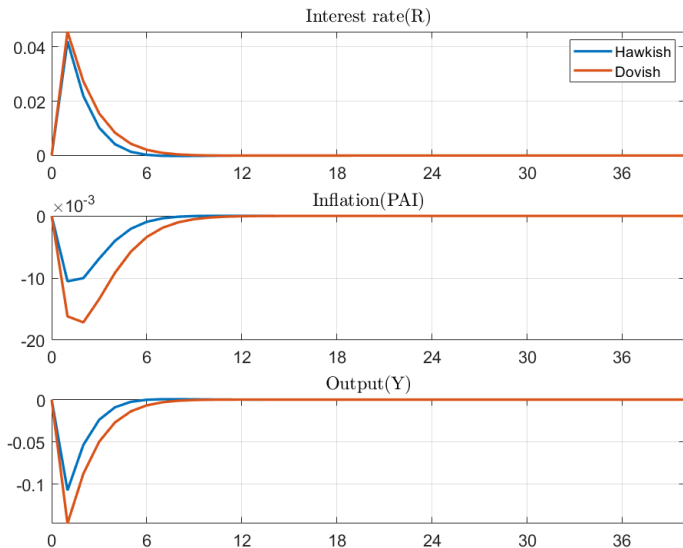
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# IRF: Demand Shock





# IRF: Monetary Policy Shock



# MATLAB Script for Running Experiments I

```
%% Housekeeping
clearvars
clc
close all

%% Create the model

mdl=rise('model_switch');

%% Parameter values
p=struct();
p.beta=0.99;
p.kappa=161;
p.paiss=1.02^0.25;
p.alpha = 0.5;
```

## MATLAB Script for Running Experiments II

```
p.eta = 6;  
p.chi = 0.7;  
p.rho = 0.7;  
p.rho_z=0.75;  
p.rho_eta=0.75;  
p.sigma_z=0.05;  
p.sigma_eta=0.05;  
p.sigma_r=0.05;  
p.pol_tp_1_2=.1/2;  
p.pol_tp_2_1=.1;  
p.psi_pol_1=2.5;  
p.psi_pol_2=0.9;  
  
mdl=set(mdl,'parameters',p);
```

# MATLAB Script for Running Experiments III

```
%% solve the model

mdl=solve(mdl);

print_solution(mdl)

%% Dynamic response to shocks

myirfs=irf(mdl);

vList={'R','PAI','Y'};

quick_irfs(mdl,myirfs,vList)
```