VARs, the Current Consensus Model and Extensions

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Overview

- A new consensus has emerged about the rough outlines of a model for the analysis of monetary policy.
  - Consensus influenced heavily by estimated impulse response functions from Structural Vector Autoregression (SVARs)
- Describe empirical SVAR results.
- Construction of the consensus models based on results from SVARs.
  - Christiano, Eichenbaum and Evans JPE (2005)
  - Smets and Wouters, AER (2007)
- Further developments of the consensus model
  - Labor market
  - Financial frictions
  - Open economy
- Monetary policy analysis: how policy should respond to interest rate spreads, relationship between monetary policy asset market volatility.

Vector Autoregressions

- Proposed by Chris Sims in 1970s, 1980s

- Major subsequent contributions by others (Bernanke, Blanchard-Watson, Blanchard-Quah)

- Useful Way to Organize Data
  - VARs serve as a 'Battleground' between alternative economic theories
  - VARs can be used to quantitatively construct a particular model

- Question that can (in principle) be addressed by VAR:
  - 'How does the economy respond to a particular shock?'
  - Current consensus model heavily guided by answers to this question

- VARs can't *actually* address such a question
  - Identification problem
  - Need extra assumptions….Structural VAR (SVAR).

Outline of SVAR discussion

- What is a VAR?
- The Identification Problem
- Identification restrictions
- Results
- Historical Decompositions of Data

Estimating the Effects of Shocks to the Economy

- Vector Autoregression for a $N \times 1$ vector of observed variables:

$$Y_t = B_1 Y_{t-1} + ... + B_p Y_{t-p} + u_t,$$

$$E u_t u_t' = V$$

- $B\prime s$, $u's$ and V are Easily Obtained by OLS.
- Problem: $u's$ are statistical innovations.
  - We want impulse response functions to fundamental economic shocks, e_t.

$$u_t = C e_t,$$

$$E e_t e_t' = I,$$

$$CC' = V$$

Estimating the Effects of a Shock to the Economy ...

$$\text{VAR:} \quad Y_t = B_1 Y_{t-1} + ... + B_p Y_{t-p} + C e_t$$

- Impulse Response to i^{th} Shock:

$$Y_t - E_{t-1} Y_t = C_i e_{it},$$

$$E_t Y_{t+1} - E_{t-1} Y_{t+1} = B_1 C_i e_{it}$$

$$\cdots$$

- To Compute Dynamic Response of Y_t to i^{th} Element of e_t We Need

$$B_1, ..., B_p \text{ and } C_i.$$

Identification Problem

$$Y_t = B_1 Y_{t-1} + ... + B_p Y_{t-p} + u_t$$

$$u_t = Ce_t, \; Eu_t u_t' = CC' = V$$

- We know $B's$ and V, we need C.
- Problem
  - N^2 Unknown Elements in C,
  - Only $N(N+1)/2$ Equations in

$$CC' = V$$

- Identification Problem: Not Enough Restrictions to Pin Down C
- Need More Identifying Restrictions!

Shocks and Identification Assumptions

- Monetary Policy Shock
- Neutral Technology Shock
- Capital-Embodied Shock to Technology

Identifying Monetary Policy Shocks

- One strategy: estimate parameters of Fed's feedback rule
  - Rule that relates Fed's actions to state of the economy:

Fed information set

Policy shock

$$R_t = f(\Omega_t) + e_t^R$$

  - f linear
  - e_t^R orthogonal to Fed information, Ω_t
  - Ω_t contains current prices and wages, aggregate quantities, lagged stuff
  - e_t^R estimated by OLS regression
  - Regress X_t on e_t^R, e_{t-1}^R, e_{t-2}^R ,…

Identification of Technology Shocks (Blanchard-Quah, Fisher, JPE 2007)

- There are two types of technology shocks: neutral and capital embodied

$$X_t = Z_t F(K_t, L_t)$$

$$K_{t+1} = (1-\delta)K_t + V_t I_t$$

- These are only shocks that can affect labor productivity in the long run.

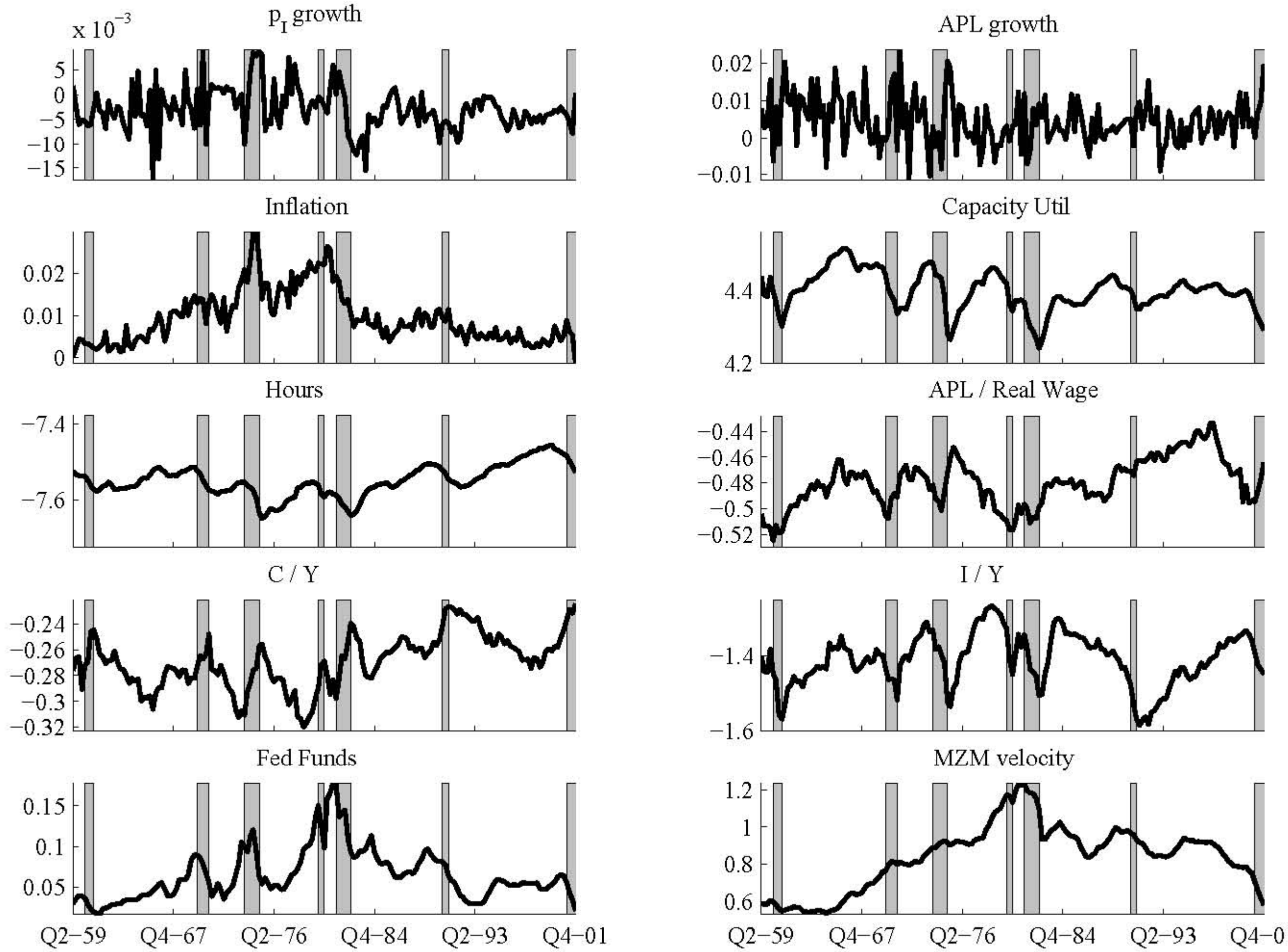
- The only shock which also has a long run effect on the relative price of capital is a capital embodied technology shock (V_t).

VAR estimation with the following data:

$$\underbrace{Y_t}_{10\times 1} = \begin{pmatrix} \Delta \ln(\text{relative price of investment}_t) \\ \Delta \ln(GDP_t/\text{Hours}_t) \\ \Delta \ln(GDP\ \text{deflator}_t) \\ \text{capacity utilization}_t \\ \ln(\text{Hours}_t) \\ \ln(GDP_t/\text{Hours}_t) - \ln(W_t/P_t) \\ \ln(C_t/GDP_t) \\ \ln(I_t/GDP_t) \\ \text{Federal Funds Rate}_t \\ \ln(GDP\ \text{deflator}_t) + \ln(GDP_t) - \ln(MZM_t) \end{pmatrix}$$

The data have been transformed to ensure stationarity
Sample period: 1959Q1-2007Q1

