Lectures in Monetary Economics

Lecture 9

Imperfect information and learning

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A model with signal extraction
Misperceived vs unanticipated money

- Lucas' Imperfect Information Rational Expectations theory was a turning point in the analysis of –monetary– business cycles.
- Money matters because something happens to its quantity but people do not realize it.
- Confusion between nominal and real price movements.

An alternative approach
People realize what is going on but cannot react properly because they have made a commitment. i.e. they have fixed a nominal price/wage (the IIRE models of Fischer, Taylor, Gray).

Key distinction between these two classes of models:

- Perceived vs Misperceived Money for flexible price models.
- vs
- vs Anticipated vs Unanticipated Money for fixed price models.

Most of the –macroeconomics– human capital of the 70s and 80s was devoted to this issue.

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- Misperceived money does not matter (Barro and Hercowitz, and Boschen and Grossman)

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- The early vintage of the IIREFPM postulated that agents could only observe the nominal aggregates (M, R, . . .) with a substantial time lag. No aggregate credit markets.
- Incredible!!!
- Later vintages: Information on monetary aggregates is readily available BUT observations on the current or recent monetary data (the preliminary figures) are ridden with measurement error.
  This error is only gradually corrected through subsequent data revisions.

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- Proponents of flexible price models immigrated to the RBC.
- Proponents of fixed price models carried on and refined the model.
- Its current version: The New Keynesian model: Sticky prices, unanticipated money shocks.
- Very nice model. Its only weakness: Does not seem to work.

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- Remarkable: We seem to be witnessing a revival of the debate that raged in the 70s-80s.
- But wasn't this debate decided conclusively against the mis-perceived money camp?
- Yes. But prematurely.

What do we do in this paper?

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- Third: Imperfect information about monetary aggregates together with sticky prices can help the standard NK model exhibit inertial inflation dynamics.
- We propose a new synthesis.

The empirical evidence

The construction of misperceived money: Use measurement errors in quarterly, real time data (Philadelphia FED).

- $M_{t|t}$ is the monetary aggregate (we use M1) of period t that is reported in period t (the initial release).
- $M_{t|t+i}$ is the revised figure for t available in $t+i, i>0$
- $g_{t|t+i} = logM_{t|t+i} - logM_{t-1|t+i}$ is the **perceived**, as of $t+i$, money growth between t and $t-1$.
- $t+i=T$ represents the "final" release.
- **Unperceived** money growth in t is defined as $\mu_{t|T} = g_{t|T} - g_{t|t}$.
- Unanticipated money growth shocks, ε_t, are measured as the residuals from an AR1 (or VAR) in money growth, computed based on final data.

Table: Properties of misperceived and unanticipated money growth shocks

	1966Q1–2002Q4		
	σ	ρ	$\rho(\cdot, \varepsilon_t)$
$\mu_{t,t+1}$	0.13	-0.11	0.03
$\mu_{t,t+2}$	0.20	0.06	0.08
$\mu_{t,t+4}$	0.33	0.11	-0.03
$\mu_{t,t+8}$	0.37	-0.05	0.03
$\mu_{t,T}$	0.45	-0.06	0.06
ε_t	0.35	-0.00	1.00

Note: σ, ρ and $\rho(\cdot, \varepsilon_t)$ are the standard deviation, 1st order auto-correlation and correlation between unperceived and unanticipated money respectively.

Patterns

- The measurement errors are substantial.
- Little autocorrelation. But do these errors correspond to the concept of monetary mis-perceptions in the model of Lucas?
- Rely on the approach pioneered by Mankiw et al., 1984 to:
  - Establish that the preliminary announcements of the money stock are best characterized as measured with classical errors-in-variables. This justifies the signal extraction specification.
  - Show that the difference between the initial and the revised announcements *cannot* be predicted on the basis of information that is available at the time of the initial release. (Predictability would contaminate the conventional measure of misperceived money with anticipated money and render it unsuitable for testing the imperfect information, rational expectations theory of Lucas)
- Both of these patterns are found to be present in the post but not in the pre 1982 period.

