# Information frictions

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# Information frictions

- So far, have assumed full information & rational expectations ("FIRE")
- **Next:** Deviations from FIRE ("information frictions")
  - incomplete information (e.g. noisy information, sticky information)
  - deviations from rational expectations (e.g. cognitive discounting, level *k* thinking)
- Leading contender to explain **key puzzles** in macro & finance, e.g.
  - Why do $\{ \pi_t , I_t , C_t \}$ respond so **sluggishly** to aggregate shocks? (but not to idiosyncratic shocks)
  - Why do asset prices **overreact** to shocks?

# A slight problem

- Deviations from FIRE already hard to simulate within simple RA models!
  - e.g. Mankiw Reis 2007, Mackowiak Wiederholt 2015

# A slight problem

- Deviations … A models!
  - e.g. Manki…

**STICKY INFORMATION IN GENERAL EQUILIBRIUM**

**N. Gregory Mankiw**
Harvard University

**Ricardo Reis**
Princeton University

**3. Solving for the Economy's Dynamics**

Our model fits into the general class of linear rational expectations models for which there are several ready-to-use solution algorithms. However, none of them is particularly useful to solve the sticky-information model. The model involves both an infinite number of past expectations of the present through sticky information, as well as present expectations of variables at an infinite number of future dates through intertemporal smoothing. This double infinity implies that the state-space of the model has an infinite dimension, which current algorithms cannot handle.[4]

# A slight problem

- Deviations from FIRE already hard to simulate within simple RA models!
    - e.g. Mankiw Reis 2007, Mackowiak Wiederholt 2015
- **Goal:** Coherent framework to model *and simulate* deviations from FIRE
    - … not just RA, but also **HA** ! (or any other block …)
- Materials here mostly a version of the approach we have developed for “Micro Jumps, Macro Humps…”

# Introductory example

# Monetary policy with myopic agents

- IKC equation for monetary policy

$$d\mathbf{Y} = \mathbf{M}^r d\mathbf{r} - \mathbf{M} d\mathbf{T} + \mathbf{M} d\mathbf{Y}$$

$d\mathbf{T}$ = endog. tax adjustment to $d\mathbf{r}$

- Imagine households are **myopic:**
  - only start responding to $dr_t$ at date $t$
  - only start responding to $dT_t$ at date $t$
  - only start responding to $dY_t$ at date $t$
- What is $d\mathbf{Y}$ in this case?

# Manipulating Jacobians

- Take the intertemporal MPC matrix … **Is it still correct with myopia?**

Response to income increase at $s = 0$

$$\mathbf{M} = \begin{pmatrix} M_{00} & M_{01} & M_{02} & M_{03} & \cdots \\ M_{10} & M_{11} & M_{12} & M_{13} & \cdots \\ M_{20} & M_{21} & M_{22} & M_{23} & \cdots \\ M_{30} & M_{31} & M_{32} & M_{33} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

Still correct with myopia? ✓

# Manipulating Jacobians

- Take the intertemporal MPC matrix … **Is it still correct with myopia?**

Response to income increase at $s = 1$

$$\mathbf{M} = \begin{pmatrix} M_{00} & \cancel{M_{01}} & M_{02} & M_{03} & \cdots \\ M_{10} & M_{11} & M_{12} & M_{13} & \cdots \\ M_{20} & M_{21} & M_{22} & M_{23} & \cdots \\ M_{30} & M_{31} & M_{32} & M_{33} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

Still correct with myopia? $\checkmark$ $\times$

# Manipulating Jacobians

- Take the intertemporal MPC matrix … **Is it still correct with myopia?**

Response to income increase at $s = 2$

$$\mathbf{M} = \begin{pmatrix} M_{00} & \cancel{M_{01}} & \cancel{M_{02}} & M_{03} & \cdots \\ M_{10} & M_{11} & \cancel{M_{12}} & M_{13} & \cdots \\ M_{20} & M_{21} & M_{22} & M_{23} & \cdots \\ M_{30} & M_{31} & M_{32} & M_{33} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

$$\begin{array}{lccc} \text{Still correct with myopia?} & \checkmark & \times & \times \end{array}$$