data used in the analysis



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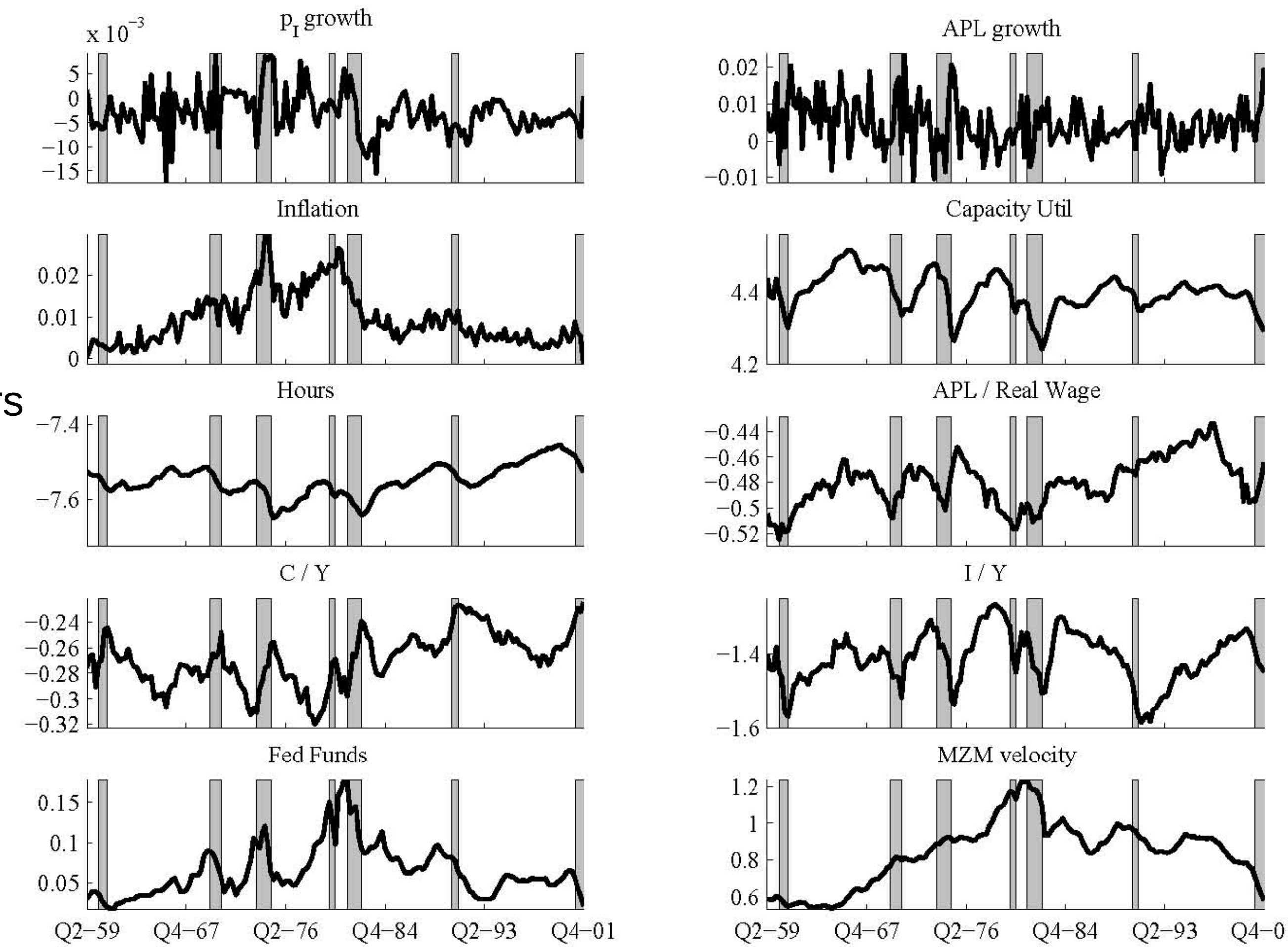
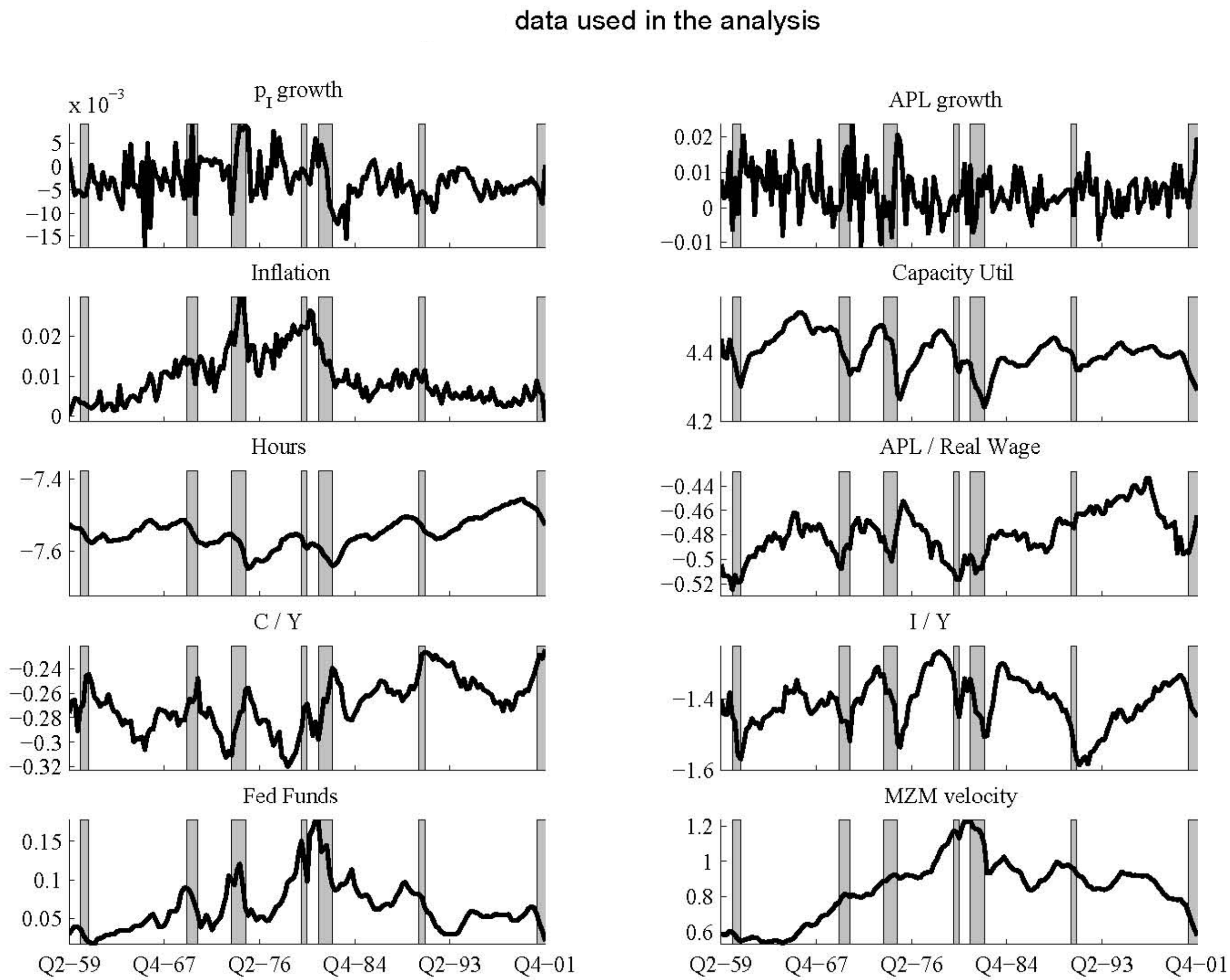
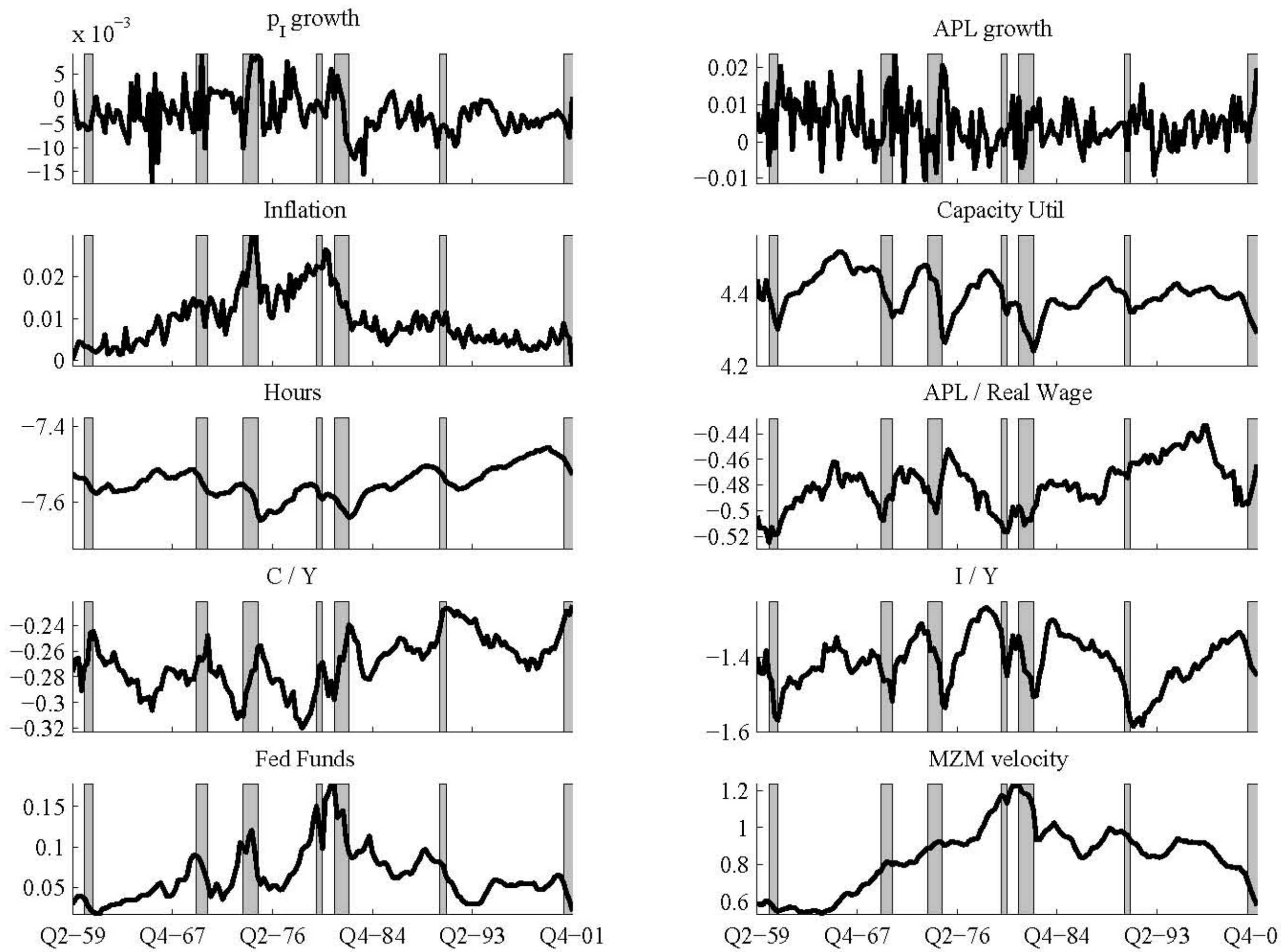