Errors–in–variables: Regress the initial release of money growth on a constant term and the final release

$$g_{t|t} = \alpha_0 + \alpha_1 g_{t|T} + u_t$$

Test the joint null hypothesis, $E\widehat{\alpha}_0 = 0$ and $E\widehat{\alpha}_1 = 1$.

Table: Errors-in-Variables

	1966Q1–2000Q4	*1966Q1–1982Q3*	*1982Q4–2000Q4*
$\mu_{t,t+4}$	3.2867	2.6817	0.9207
	[0.0402]	[0.0761]	[0.4025]
$\mu_{t,t+8}$	4.2642	3.4882	1.1059
	[0.0159]	[0.0364]	[0.3360]
$\mu_{t,T}$	3.9013	2.8013	1.3492
	[0.0224]	[0.0681]	[0.2654]

Note: The table reports the Fisher statistic for the test $\alpha_0 = 0$ and $\alpha_1 = 1$. p–values into brackets.

Over the second sub–sample, the initial release indeed corresponds to an errors–in–variables phenomenon.

Predictability of the errors: Regress $\mu_{t|T}$ on values of the federal fund rate and changes in the stock market (as in Mankiw et al., 1984) as well as output growth and inflation that were available at the time of the release.

- Measurement errors cannot be predicted.
- The standard measure of misperceived money is appropriate.

- Does misperceived money matter for macroeconomic activity?
- Two alternative methodologies:
- First method (as in Boschen and Grossman, 1982)

Estimate equations for HP output (GDP) and the inflation rate (GDP deflator)

$$x_t = \sum_{i=1}^{p} \rho_i x_{t-i} + \sum_{\ell=0}^{n} [\alpha_i \mu_{t-\ell} + \beta_i \varepsilon_{t-\ell}] + u_t \quad (1)$$

Table: The effects of unperceived and unanticipated money, F–Tests

	Output			Inflation Rate		
	(p, n)	$\mu_{t\|T}$	ε_t	(p, n)	$\mu_{t\|T}$	ε_t
1966Q1–2002Q4	(3,2)	4.7934	6.8977	(5,7)	3.4001	1.4246
		[0.0033]	[0.0002]		[0.0015]	[0.1935]
1966Q1–1982Q3	(3,2)	4.8187	5.9241	(2,1)	0.0949	0.8072
		[0.0050]	[0.0015]		[0.9096]	[0.4513]
1982Q4–2002Q4	(3,1)	0.2592	0.1572	(4,8)	2.2657	1.0958
		[0.7724]	[0.8549]		[0.0336]	[0.3841]

Note: p–values in brackets (they correspond to the F-test of the significance of each type of shock). (p, n) refers to the number of lags of the endogenous variable, p, and of the monetary shocks, n. $\mu_{t|T}$ is unperceived and ε_t is the unanticipated money shock.

Main findings:

- Both types of shocks seem to matter for economic activity but in the pre 1982 period.

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- Both types of shocks seem to matter for economic activity but in the pre 1982 period.
- The results are robust to including only unperceived money, using different lag structures, using 1979 as the cut off point, and so on.

Second method

- Compute the effects of unanticipated inflation using a standard VAR for money growth, output growth, inflation and the federal fund rate.

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Second method

- Compute the effects of unanticipated inflation using a standard VAR for money growth, output growth, inflation and the federal fund rate.
- Compute the effects of unperceived money using the μ series in a VARX with output growth, inflation and the federal fund rate as endogenous and μ_t as an exogenous variable.
- Result The reaction of output and inflation to unanticipated and misperceived shocks is similar. A hump shaped pattern. The effects of misperceived are quantitatively larger.