# Manipulating Jacobians

- Take the intertemporal MPC matrix … **Is it still correct with myopia?**

Response to income increase at $s = 3$

$$\mathbf{M} = \begin{pmatrix} M_{00} & \cancel{M_{01}} & \cancel{M_{02}} & \cancel{M_{03}} & \cdots \\ M_{10} & M_{11} & \cancel{M_{12}} & \cancel{M_{13}} & \cdots \\ M_{20} & M_{21} & M_{22} & \cancel{M_{23}} & \cdots \\ M_{30} & M_{31} & M_{32} & M_{33} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

Still correct with myopia? ✓ ✗ ✗ ✗

Do we need to modify the other entries in each column?

# Manipulating Jacobians

- Take the intertemporal MPC matrix … **Is it still correct with myopia?**

$$\mathbf{M} = \begin{pmatrix} M_{00} & 0 & M_{02} & M_{03} & \cdots \\ M_{10} & M_{00} & M_{12} & M_{13} & \cdots \\ M_{20} & M_{10} & M_{22} & M_{23} & \cdots \\ M_{30} & M_{20} & M_{32} & M_{33} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

# Manipulating Jacobians

- Take the intertemporal MPC matrix … **Is it still correct with myopia?**

$$\mathbf{M} = \begin{pmatrix} M_{00} & 0 & 0 & M_{03} & \cdots \\ M_{10} & M_{00} & 0 & M_{13} & \cdots \\ M_{20} & M_{10} & M_{00} & M_{23} & \cdots \\ M_{30} & M_{20} & M_{10} & M_{33} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

# Manipulating Jacobians

- Take the intertemporal MPC matrix … **Is it still correct with myopia?**

$$\mathbf{M} = \begin{pmatrix} M_{00} & 0 & 0 & 0 & \cdots \\ M_{10} & M_{00} & 0 & 0 & \cdots \\ M_{20} & M_{10} & M_{00} & 0 & \cdots \\ M_{30} & M_{20} & M_{10} & M_{00} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

After date $s$, $M_{t,s}$ is just like the date $t-s$ response to an unanticipated shock!

# Expectations matrix

- Another way to look at this: What are **expectations** about a date-$s$ shock?
- Define matrix $\mathbf{E}$ that in column $s$ has the expectations about date-$s$ shock of 1

$$\mathbf{E} = \begin{pmatrix} 1 & 1 & 1 & 1 & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix} \qquad \rightsquigarrow \mathbf{E} = \begin{pmatrix} 1 & 0 & 0 & 0 & \cdots \\ 1 & 1 & 0 & 0 & \cdots \\ 1 & 1 & 1 & 0 & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