Whether
per capita hours
are stationary
has stimulated
much debate



Inflation a little non-stationary

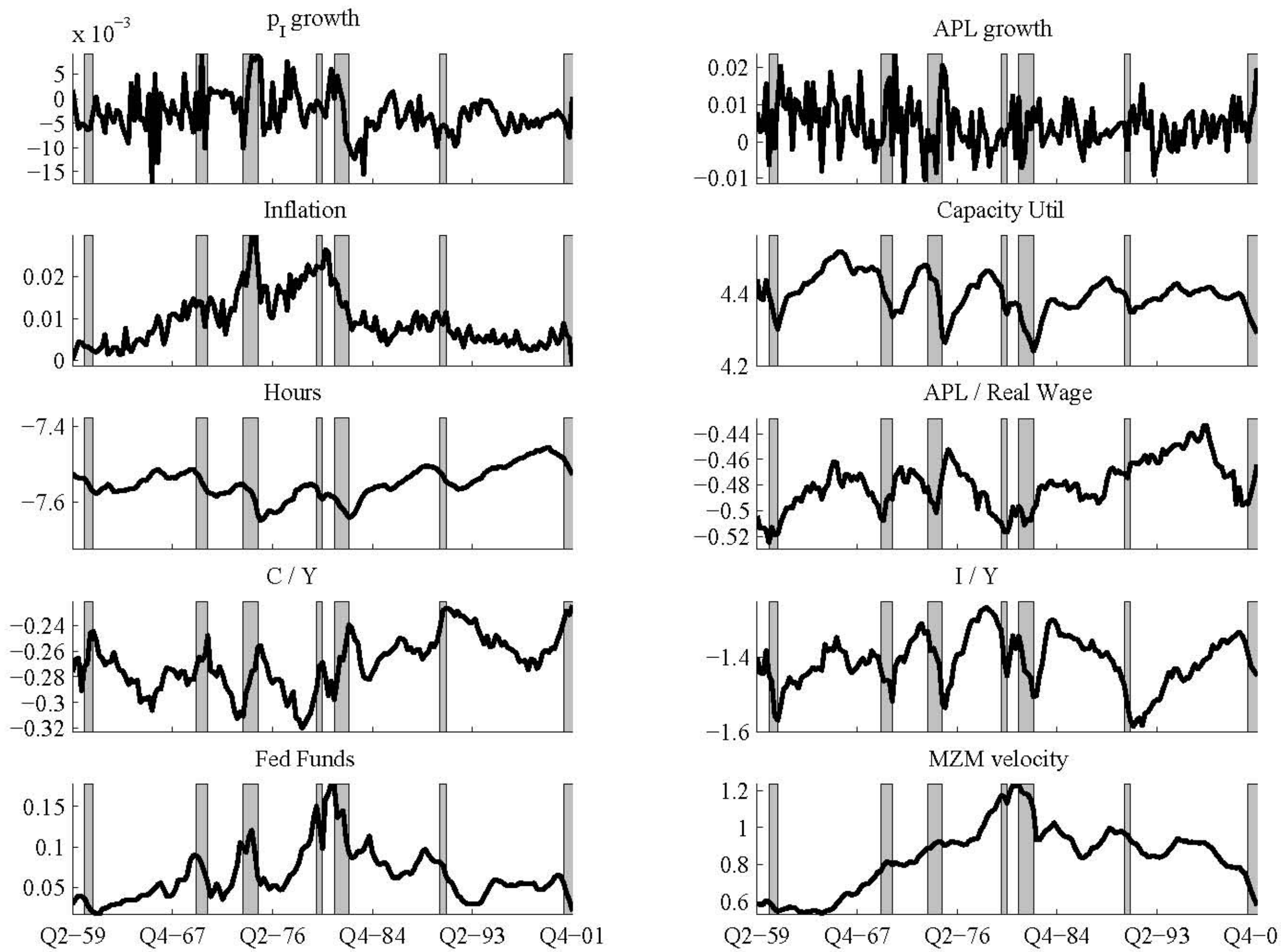
data used in the analysis



US trade Balance issue

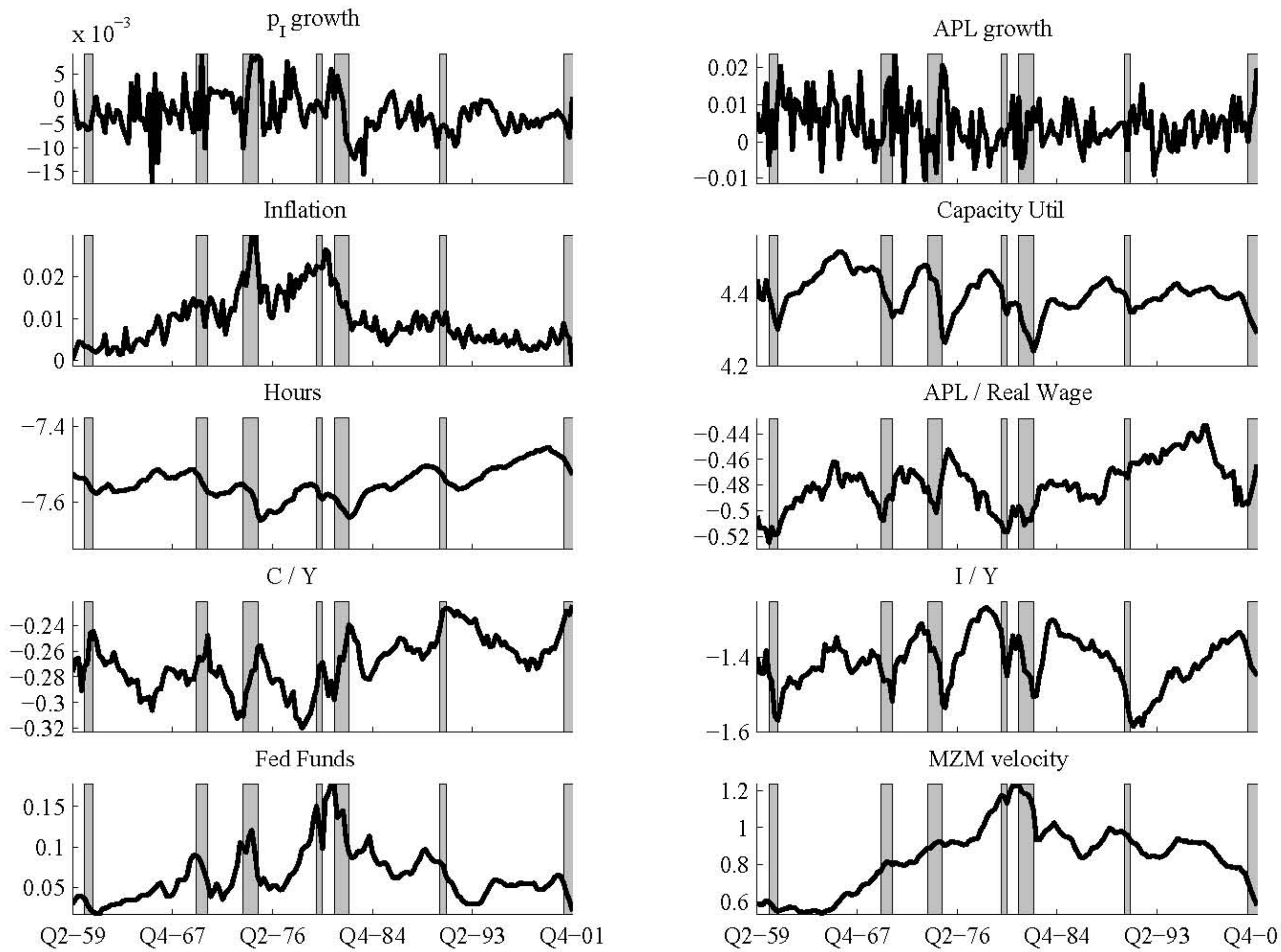
Sort of stationary

data used in the analysis



Note how high rates
tend to precede recessions

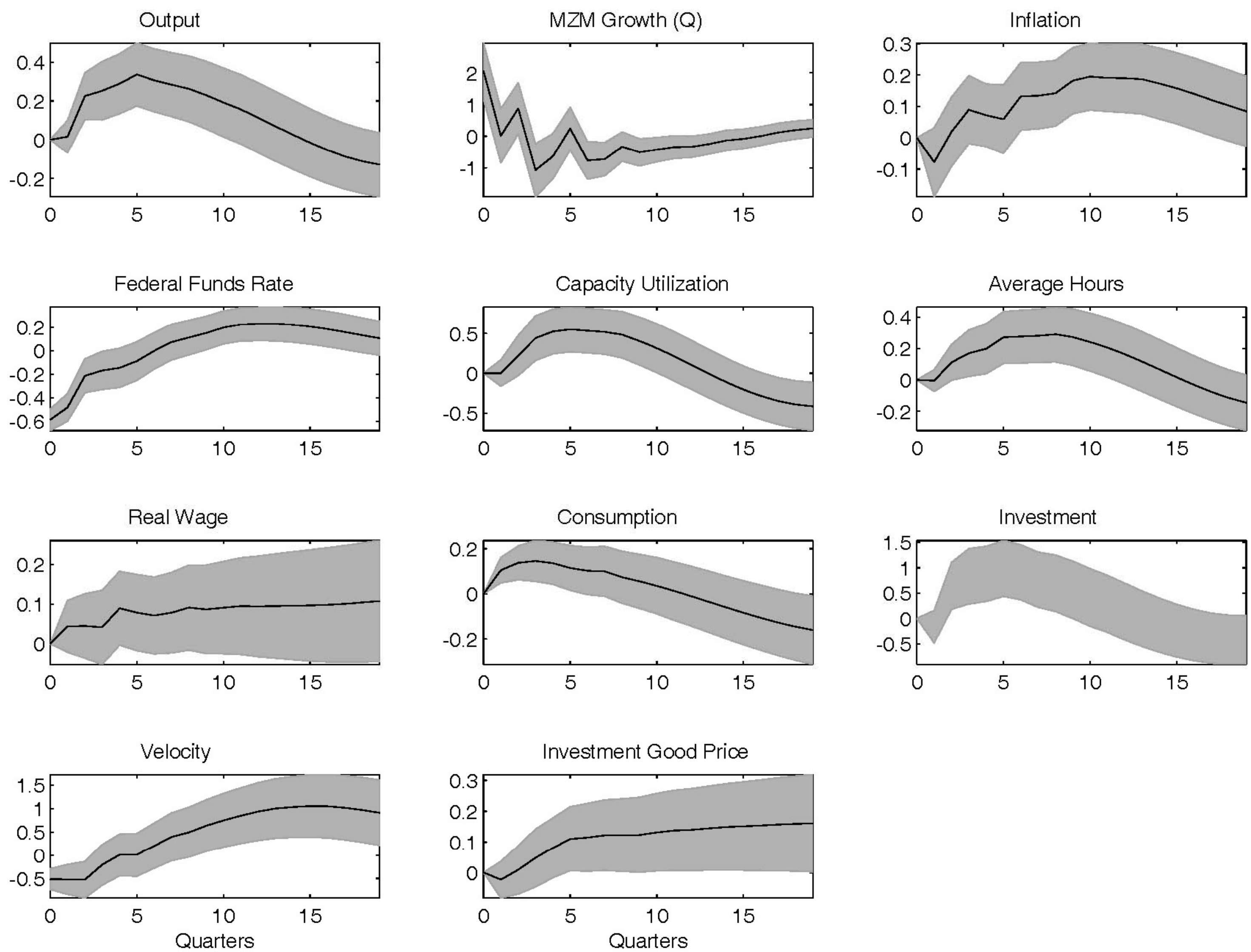