Figure: Response to an unanticipated shock

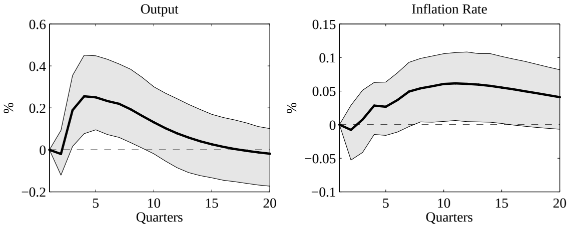
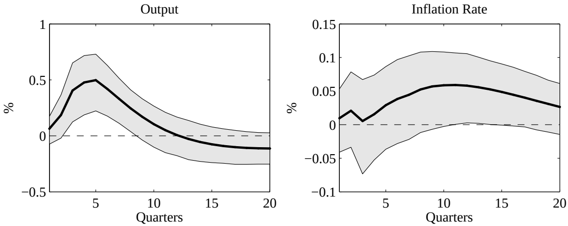


Figure: Response to a misperceived shock



The standard NK model with or without real rigidities. Rational agents

Information

- The *true* aggregate state of the economy is imperfectly observed.
- The agents learn gradually about it using the Kalman filter.

For mis–measured variable x we assume that

$$x_t^{\star} = x_t^{\mathrm{T}} + \eta_t$$

x_t^{T} denotes true value and η_t is a noisy process that satisfies $E(\eta_t) = 0$ for all t; $E(\eta_t \varepsilon_{a,t}) = E(\eta_t \varepsilon_{g,t}) = E(\eta_t \varepsilon_{\mu,t}) = 0$; and

$$E(\eta_t \eta_k) = \begin{cases} \sigma_\eta^2 & \text{if } t = k \\ 0 & \text{Otherwise} \end{cases}$$

Specification of the monetary policy rule

$$\log(R_t) = \rho_r \log(R_{t-1}) + (1-\rho_r)\left[\log(\overline{R}) + \kappa_\pi(\log(\pi_t) - \log(\pi^\star)) + \kappa_y(\log(y_t) - \log(y^\star))\right] + \varepsilon_{R,t}$$

The process for government expenditures was estimated on historical data.
σ_a and σ_R were selected so that the model matches the volatility of output (1.49) and the volatility of inflation (0.30)

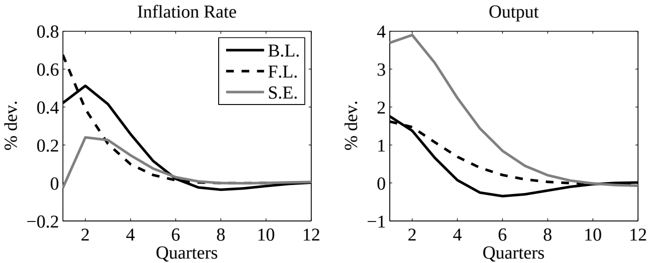
Information

In period t the agents receive noisy signals $\{\pi_{t|t}, \pi_{t-1|t}, \pi_{t-2|t}, \mu_{t|t}, \mu_{t-1|t}, \mu_{t-2|t}, y_{t|t}, y_{t-1|t}, y_{t-2|t}\}$.
We calibrate the noise in the signals of inflation, money and output so that the variances of the –endogenously determined in the model– measurement error in these variables match those in the Real Time Data Set.

Table: Volatility of revisions

	$\zeta^{\mathrm{D}}_{t\|t}$	$\zeta^{\mathrm{D}}_{t-1\|t}$	$\zeta^{\mathrm{D}}_{t-2\|t}$
Output Growth	0.5419	0.5319	0.5189
Inflation	0.2211	0.2335	0.2301
Money Growth	0.4546	0.4367	0.3906

Figure: IRF to a monetary policy shock



Note: Three model specifications: a) B.L.: Backward looking, b) F.L.: Forward looking, c) S.E.: Signal extraction.

In order to generate sufficient inertia in inflation we need:

- Either backward price indexation OR mis-perceptions
- Real rigidities
- Price rigidity

There is a trade off between the size of real rigidities and noise.

