Learning and the Great Moderation

James Bullard Aarti Singh

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- Stability theorems: where are they?
- It's all rational expectations with limited information.

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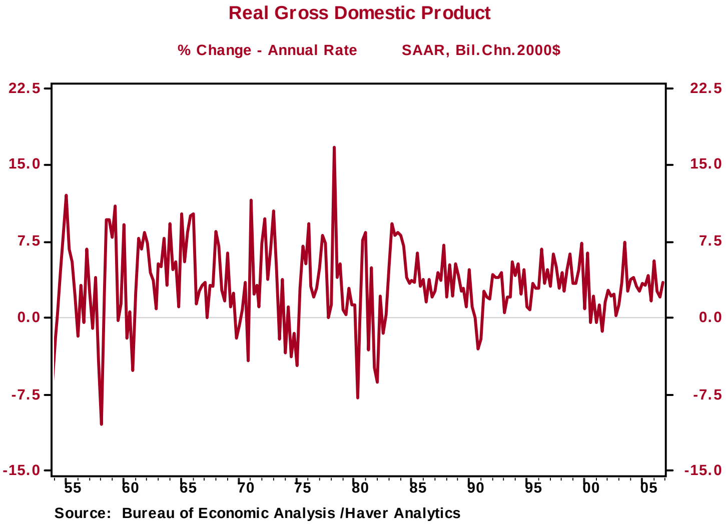
- Perhaps the leading explanation: It was good luck, smaller and less frequent shocks to the economy.
- But why should shocks suddenly be fifty percent less volatile?


Real Gross Domestic Product
% Change - Annual Rate
SAAR, Bil.Chn.2000$
22.5
15.0
7.5
0.0
-7.5
-15.0
55
60
65
70
75
80
85
90
95
00
05
Source: Bureau of Economic Analysis /Haver Analytics

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- ... but equilibrium behavior of private sector agents also changes in response to the smaller shocks.
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- So the moderation is due partly to good luck and partly to moderated private sector behavior.

How the shocks changed

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- Kim and Nelson (1999): Regimes moved closer, conditional variance unchanged.
- All of our economies will have this feature.

Learning effect

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- When regimes move closer with conditional variance constant, this inference problem becomes more difficult.
- Agents moderate their behavior, making choices which are convex combinations of the choices they would make under complete information.
- Macroeconomic variables are less volatile.

What we do

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- We include regime switching, incomplete information, and Bayesian learning.
- We solve the nonlinear model using perturbation methods.
- We isolate the learning effect we are interested in by comparing to well-known benchmarks without learning.

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- In this comparison, we decompose the moderation:
  - the learning effect accounts for about 30 percent
  - less volatile shocks—"good luck"—accounts for about 70 percent.

Related literature

- Empirical: Kim and Nelson (1999, *REStat*) and McConnell and Perez-Quiros (2000, *AER*), Kim, Nelson, and Piger (2004, *JBES*), Stock and Watson (2003, *NBER Macro Annual*).

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- Good luck: Arias, Hansen, Ohanian (2006, *WP UCLA*), Ahmed, Levin, Wilson (2004, *REStat*).

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- Good luck: Arias, Hansen, Ohanian (2006, *WP UCLA*), Ahmed, Levin, Wilson (2004, *REStat*).
- Bayesian learning in general equilibrium: Van Nieuwerburgh and Veldkamp (2006, *JME*) concerning business cycle asymmetries, in asset pricing see Cagetti, Hansen, Sargent, Williams (2002, *Rev. Fin. Studies*), uncertain growth.

Standard equilibrium business cycle model

- Representative household with preferences $E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, 1-\ell_t)$, period utility

$$u(c_t, \ell_t) = \frac{[c_t^{\theta}(1-\ell_t)^{1-\theta}]^{1-\tau}}{1-\tau}. \quad (1)$$

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Stochastic environment

- We assume z_t depends on a latent, unobserved state s_t through

$$z_t = (a_H + a_L)(s_t + \triangle \eta_t) - a_L, \tag{3}$$

where

$$z_t = \begin{cases} a_H + (a_H + a_L) \triangle \eta_t & \text{if } s_t = 1 \\ -a_L + (a_H + a_L) \triangle \eta_t & \text{if } s_t = 0 \end{cases}, \tag{4}$$

and $a_H \geq 0$, $a_L \geq 0$, $\eta_t \sim i.i.d.\ N(0,1)$, and $\triangle > 0$ is a weighting parameter.