data used in the analysis



Moves with Interest rate

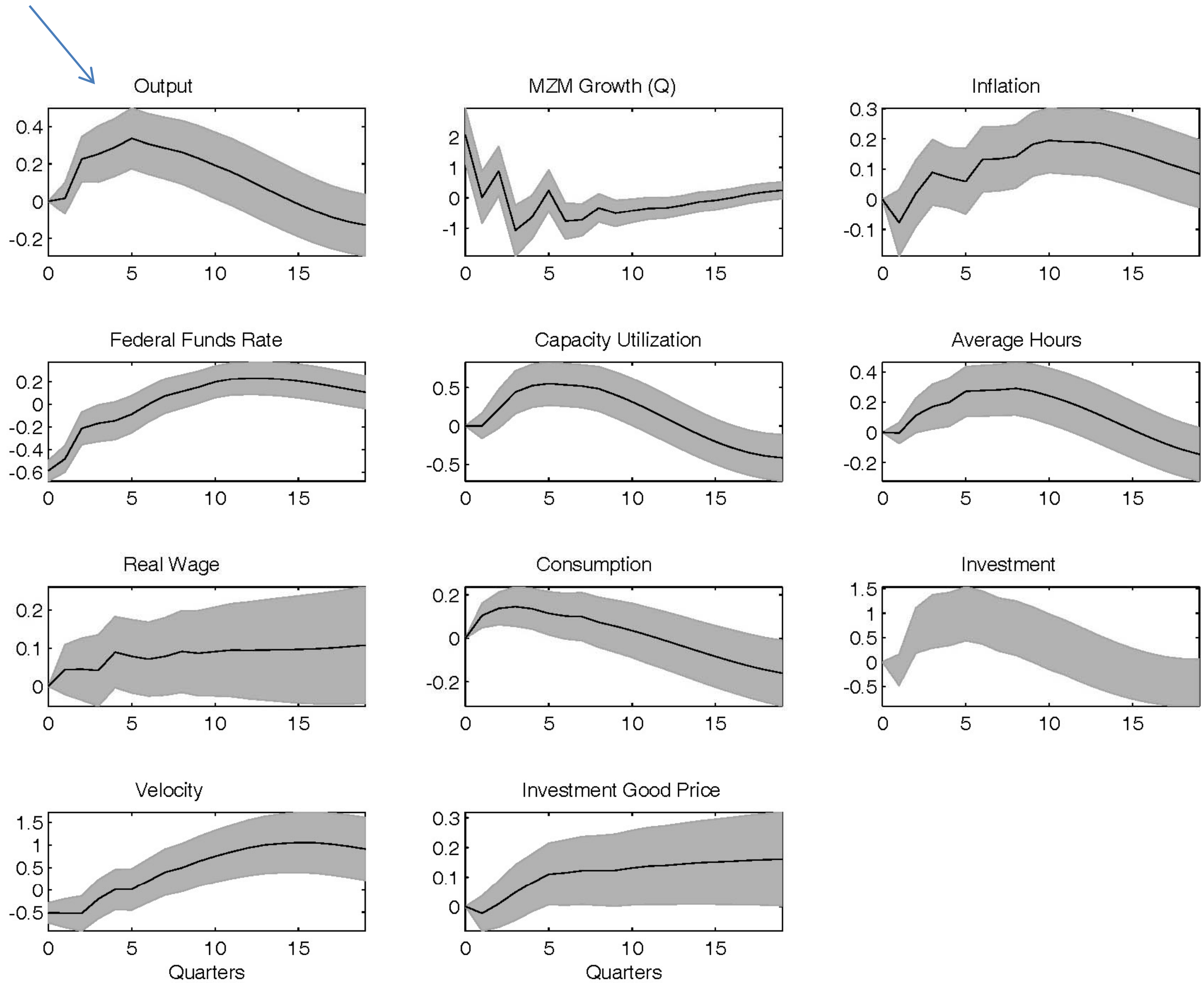
- Results…..

Response to a monetary policy shock



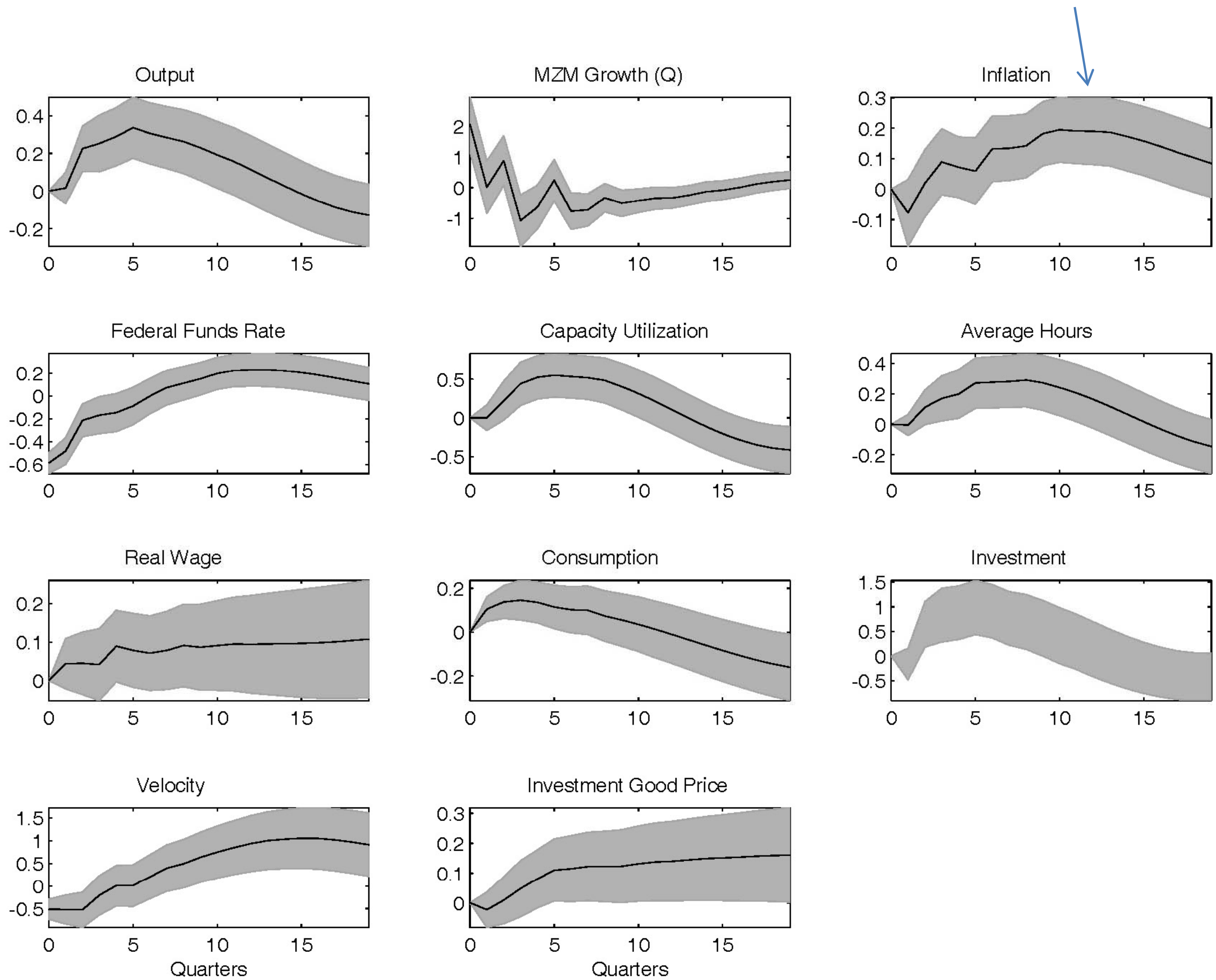
Lots of persistence!

Response to a monetary policy shock

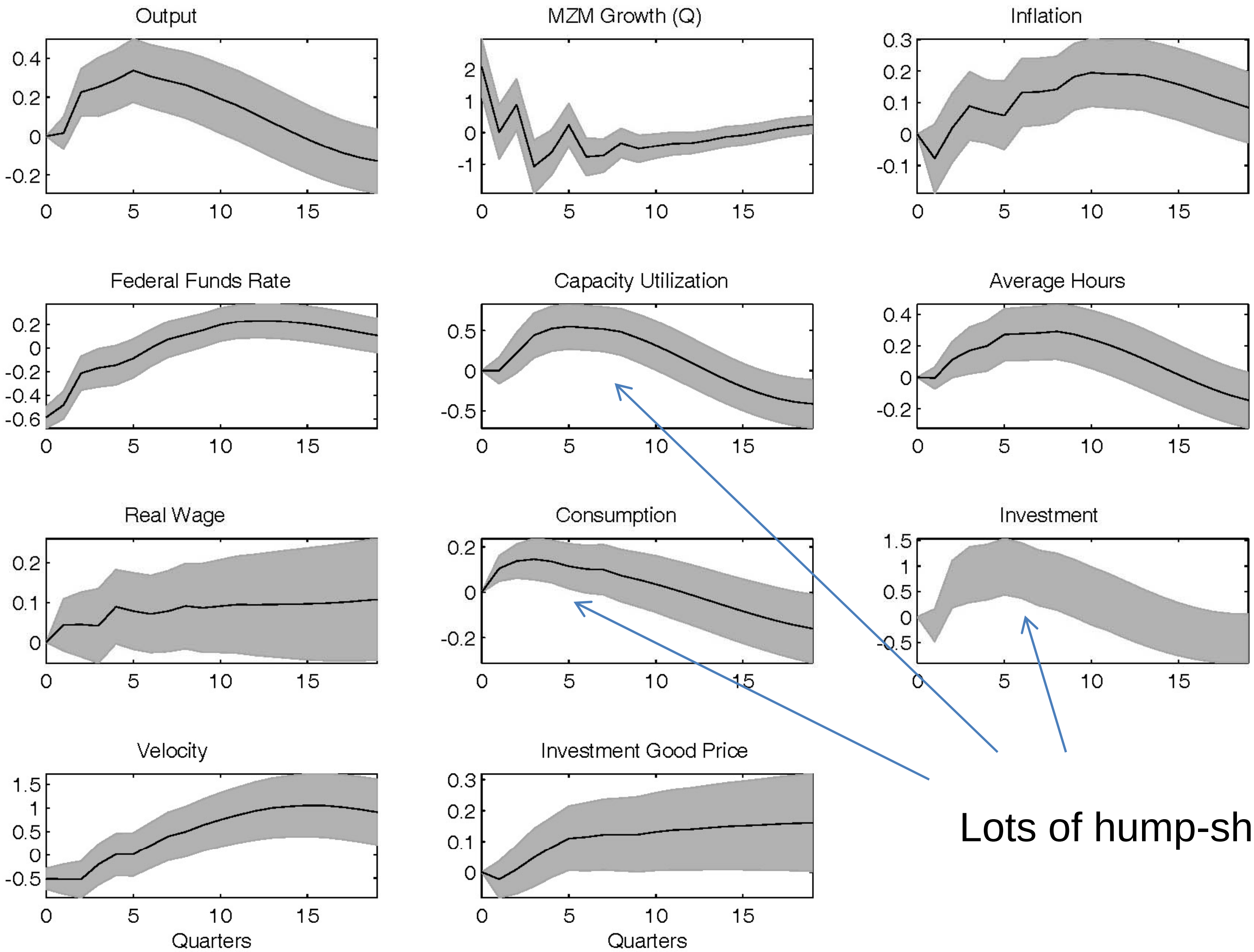


Response to a monetary policy shock

Inflation *very* slow to respond!