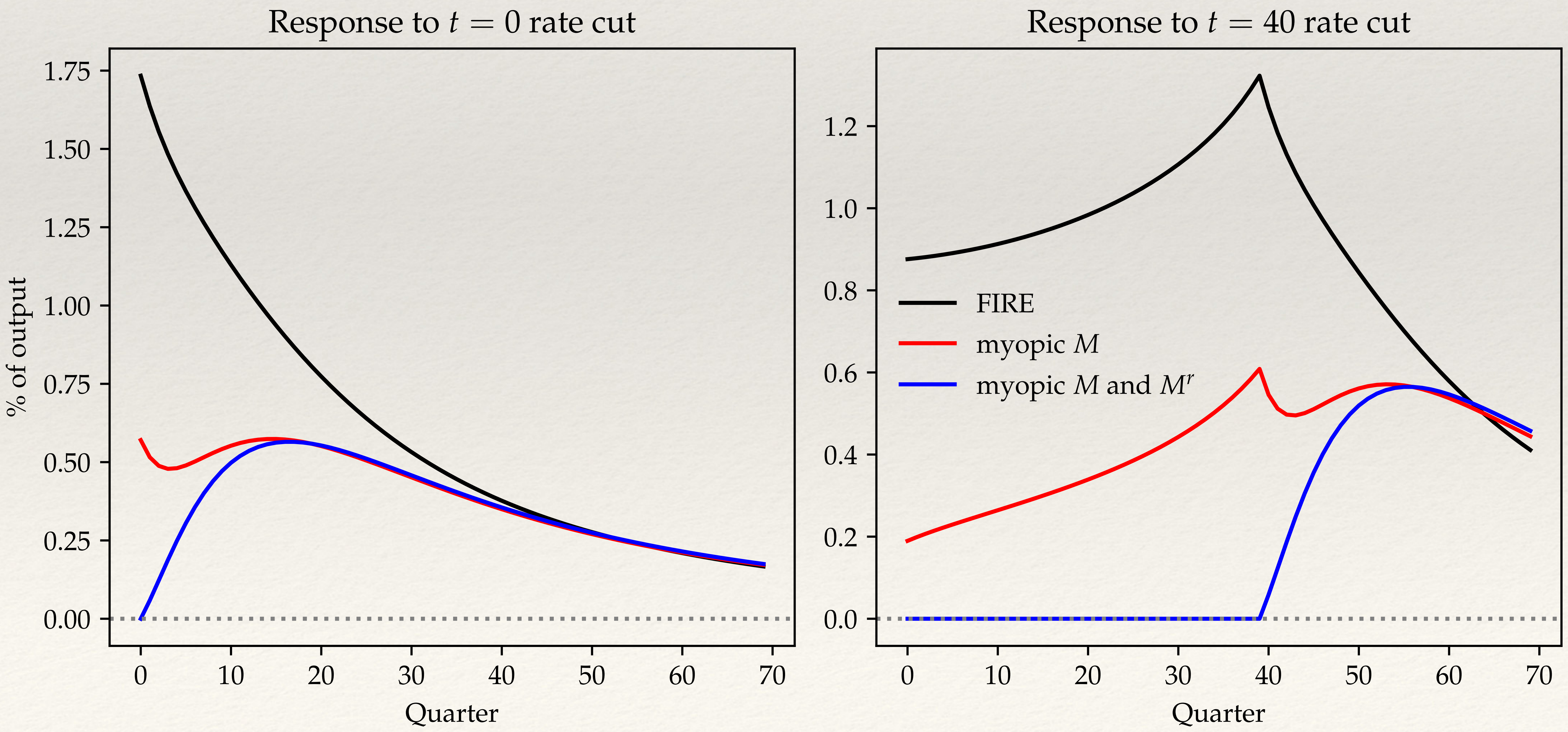
- $E_{t,s} dY_s$ is then the expected value of $dY_s$ at date $t$.

# Solving the myopic IKC

- How can we solve for the GE response of $d\mathbf{Y}$ then?

$$d\mathbf{Y} = \mathbf{M}^r d\mathbf{r}^{ante} + \mathbf{M} d\mathbf{Y}$$

- With zero new computational burden, we can solve our myopic economy!



# Solving myopic IKC for fiscal policy

- Another application: Imagine we want to solve for fiscal multipliers but agents expect neither future taxes nor future income.

- What's the right IKC?

$$d\mathbf{Y} = d\mathbf{G} - \mathbf{M}d\mathbf{T} + \mathbf{M}d\mathbf{Y}$$

- **Next:** Generalize this to more general models of belief formation!

# Two general assumptions we make

- We make two implicit assumptions

- Agents are only "behavioral" about **future changes** in aggregate variables
  - steady state unaffected
  - not behavioral w.r.t. *idiosyncratic* income process

- Deviations from FIRE are **orthogonal** to idiosyncratic state
  - can relax, but too much today. See Guerreiro (2022).