Question 1:
Do models with imperfect information contain additional explanatory power for business fluctuations relative to models without it?

Question 2:
Does signal extraction provide a quantitatively important endogenous, business cycle, propagation mechanism?

Why and how does imperfect information matter?
The agents react to shocks when they should not and this generates "excessive" volatility (for instance, they may react to monetary policy shocks).
Imperfect information imparts caution on economic behavior. Initially mooted reaction followed by a stronger subsequent response $\Rightarrow$
Imperfect information provides an endogenous propagation mechanism that can generate inertia, persistence and reversals, and it can often lead to hump shaped dynamics

- Undertake (the first) comprehensive **empirical** study of the role of imperfect information in macroeconomic fluctuations.
- Estimate a small scale NK model under alternative informational setups.
- We compare these versions not only among themselves but also with standard -empirically successful- versions that abstract from it.

We consider *five* versions of the "*three equation NK*" model, y, π, R.

- Imperfect (symmetric) information
  - Endogenous variables y, π, R are perfectly observed. Shocks are not. Confusion between temporary and permanent shocks.
  - As above plus confusion about the inflation target of the central bank.
  - Some endogenous variables (R) are perfectly observed. Other(y, π) as well as the shocks are observed with (measurement) error.
- Perfect information
  - Purely forward looking NK model plus real rigidities
  - Hybrid NK version

$$\widehat{y}_t = \frac{\vartheta}{1+\vartheta}\widehat{y}_{t-1} + \frac{1}{1+\vartheta}\mathbb{E}_t\widehat{y}_{t+1} - \frac{1-\vartheta}{1+\vartheta}(\widehat{R}_t - \mathbb{E}_t\widehat{\pi}_{t+1}) + \widehat{x}_t \tag{2}$$

$$\begin{aligned}\widehat{\pi}_t = {} & \frac{\gamma}{1+\beta\gamma}\widehat{\pi}_{t-1} + \frac{\beta}{1+\beta\gamma}\mathbb{E}_t\widehat{\pi}_{t+1} + \frac{\xi(1-\beta(1-\xi))}{(1-\xi)(1+\beta\gamma)(\varphi\zeta+1)}\frac{2+\varphi-\vartheta}{(1+\varphi)(1-\vartheta)}\widehat{y}_t \\ & - \frac{\xi(1-\beta(1-\xi))}{(1-\xi)(1+\beta\gamma)(\varphi\zeta+1)}\frac{\vartheta}{1-\vartheta}\widehat{y}_{t-1} - \widehat{z}_t + \widehat{\nu}_t\end{aligned} \tag{3}$$

$$\widehat{R}_t = \rho_r\widehat{R}_{t-1} + (1-\rho_r)(\alpha_y(\widehat{y}_t - \widehat{y}_t^{\mathrm{N}}) + \alpha_\pi\widehat{\pi}_t + (1-\alpha_\pi)\widehat{\overline{\pi}}_t) + \epsilon_{r,t} \tag{4}$$

$$\widehat{y}_t^{\mathrm{N}} = \frac{\vartheta(1+\varphi)}{2+\varphi-\vartheta}\widehat{y}_{t-1}^{\mathrm{N}} + \frac{(1+\varphi)(1-\vartheta)(1-\xi)(1+\beta\gamma)(\varphi\zeta+1)}{(2+\varphi-\vartheta)\xi(1-\beta(1-\xi))}\widehat{z}_t \tag{5}$$