Response to a monetary policy shock

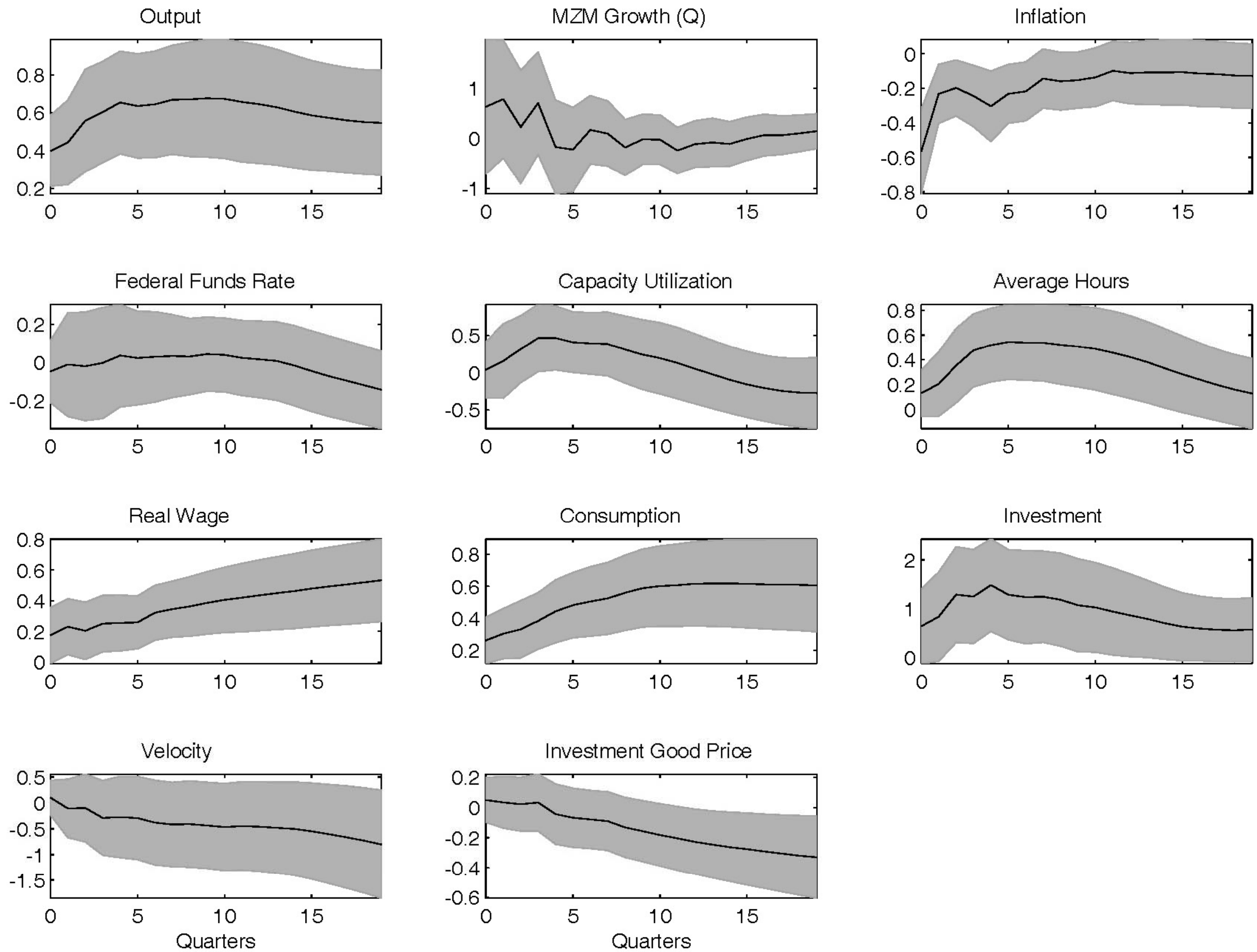


Lots of hump-shapes

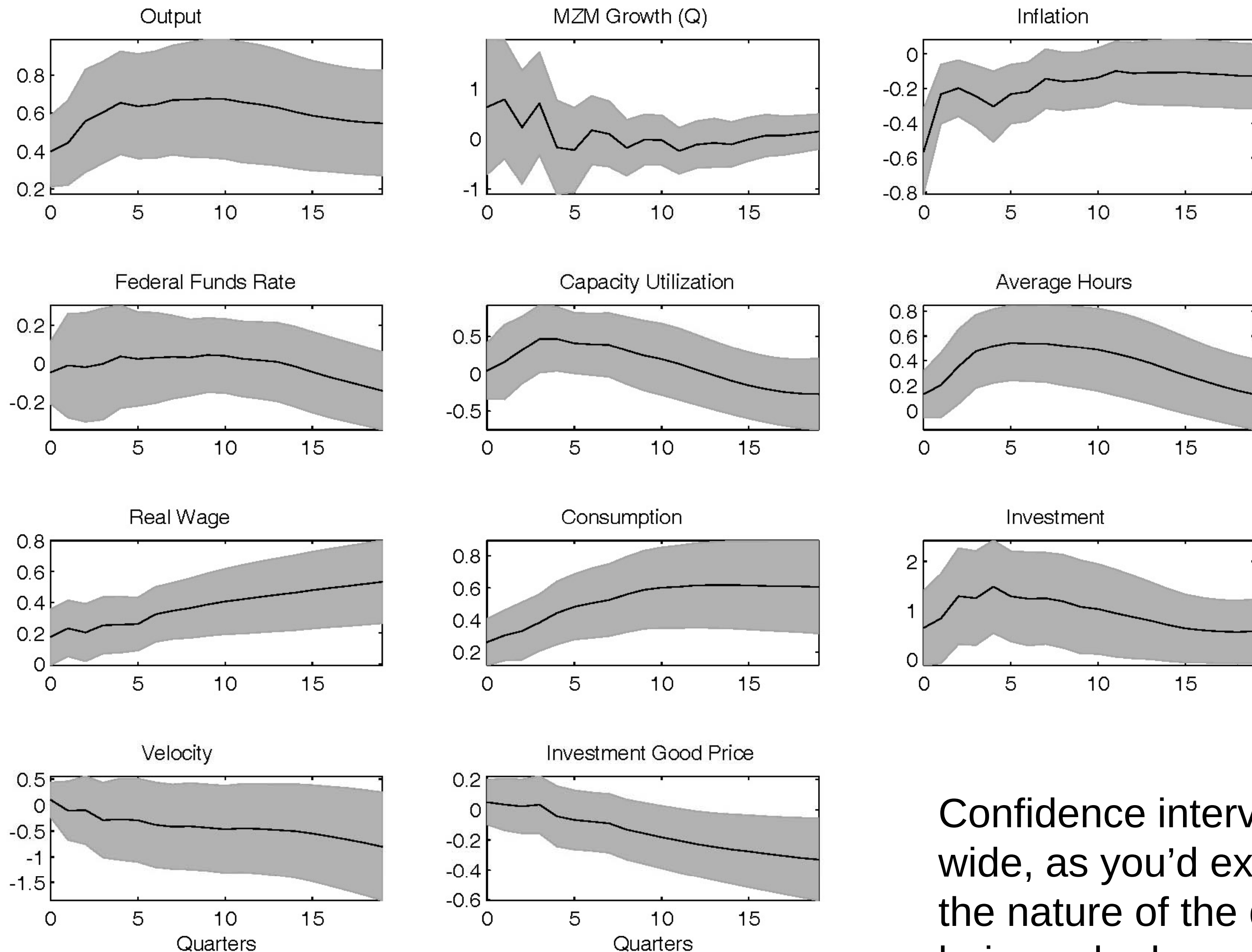
Interesting Properties of Monetary Policy Shocks

- Plenty of endogenous persistence:
  - money growth and interest rate over in 1 year, but other variables keep going….
- Inflation slow to get off the ground: peaks in roughly two years
  - It has been conjectured that explaining this is a major challenge for economics
  - Chari-Kehoe-McGrattan (*Econometrica*), Mankiw.
  - Kills models in which movements in *P* are key to monetary transmission mechanism (Lucas misperception model, pure sticky wage model)
  - Has been at the heart of the recent emphasis on sticky prices.
- Output, consumption, investment, hours worked and capacity utilization hump-shaped
- Velocity comoves with the interest rate