# General Expectations matrices

# Typical example

$$\mathbf{E} = \begin{pmatrix} 1 & * & * & * & \cdots \\ 1 & 1 & * & * & \cdots \\ 1 & 1 & 1 & * & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

# Typical example

Like a news shock at date 1, that one period later $dY$ goes up by 0.3

$$\mathbf{E} = \begin{pmatrix} 1 & 0.4 & \boxed{0.3} & 0.2 & \cdots \\ 1 & 1 & \boxed{0.6} & 0.4 & \cdots \\ 1 & 1 & 1 & 0.8 & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

# Typical example

Like a news shock at date 1, that two periods later $dY$ goes up by 0.2

$$\mathbf{E} = \begin{pmatrix} 1 & 0.4 & 0.3 & \boxed{0.2} & \cdots \\ 1 & 1 & 0.6 & \boxed{0.4} & \cdots \\ 1 & 1 & 1 & 0.8 & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

$$\boxed{M_{t,s} = \sum_{\tau=0}^{\min\{t,s\}} \boxed{\left(E_{\tau,s} - E_{\tau-1,s}\right)} \cdot M_{t-\tau,s-\tau}}$$

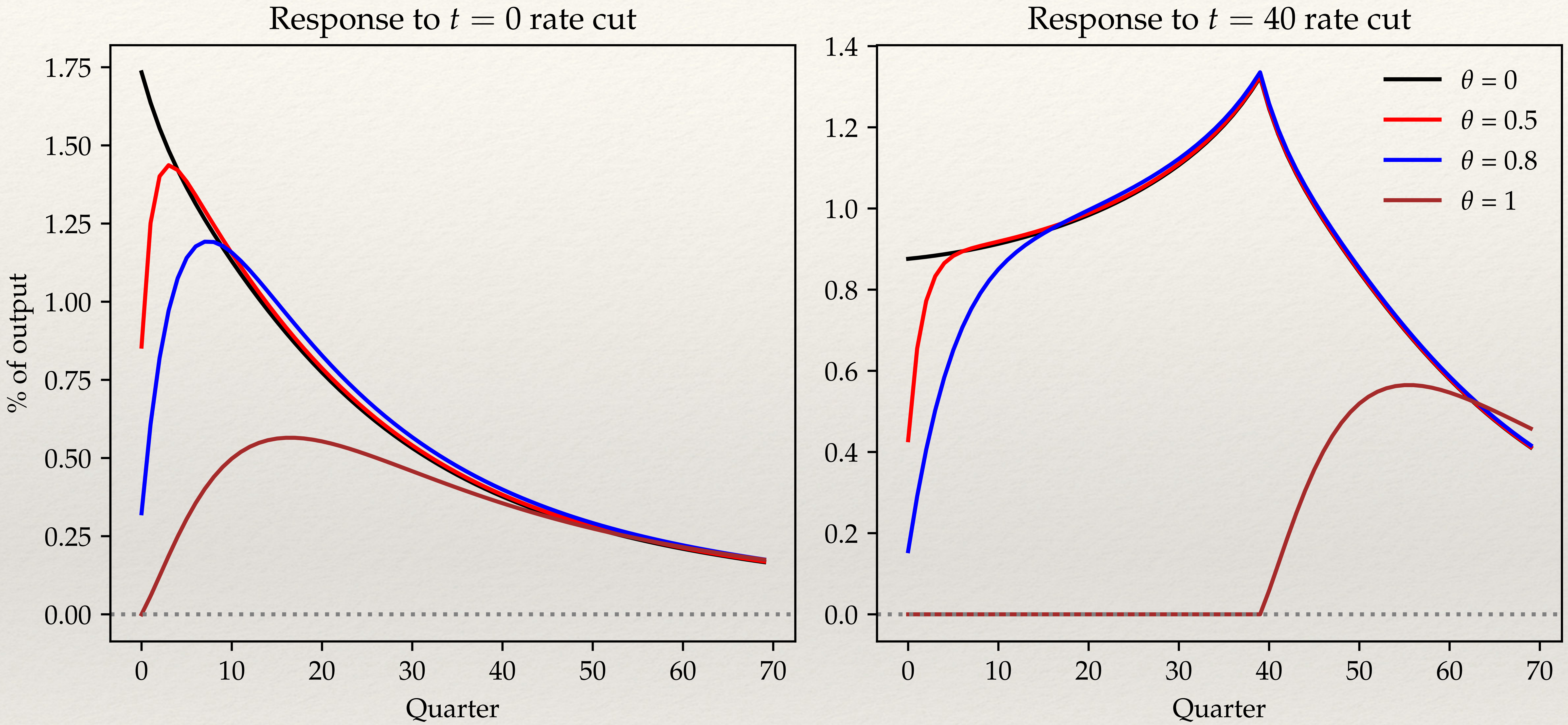
# Richer Examples

# (1) Sticky expectations

- Mankiw Reis (2002), Carroll et al (2020)
- Each period, households update info with prob. $1-\theta$

$$\mathbf{E} = \begin{pmatrix} 1 & 1-\theta & 1-\theta & \cdots \\ 1 & 1 & 1-\theta^2 & \cdots \\ 1 & 1 & 1 & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix} \qquad \mathbf{M} = \begin{pmatrix} M_{00} & (1-\theta)M_{01} & (1-\theta)M_{02} & \cdots \\ M_{10} & (1-\theta)M_{11}+\theta M_{00} & (1-\theta)M_{12}+\theta(1-\theta)M_{01} & \cdots \\ M_{20} & (1-\theta)M_{21}+\theta M_{10} & \vdots & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

# (1) HANK with sticky expectations




- Intermediate $\theta$ generates strong hump shape
- Nice way to replace habit and other slow-adjustment frictions in DSGE models