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- We assume s_t follows a first order Markov process.

The perturbation parameter

- The state s_t can be written as

$$s_t = \lambda_0 + \lambda_1 s_{t-1} + v_t, \tag{5}$$

and $\lambda_0 = (1 - q)$, $\lambda_1 = (p + q - 1)$, v_t white noise.

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- The stochastic process for technology can be written as

$$z_t = \xi_0 + \xi_1 z_{t-1} + \sigma \epsilon_t, \tag{6}$$

where $\xi_0 = (a_H + a_L)\lambda_0 + \lambda_1 a_L - a_L$, $\xi_1 = \lambda_1$,
$\sigma = (a_H + a_L)$, and

$$\epsilon_t = v_t + \triangle \eta_t - \lambda_1 \triangle \eta_{t-1}. \tag{7}$$

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$$\epsilon_t = v_t + \triangle \eta_t - \lambda_1 \triangle \eta_{t-1}. \tag{7}$$

- $\sigma = a_H + a_L$ plays the role of the perturbation parameter in Auroba, Fernandez-Villaverde, and Rubio-Ramirez (2006) "AFR."

Information

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- Beliefs are updated using Bayes' rule.

Social planner's problem

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- The second state is the state of expectations concerning the level of technology, so that

$$V\left(k_t, z_t^e\right) = \max_{c_t, \ell_t} u(c_t, 1 - \ell_t) + \beta E\left[V\left(k_{t+1}, z_{t+1}^e\right) | F_t\right] \tag{8}$$

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- We use second-order perturbation methods using a version of the code provided by Auroba et al (2006).

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- Since $\sigma = a_H + a_L$ we set $a_H = a_L = 0.0035$.

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- Since $\xi_1 = p + q - 1$, we set $p = q = 0.975$. Then $\xi_0 = 0$.

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- Since $\xi_1 = p + q - 1$, we set $p = q = 0.975$. Then $\xi_0 = 0$.
- To get $\sigma_\epsilon = 1$, we set $\Delta = 0.719$. This implies $\sigma\Delta = 0.005$.

TABLE 1.
Benchmark comparison.

Variable	AFR	Model
Output	1.2418	1.2398
Consumption	0.4335	0.4323
Hours	0.5714	0.5706
Investment	3.6005	3.5953
Capital	0.2490	0.2466

Table: A comparison of standard deviations of key endogenous variables for a standard equilibrium business cycle model (AFR) and the complete information version of the present model with regime switching. The addition of regime switching does not change the standard deviations appreciably.

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- In particular, we would like both conditional and unconditional standard deviations to remain unchanged.
- We only have one parameter, Δ, to use to keep both constant.
- But we can get close even when regime distance increases by a factor of three.

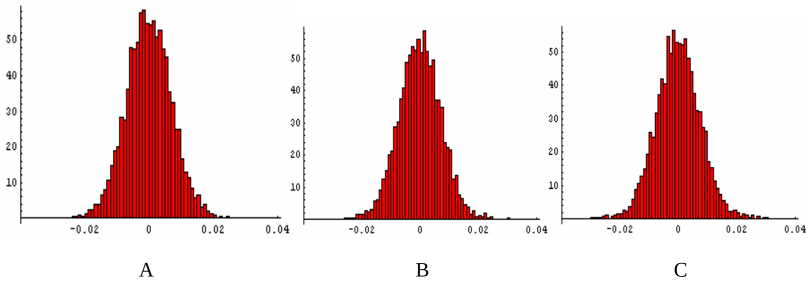

Figure: Shock distributions for economies A, B, and C are very similar, but the regimes for economy B are twice as far apart as those for economy A. For economy C, the regimes are three times as far apart. Figures are drawn for 6,500 draws from each distribution.