Table: Estimation Results

Parameter	(1)	(2)	(3)	(4)	(5)
ϑ	–	0.94 [0.90,0.97]	–	–	–
ξ	0.49 [0.33,0.64]	0.08 [0.03,0.14]	0.49 [0.34,0.64]	0.68 [0.51,0.83]	0.22 [0.14,0.31]
φ	0.26 [0.04,0.48]	0.29 [0.07,0.51]	0.27 [0.05,0.49]	0.24 [0.02,0.46]	0.28 [0.06,0.50]
$r^\star$	0.61 [0.31,0.86]	0.66 [0.36,0.97]	0.62 [0.34,0.87]	0.56 [0.11,0.92]	0.62 [0.22,1.02]
$\pi^\star$	0.90 [0.53,1.24]	1.01 [0.69,1.33]	0.91 [0.57,1.26]	0.86 [0.34,1.30]	0.97 [0.57,1.34]
ρ_r	0.67 [0.60,0.75]	0.84 [0.77,0.91]	0.67 [0.60,0.74]	0.21 [0.02,0.39]	0.27 [0.14,0.42]
α_π	1.61 [1.29,1.90]	1.40 [1.06,1.75]	1.58 [1.31,1.90]	2.37 [2.05,2.70]	1.64 [1.19,2.10]
α_y	0.13 [0.04,0.23]	0.04 [0.00,0.12]	0.15 [0.05,0.24]	0.13 [0.03,0.22]	0.20 [0.11,0.28]
ρ_a	0.98 [0.96,1.00]	0.07 [0.00,0.18]	0.98 [0.96,1.00]	0.99 [0.97,1.00]	0.95 [0.92,0.97]
ρ_χ	0.91 [0.85,0.97]	0.26 [0.09,0.42]	0.91 [0.85,0.97]	0.92 [0.85,0.98]	0.86 [0.80,0.92]
ρ_π	–	–	–	0.92 [0.86,0.98]	–

Table: Estimation Results

Parameter	(1)	(2)	(3)	(4)	(5)
σ_a	0.27	0.11	0.25	0.81	0.12
	[0.14,0.44]	[0.08,0.14]	[0.12,0.40]	[0.35,1.38]	[0.09,0.16]
σ_χ	0.16	0.62	0.17	0.20	0.29
	[0.11,0.22]	[0.48,0.77]	[0.12,0.23]	[0.16,0.24]	[0.21,0.37]
σ_r	0.36	0.26	0.35	0.49	0.13
	[0.30,0.41]	[0.23,0.29]	[0.30,0.41]	[0.37,0.63]	[0.09,0.16]
σ_ν	0.14	0.15	0.16	–	0.21
	[0.10,0.19]	[0.11,0.18]	[0.11,0.22]		[0.18,0.25]
σ_π	–	–	–	0.11	–
				[0.08,0.15]	
η_y	–	–	–	–	0.28
					[0.10,0.52]
η_π	–	–	–	–	6.72
					[2.18,13.15]
$\mathcal{L}$	-323.472	-267.388	-321.101	-296.148	-264.729

Note: This table reports the mean of the posterior distribution of each parameter and the associated 95% HPDI (in brackets). (1): Baseline NK, (2): Hybrid NK (Backward Indexation, Real Rigidities), (3): Imperfect Info. Temporary vs Permanent Shocks, (4): Imperfect Info., Unobserved Inflation Target (Cogley–Sbordone), (5): Imperfect Info., Noisy Signals. $\mathcal{L}$ denotes the average log marginal density of the model. 95% HPDI in brackets.

Table: Moments (HP–filtered series)