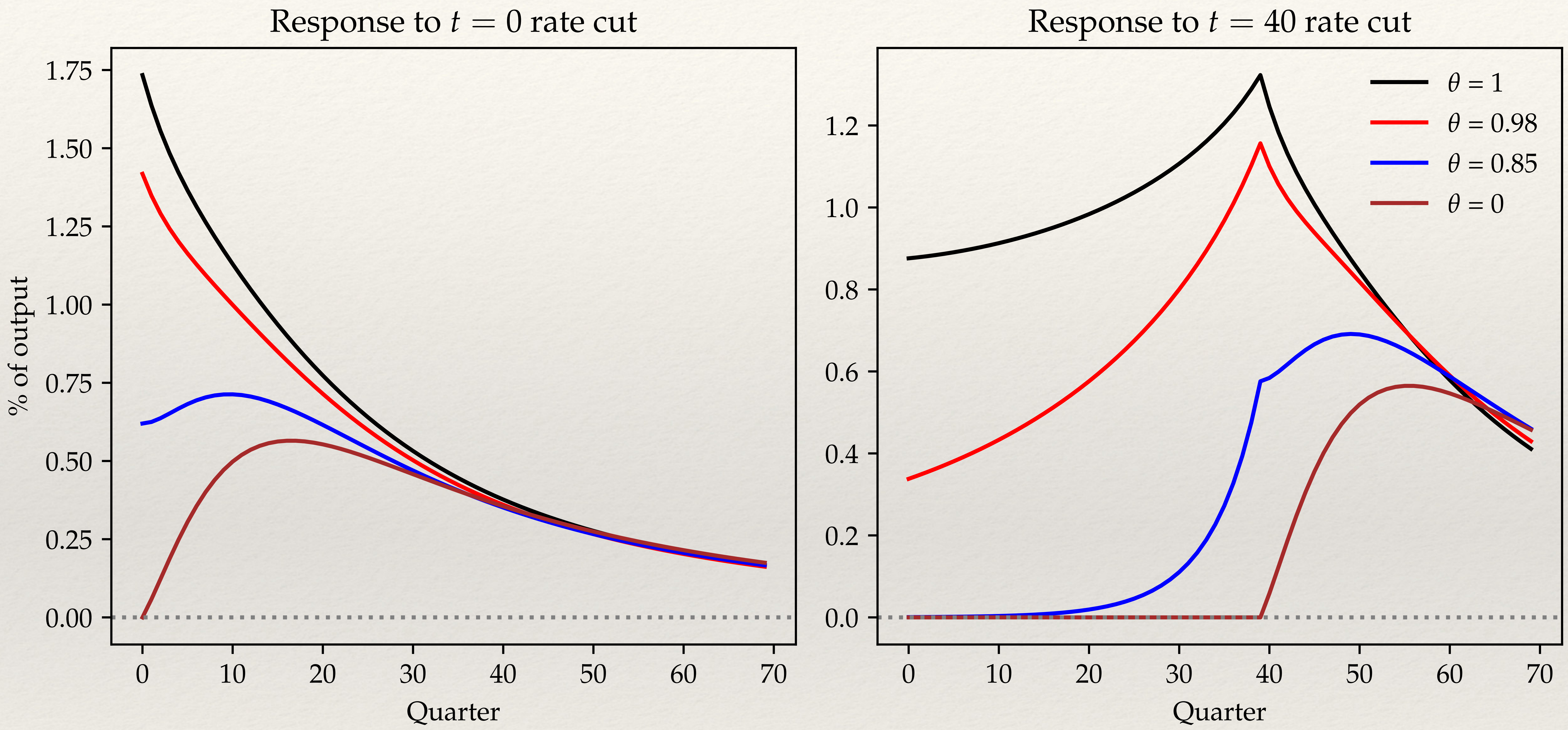
# (2) Cognitive discounting

- Gabaix (2020) introduces **cognitive discounting**
- Idea: Agents respond to shock in $h$ periods as if shock size is dampened by $\theta^h$
  - this is as if agents *expect* shock size $\theta^h$, instead of 1

$$\mathbf{E} = \begin{pmatrix} 1 & \theta & \theta^2 & \theta^3 & \cdots \\ 1 & 1 & \theta & \theta^2 & \cdots \\ 1 & 1 & 1 & \theta & \cdots \\ 1 & 1 & 1 & 1 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