Response to a neutral technology shock

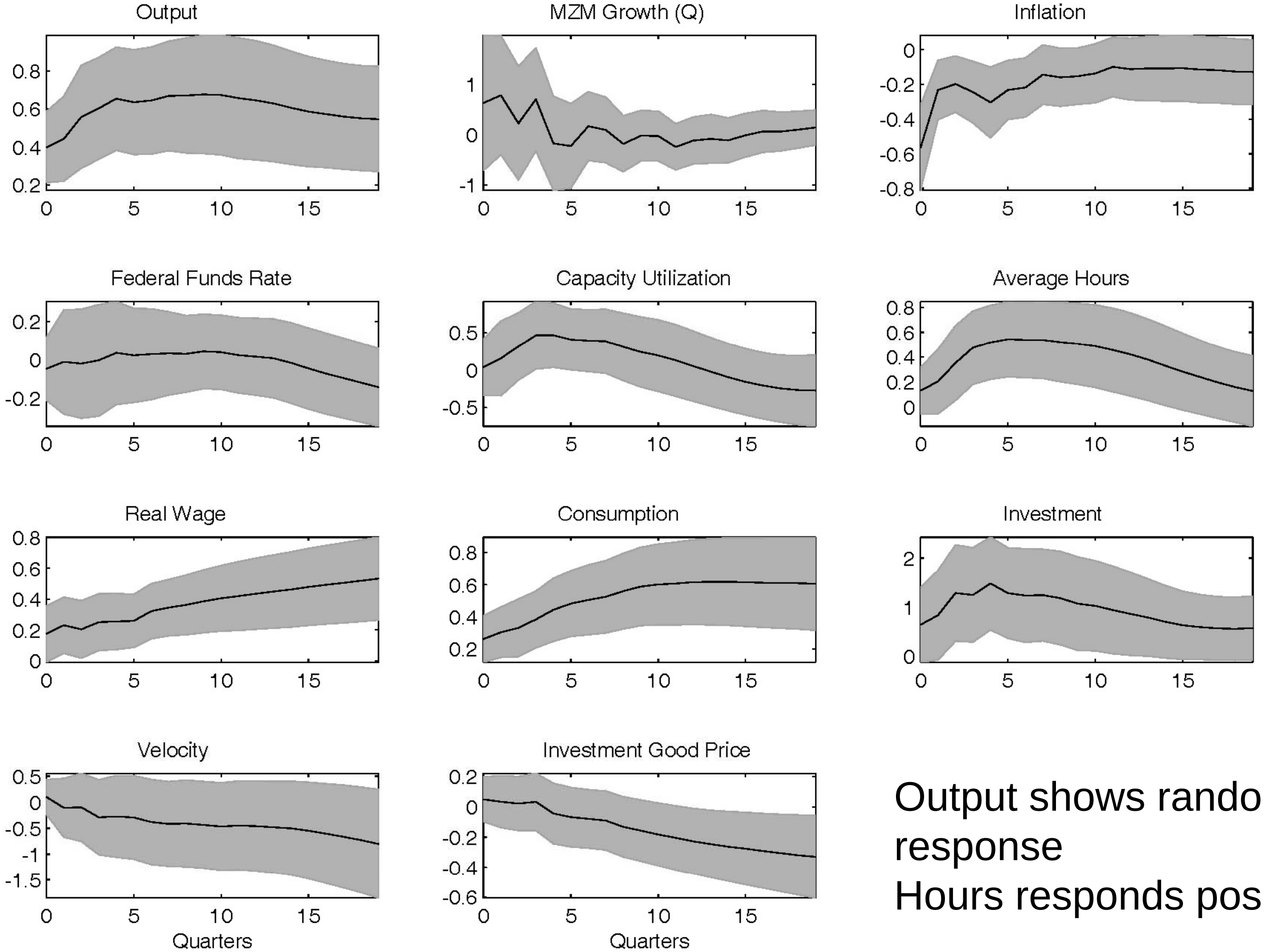


Response to a neutral technology shock



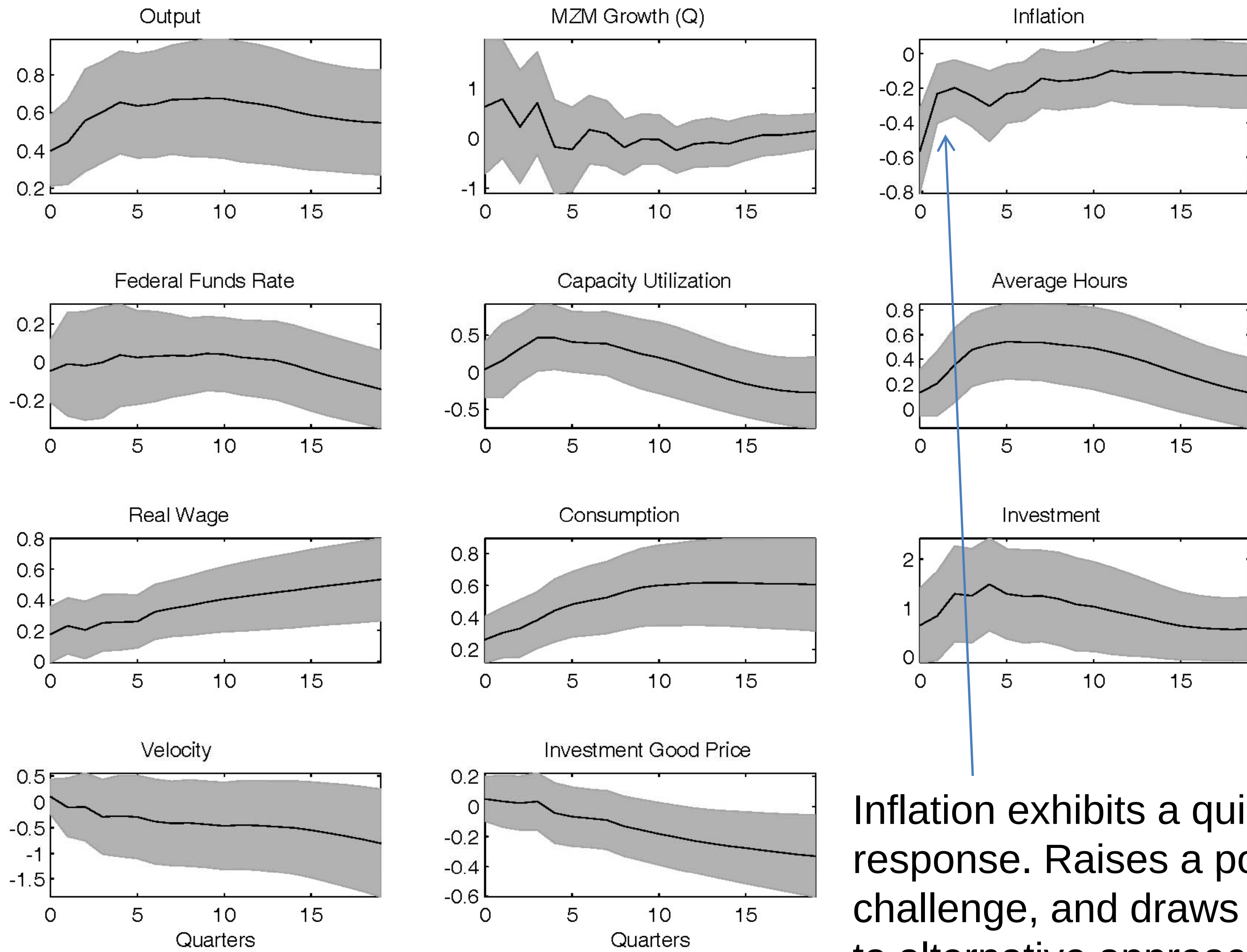
Confidence intervals are wide, as you'd expect given the nature of the question being asked

Response to a neutral technology shock



Output shows random walk response
Hours responds positively

Response to a neutral technology shock



Inflation exhibits a quick response. Raises a potential challenge, and draws attention to alternative approaches.