TABLE 2. INCREASING σ

	Economy		
	A	B	C
	Parameter values		
a_H	0.0035	0.0070	0.0105
a_L	0.0035	0.0070	0.0105
σ	0.0070	0.0140	0.0210
$\sigma\sigma_\epsilon$	0.0070	0.0073	0.0077
$\sigma\Delta$	0.0050	0.0050	0.0050
	Volatility, in percent s.d.		
Output	0.9300	1.0100	1.1060
Consumption	0.1450	0.1730	0.2050
Hours	0.1240	0.2850	0.4450
Investment	3.5580	3.8040	4.1060
Capital	0.2430	0.2640	0.2870
$\frac{1}{T}\sum(s^e - s)^2$	0.3900	0.3680	0.2970

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- It is between zero and one.
- Confusion falls as regimes become more distinct.

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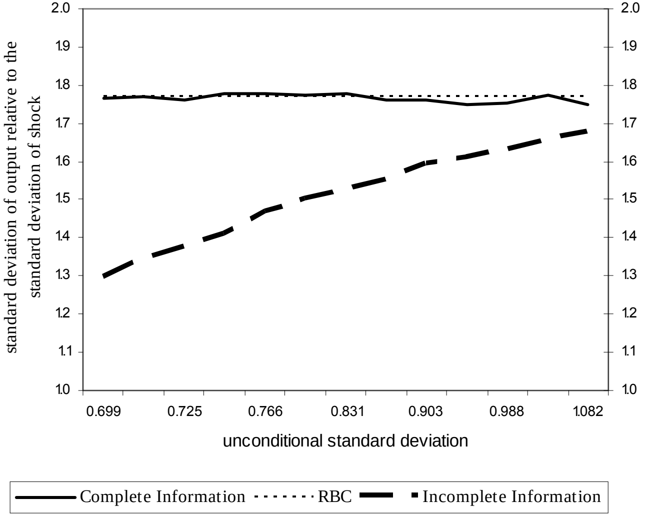
- We expect to approach complete information as regime distance increases, keeping conditional variance constant.

Figure 2


2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
standard deviation of output relative to the standard deviation of shock
0.699
0.725
0.766
0.831
0.903
0.988
1.082
unconditional standard deviation
Complete Information
RBC
Incomplete Information

Comparing economies with observed moderation

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- High volatility: $a_H = a_L = 0.0225$. Low volatility $a_H = a_L = 0.0025$.

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- We now consider a calibration that has this feature.
  - We want regime distance to differ ...
  - ... keeping conditional variance constant ...
  - ... and causing endogenous output volatility to fall by 1/2.
- High volatility: $a_H = a_L = 0.0225$. Low volatility $a_H = a_L = 0.0025$.
- This implies $\sigma\sigma_\epsilon = 1.08$ percent in the high volatility case, and 0.7 percent in the low volatility case.

Moderation accounting

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- The unconditional shock standard deviation falls 35 percent ($1 - .007/.0108$).
- The complete information model is close to linear. Output volatility would fall 35 percent in that case. The remaining $50 - 35 = 15$ percentage points is due to learning.

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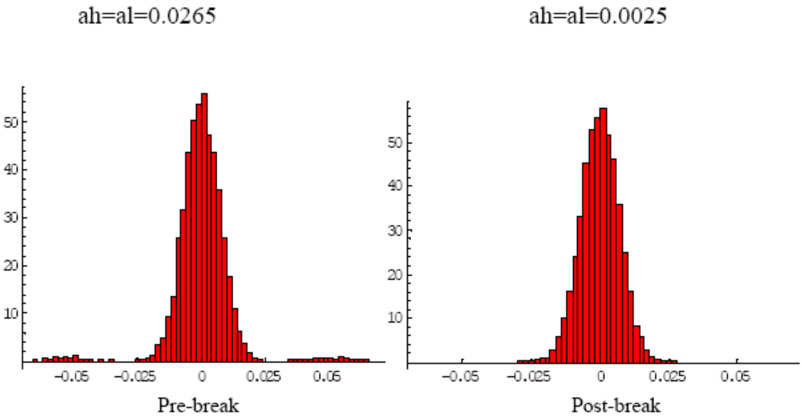
- The unconditional shock standard deviation falls 35 percent $(1 - .007/.0108)$.
- The complete information model is close to linear. Output volatility would fall 35 percent in that case. The remaining $50 - 35 = 15$ percentage points is due to learning.
- The moderation is 30 percent learning and 70 percent good luck.