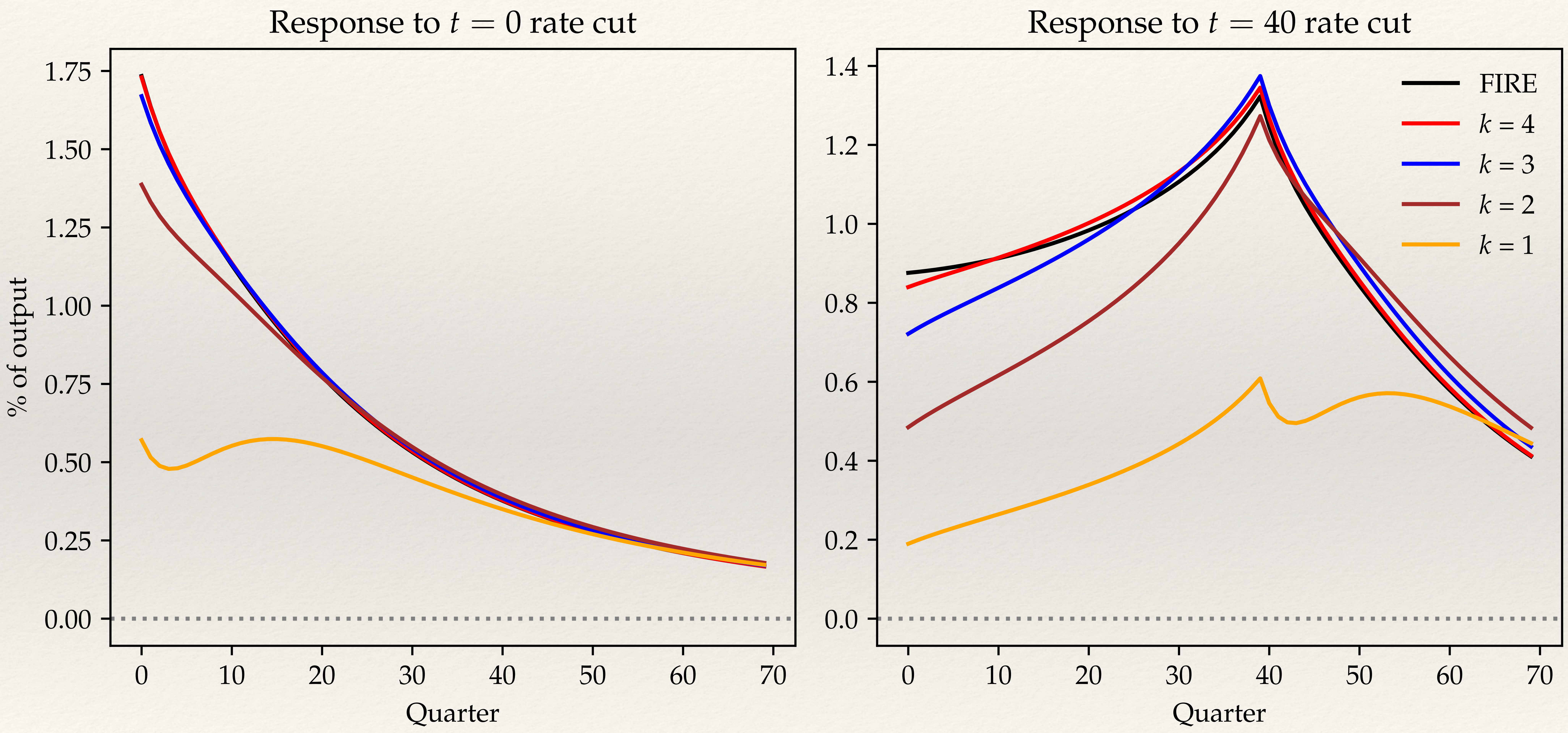
- Here, dampening relative to *diagonal*
  - $\neq$ sticky info, where dampening relative to *initial period*