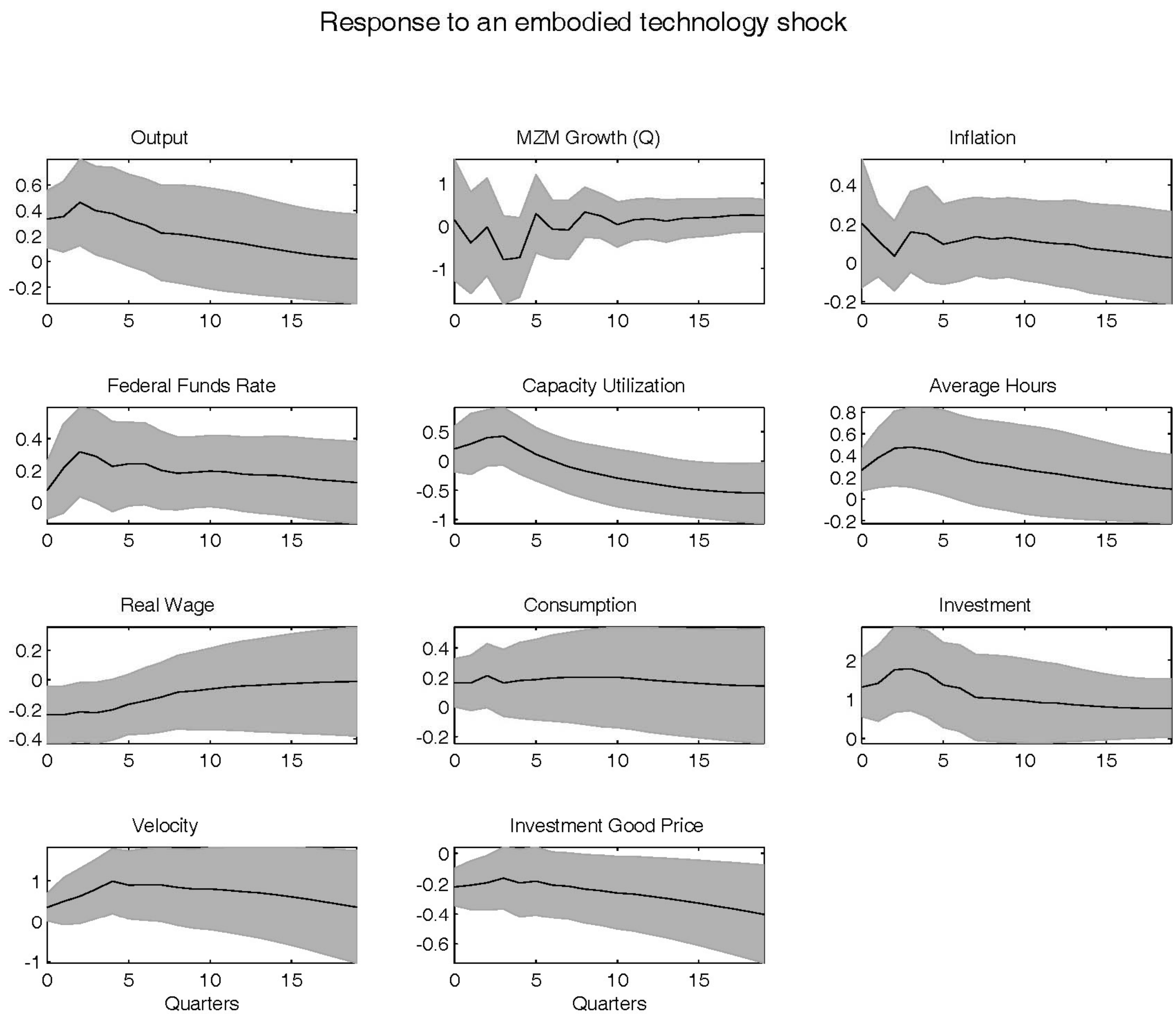
Observations on Neutral Shock

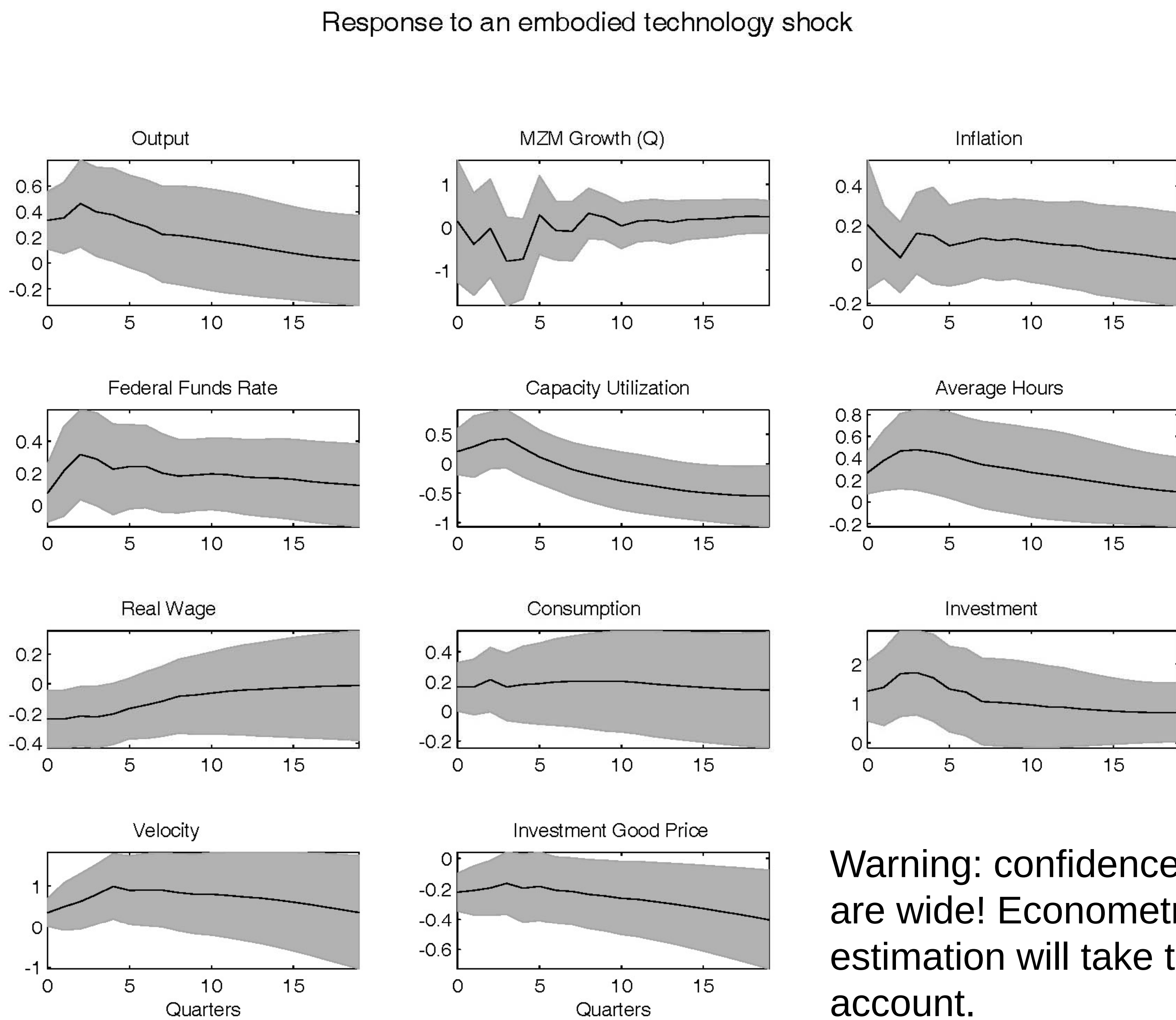
- Generally, results are 'noisy', as one expects.
  - Interest, money growth, velocity responses not pinned down.

- Interestingly, inflation response is immediate and *precisely* estimated.

- Does this raise a question about the conventional interpretation of the response of inflation to a monetary shock?

- Alternative possibility: information confusion stories.
  - A variant of recent work by Rhys Mendes that builds on Guido Lorenzoni's work.


Response to an embodied technology shock
Output
MZM Growth (Q)
Inflation
Federal Funds Rate
Capacity Utilization
Average Hours
Real Wage
Consumption
Investment
Velocity
Investment Good Price
Quarters
Quarters

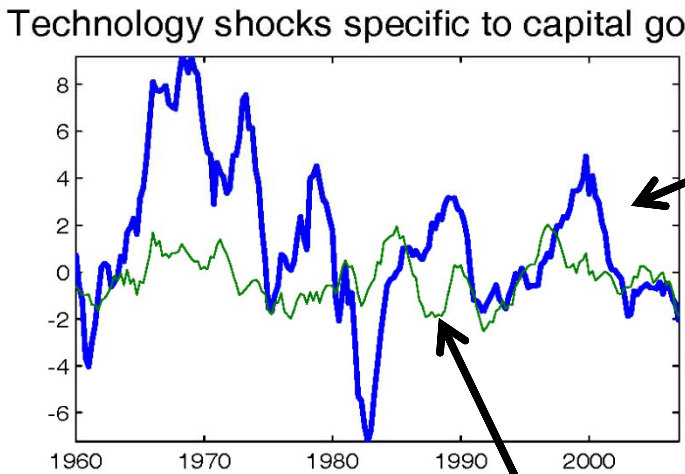


Warning: confidence intervals are wide! Econometric model estimation will take this into account.

Historical Decomposition of Data into Shocks

- We can ask:
  - What would have happened if only monetary policy shocks had driven the data?
  - We can ask this about other identified shocks, or about combinations of shocks
  - We find that the three shocks together account for a large part of fluctuations

Historical decomposition of US GDP



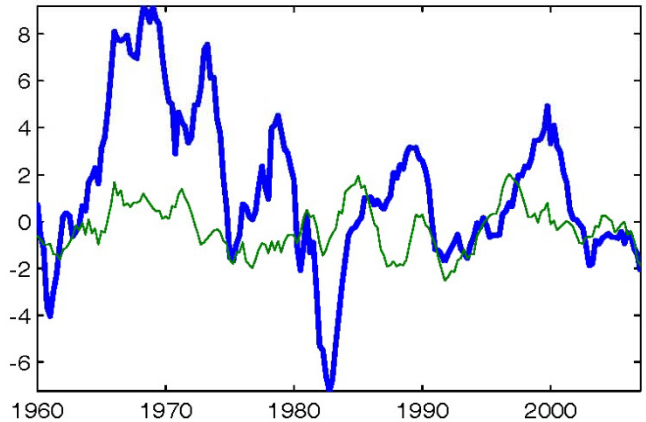
Dark line: detrended actual GDP

Thin line: what GDP would have been if there had only been one type of technology shock, the type that affects only the capital goods industry

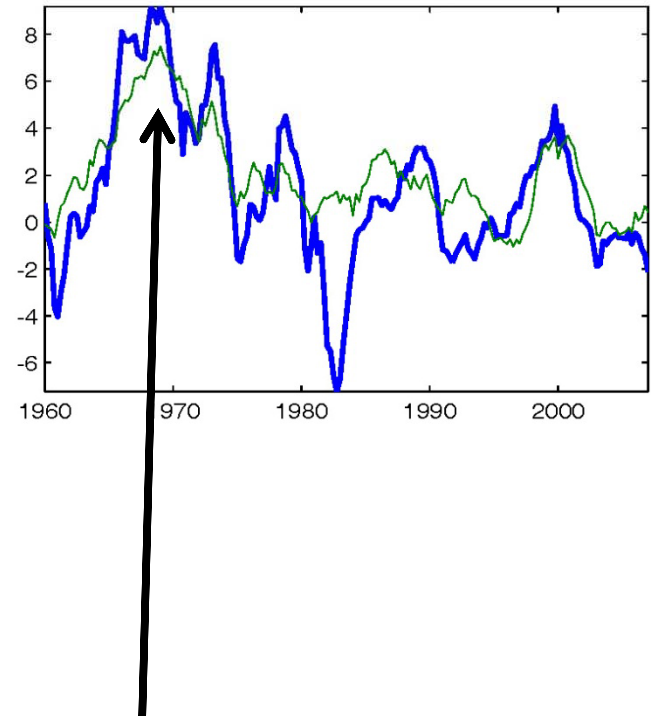
These shocks have some effect, but not terribly important

Historical decomposition of US GDP

Technology shocks specific to capital goods



General (neutral) technology shocks only



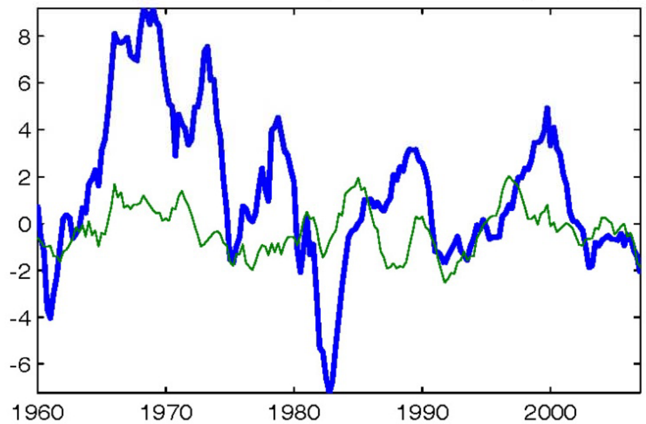
Type of technology shock that affects all industries

This has very large impact on broad trends in the data, and a smaller impact on business cycles.

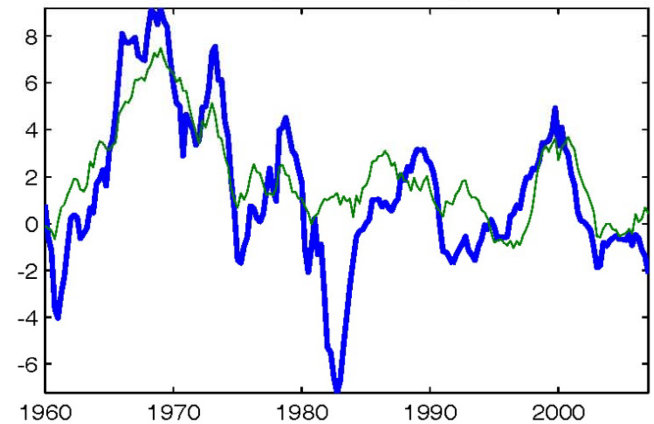
Has big impact on trend in data, and 2000 boom-bust

Historical decomposition of US GDP

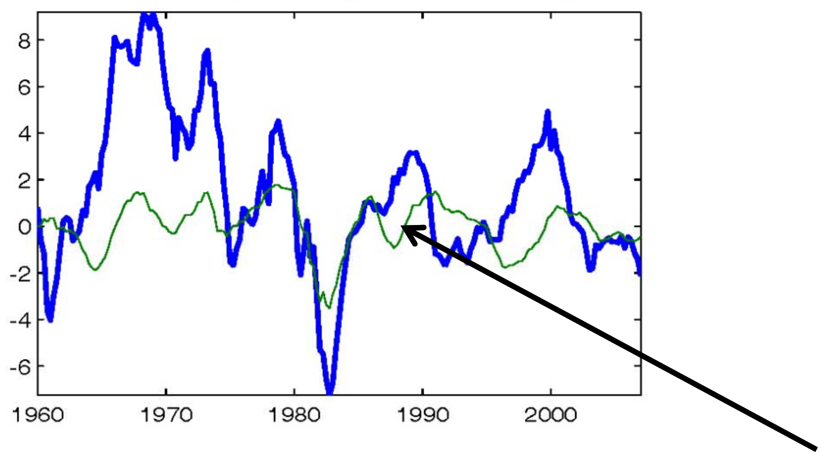
Technology shocks specific to capital goods