TABLE 3. MODERATION.

	Economy	
	High volatility	Low volatility
	Parameter Values	
a_H	0.0265	0.0025
a_L	0.0265	0.0025
σ	0.053	0.005
$\sigma\sigma_\epsilon$	0.0108	0.007
$\sigma\Delta$	0.005	0.005
	Volatility, in percent s.d.	
Output	1.816	0.908
Consumption	0.390	0.138
Hours	1.141	0.082
Investment	6.504	3.487
Capital	0.451	0.238
$\frac{1}{T}\sum(s^e - s)^2$	0.125	0.415

Figure 3


ah=al=0.0265
ah=al=0.0025
50
40
30
20
10
-0.05
-0.025
0
0.025
0.05
Pre-break
Post-break

Inference problems

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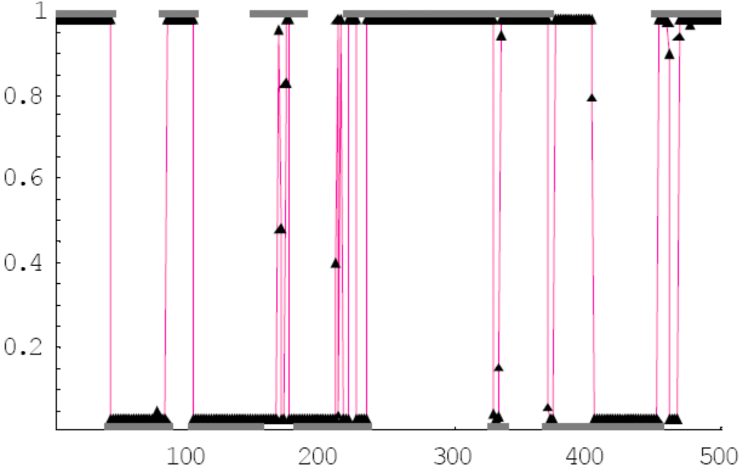
- There are also self-confirming effects.

Figure 4

Pre-Break ah→0.0265, al→0.0265 (Sum of Squared Dev= 0.149383 while the average value reported in above is 0.125)



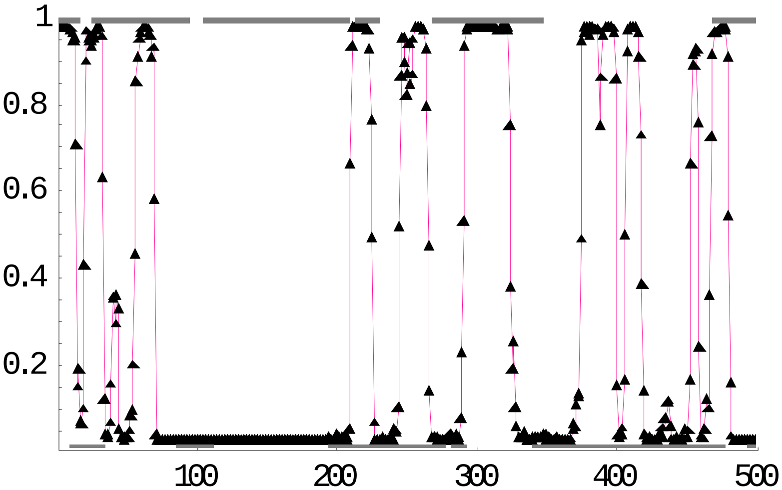


Figure: The true state versus the expected state in the low volatility economy. The agent is relatively confused about the true state, causing moderated behavior.

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- But a 50 reduction in shock volatility strains credulity.
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- We found this effect might account for 30 percent of a moderation of the magnitude observed in the U.S. in a stylized economy.