# (2) HANK with cognitive discounting

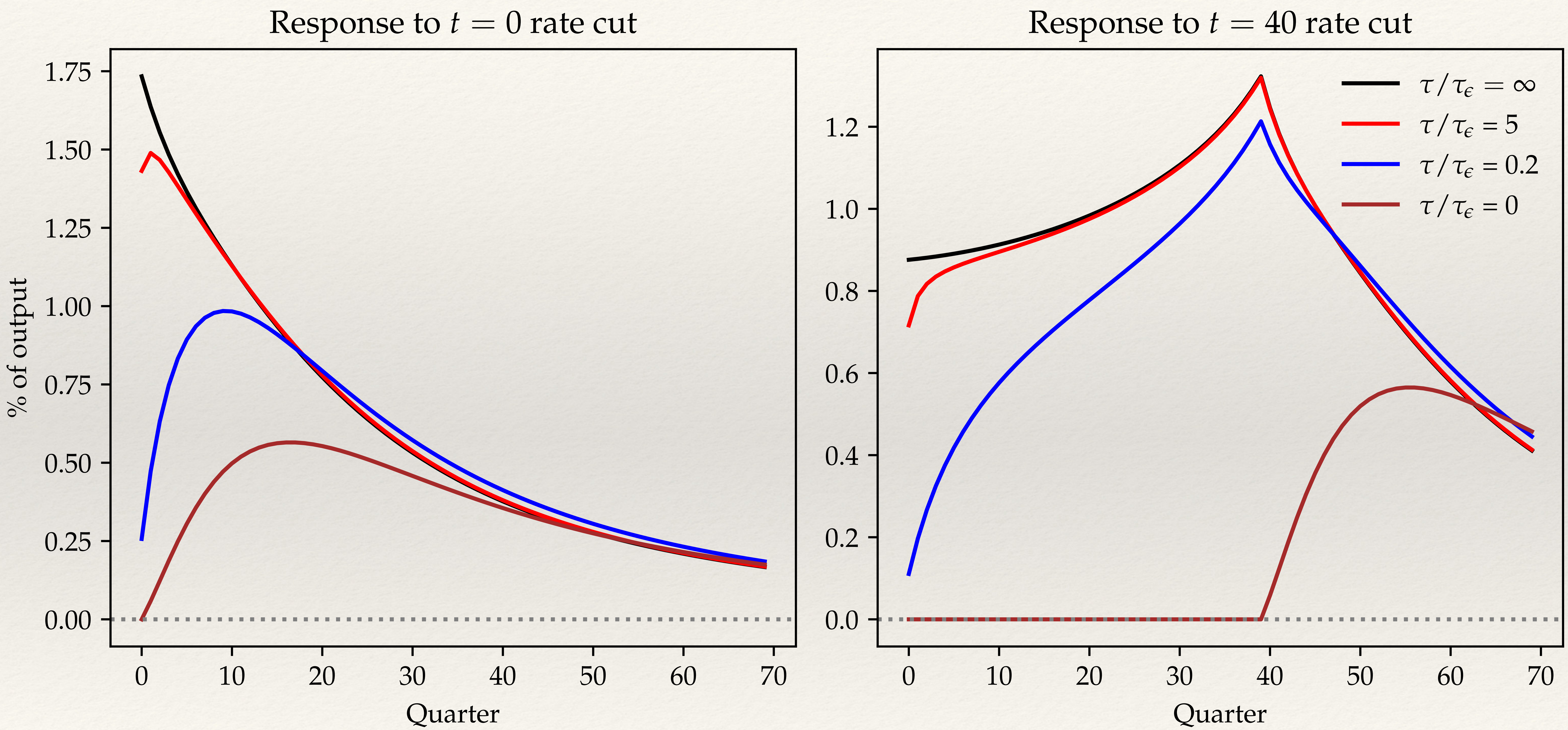



- Doesn't generate humps so well, but dampens forward guidance!

# (3) HANK with level $k$



# (4) HANK with dispersed information



# Takeaway

# Conclusion

- Information rigidities can be nested quite nicely in the sequence space
- Not just gives us a straightforward way of simulating them for RA models,
  - but allows us to apply it to HA models equally well!

# More on level-$k$

# (4) Level-$k$ thinking

- Farhi Werning (2019) is first paper to combine HANK with deviations from FIRE
- They use **level-*k* thinking:**
  - $k = 1$: all agents believe output is at steady state
  - $k = 2$: all agents believe *all other* agents are at level $k = 1$
  - $k = 3$: all agents believe *all other* agents are at level $k = 2$, … etc

# (4) Level-1 thinking

- Level $k = 1$ very close to our myopic example:

$$\mathbf{M}^{(1)} = \begin{pmatrix} M_{00} & 0 & 0 & 0 & \cdots \\ M_{10} & M_{00} & 0 & 0 & \cdots \\ M_{20} & M_{10} & M_{00} & 0 & \cdots \\ M_{30} & M_{20} & M_{10} & M_{00} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix}$$

$$d\mathbf{Y}^{(1)} = \mathbf{M}^r d\mathbf{r} + \mathbf{M}^{(1)} \cdot d\mathbf{Y}^{(1)}$$

# (4) Level-2 thinking

- What about level-2?

$$dY^{(2)} = M^r dr + M \cdot dY^{(1)}$$

Everybody expects everyone else to spend money according to level-1! Hence everyone expects income = $dY^{(1)}$

$$+M^{(1)} \cdot \left(dY^{(2)} - dY^{(1)}\right)$$

… but actual income is $dY^{(2)}$ !

Agents are constantly surprised when actual income $dY^{(2)}$ differs from $dY^{(1)}$

General recursion: $dY^{(k+1)} = M^r dr + M \cdot dY^{(k)} + M^{(1)} \cdot \left(dY^{(k+1)} - dY^{(k)}\right)$

# (4) HANK with level $k$