	Data	(1)	(2)	(3)	(4)	(5)
σ_y	1.56	1.47	1.56	1.45	1.21	1.15
		[1.27,1.67]	[1.26,1.89]	[1.25,1.64]	[1.07,1.36]	[1.02,1.28]
σ_π	0.30	0.38	0.45	0.37	0.35	0.30
		[0.33,0.43]	[0.40,0.51]	[0.33,0.42]	[0.31,0.39]	[0.26,0.33]
σ_R	0.44	0.37	0.49	0.37	0.43	0.35
		[0.33,0.41]	[0.40,0.59]	[0.33,0.41]	[0.38,0.48]	[0.31,0.40]
$\rho(\pi, y)$	0.12	0.24	0.19	0.26	0.09	0.21
		[0.12,0.36]	[0.05,0.34]	[0.13,0.38]	[0.02,0.16]	[0.13,0.29]
$\rho(R, y)$	0.34	-0.25	-0.21	-0.25	-0.05	0.26
		[-0.37,-0.13]	[-0.40,-0.01]	[-0.36,-0.13]	[-0.12,0.02]	[0.11,0.41]
$\rho_y(1)$	0.87	0.65	0.85	0.63	0.71	0.68
		[0.63,0.68]	[0.81,0.89]	[0.60,0.66]	[0.69,0.72]	[0.66,0.71]
$\rho_\pi(1)$	0.48	0.37	0.72	0.40	0.42	0.33
		[0.30,0.45]	[0.69,0.75]	[0.33,0.46]	[0.33,0.52]	[0.22,0.43]
$\rho_R(1)$	0.82	0.65	0.81	0.65	0.73	0.71
		[0.59,0.70]	[0.77,0.86]	[0.60,0.71]	[0.69,0.76]	[0.66,0.77]
$\rho_y(2)$	0.69	0.41	0.64	0.39	0.47	0.43
		[0.38,0.44]	[0.58,0.71]	[0.34,0.42]	[0.46,0.48]	[0.40,0.47]
$\rho_\pi(2)$	0.31	0.13	0.47	0.14	0.25	0.20
		[0.07,0.20]	[0.42,0.50]	[0.08,0.21]	[0.18,0.31]	[0.12,0.27]
$\rho_R(2)$	0.58	0.40	0.61	0.40	0.47	0.44
		[0.33,0.46]	[0.55,0.67]	[0.34,0.46]	[0.43,0.51]	[0.38,0.51]

- Imperfect information seems to play an important role in accounting for the US business cycle.
- It can help the NK model match key dynamic properties of the data (such as inflation inertia) without any need for other, popular inertial features (such as real rigidities and backward price indexation schemes.
- Its success is not confined to a sample that also includes "unusual" macroeconomic behavior (the 70s) but it also extends to a period that only contains the great moderation.
- Its good performance does not hinge on implausibly large amount of informational frictions. Measurement errors well within the range observed in real time data.

Fiscal shocks

The effect of a fiscal shock on consumption. Positive in the data (Fatas and Mihov, 2004, Perotti, 2005), negative in the models.

Fiscal multipliers have become smaller during the last couple of decades (Perotti, 2005).

The great moderation. The reduction in macroeconomic volatility during the last two decades.

Can we account for all these developments? How?

The open economy IS-LM model.

Canzoneri et al., 2008.
The structure of the model: Small open economy, calibrated to Canadian data.
Information: The nominal interest rate and the exchange rate are perfectly observable. For the rest, Kalman filtering.
Shocks: Government spending, productivity, foreign output, relative demand.
Two benchmarks:

- Fixed (+ capital controls + low degree of openness)
- Flexible (+ capital mobility + higher degree of openness)

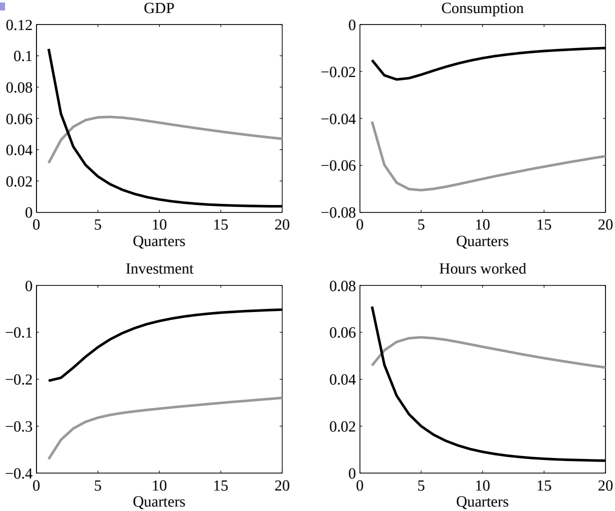
- The role of monetary policy
  1. The exchange rate regime
  2. The policy rule
- The role of globalization
  1. Greater trade openness
  2. Capital mobility

  item The role of luck: More stable fiscal policy

Table: Experiments (Perfect information)

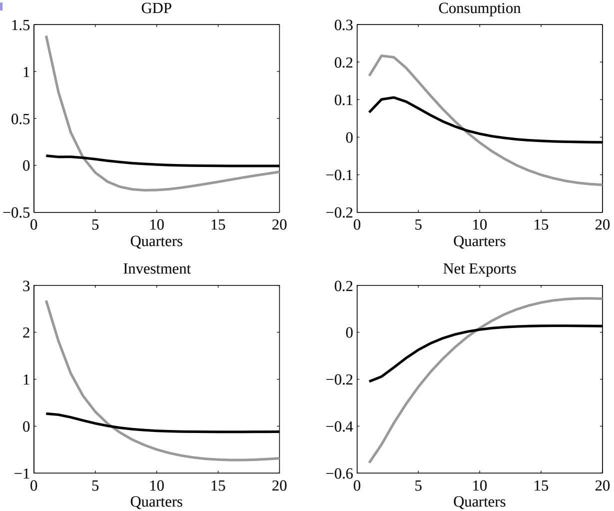
Model	μ_1	μ_4	μ_8
(1) Benchmark Fixed	0.0315	0.0508	0.0621
(5) Benchmark flexible	0.1044	0.0836	0.0781

Figure: IRF to a Fiscal Shock – Perfect Information



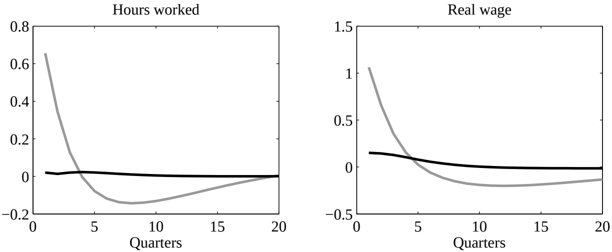
Note: dark line: Benchmark flexible (Post–1980), Gray line: Benchmark fixed (Pre–1980)

Figure: IRF to a Fiscal Shock – Imperfect Information



Note: dark line: Benchmark flexible (Post–1980), Gray line: Benchmark fixed (Pre–1980)

Figure: Perceived Shocks Following a Fiscal Shock (Imperfect Information)



Note: dark line: Benchmark flexible (Post–1980), Gray line: Benchmark fixed (Pre–1980)

Table: Experiments (individual contribution)

Model	μ_1	μ_4	μ_8
(1) Benchmark Fixed	1.4809	0.6101	0.1617
(2) Flexible Exchange rate	0.1429	0.1211	0.0994
(3) Lower capital control ($\chi = 0.0025$)	1.1982	0.5612	0.2245
(4) Higher imports ($\omega = 0.72$)	0.6405	0.2776	0.0895
(5) new fiscal shock ($\rho_g = 0.78$,$\sigma_g = 0.0154$)	1.7010	0.7325	0.1732
(6) Benchmark flexible	0.0914	0.1339	0.1262

Table: Experiments (Cumulative effects)

Model	μ_1	μ_4	μ_8
(1) Benchmark Fixed	1.4809	0.6101	0.1617
(2)=(1) + Flexible Exchange rate	0.1429	0.1211	0.0994
(3)=(2) + Higher imports ($\omega = 0.72$)	0.0805	0.0994	0.0920
(4)=(3) + Lower capital control ($\chi = 0.0025$)	0.0699	0.0976	0.0932
(5)=(4) + Fiscal Shock=Benchmark flexible	0.0914	0.1339	0.1262
(6) Benchmark flexible (Money growth rule)	-0.0214	0.0447	0.0729
(7) Benchmark flexible but strict inflation targeting	0.3483	0.1668	0.0973