General (neutral) technology shocks only

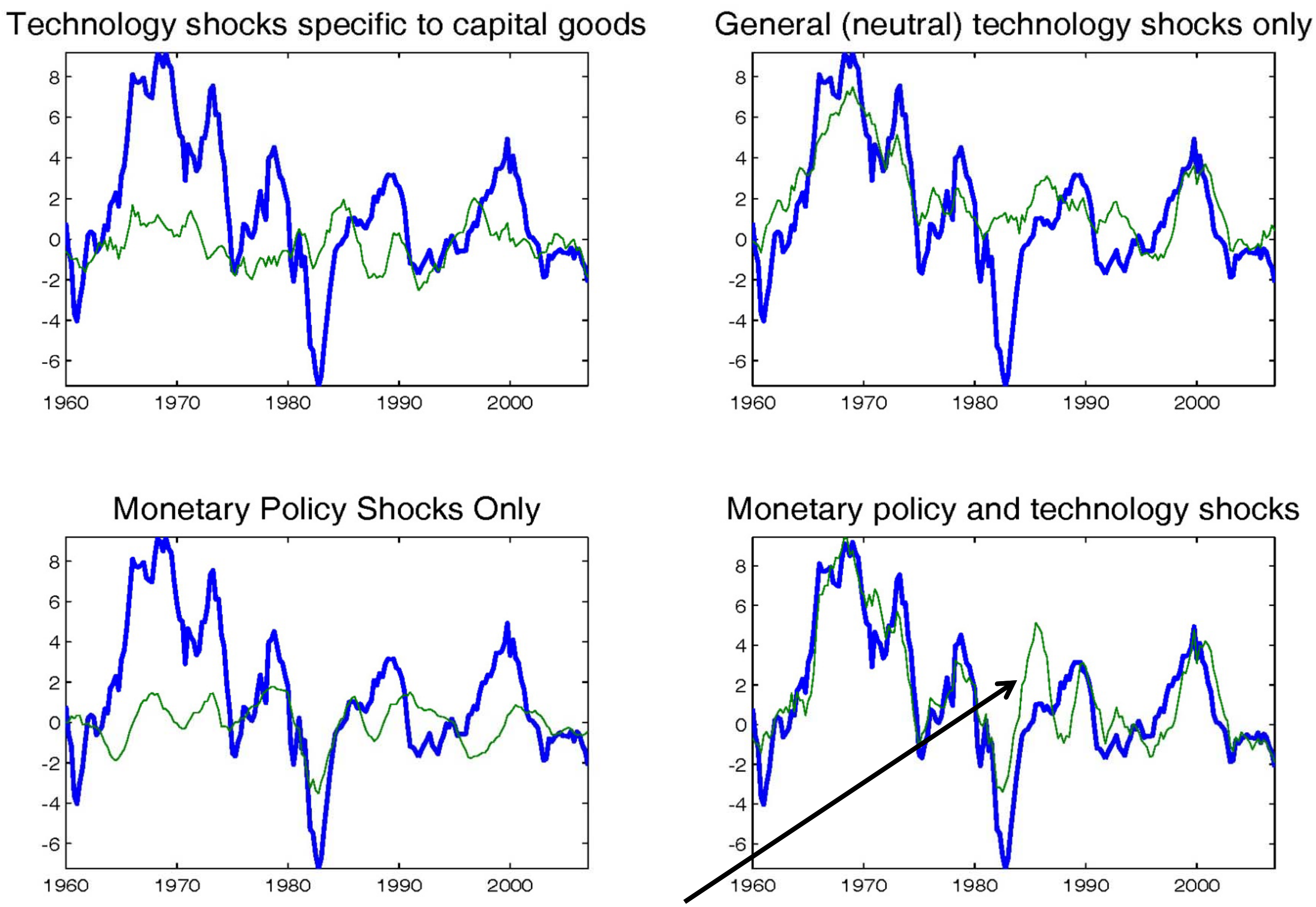


Monetary Policy Shocks Only



Monetary policy shocks have a big impact on 1980 ‘Volcker recession’

Historical decomposition of US GDP



All three shocks together account for
large part of business cycle

Variance Decomposition

Variable	BP(8,32)
Output	86 [18]
Money Growth	23 [11]
Inflation	33 [17]
Fed Funds	52 [16]
Capacity Util.	51 [16]
Avg. Hours	76 [17]
Real Wage	44 [16]
Consumption	89 [21]
Investment	69 [16]
Velocity	29 [16]
Price of investment goods	11 [16]

Figure 4: Historical decomposition - monetary policy and technology shocks

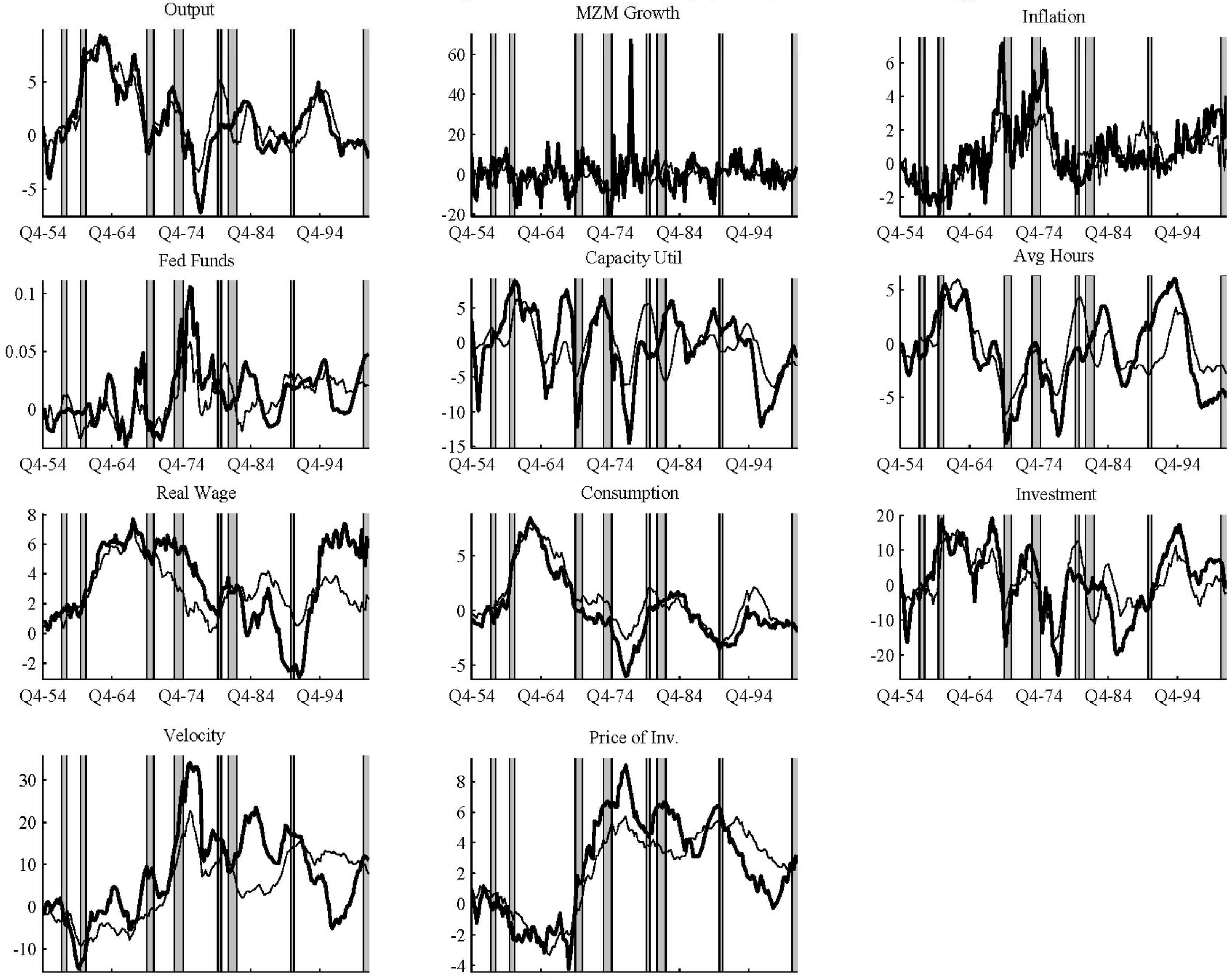


Table 1: Decomposition of Variance - In-sample Band Pass Filter and 30-Quarter Ahead Forecast Error

Variable	Embodied Technology		Neutral Technology		Monetary Policy		All Three Shocks	
	BP(8,32)	Forec. Error	BP(8,32)	Forec. Error	BP(8,32)	Forec. Error	BP(8,32)	Forec. Error
Output	19 [10]	10 [8]	22 [13]	63 [15]	25 [9]	6 [3]	86 [18]	80 [12]
MZM Growth	2 [6]	3 [3]	3 [7]	3 [3]	17 [7]	13 [3]	23 [11]	18 [5]
Inflation	3 [10]	7 [11]	16 [12]	25 [9]	15 [7]	11 [5]	33 [17]	43 [11]
Fed Funds	6 [9]	14 [9]	2 [7]	1 [5]	45 [10]	20 [5]	52 [16]	36 [9]
Capacity Util.	7 [9]	13 [9]	7 [8]	7 [6]	25 [9]	11 [5]	51 [16]	31 [10]
Avg. Hours	19 [11]	19 [11]	18 [11]	34 [13]	22 [8]	7 [4]	76 [17]	60 [13]
Real Wage	28 [11]	5 [10]	7 [12]	49 [19]	2 [3]	2 [3]	44 [16]	57 [17]
Consumption	14 [10]	8 [11]	37 [17]	71 [20]	23 [8]	2 [3]	89 [21]	82 [17]
Investment	19 [10]	30 [12]	10 [10]	22 [12]	20 [8]	7 [4]	69 [16]	59 [12]
Velocity	7 [10]	11 [13]	1 [8]	5 [7]	24 [10]	12 [6]	29 [16]	27 [13]
Price of Inv.	9 [16]	26 [20]	4 [7]	13 [10]	3 [4]	5 [4]	11 [16]	44 [16]

Notes: Numbers are point estimates, number in square brackets are standard deviation of point estimates across bootstrap simulations. In the case of the forecast error decomposition row sums fail to add only because of rounding error. In the case of BP(8,32) row sums fail to add due to in-sample correlation between shocks.

- Now, to the construction of a monetary equilibrium model, based on the previous impulse response functions….

- Based on
  - Christiano-Eichenbaum-Evans JPE(2005)
  - Altig-Christiano-Eichenbaum-Linde

Objectives

- Constructing a standard ('consensus') DSGE Model
  - Model features.
  - Estimation of model using impulse responses from SVAR's.

- Determine if there is a conflict regarding price behavior between micro and macro data.

  - Macro Evidence:
    - Inflation appears sluggish
    - Inflation responds slowly to monetary shock

  - Micro Evidence:
    - Bils-Klenow, Nakamura-Steinsson report evidence on frequency of price change at micro level: 5-11 months.

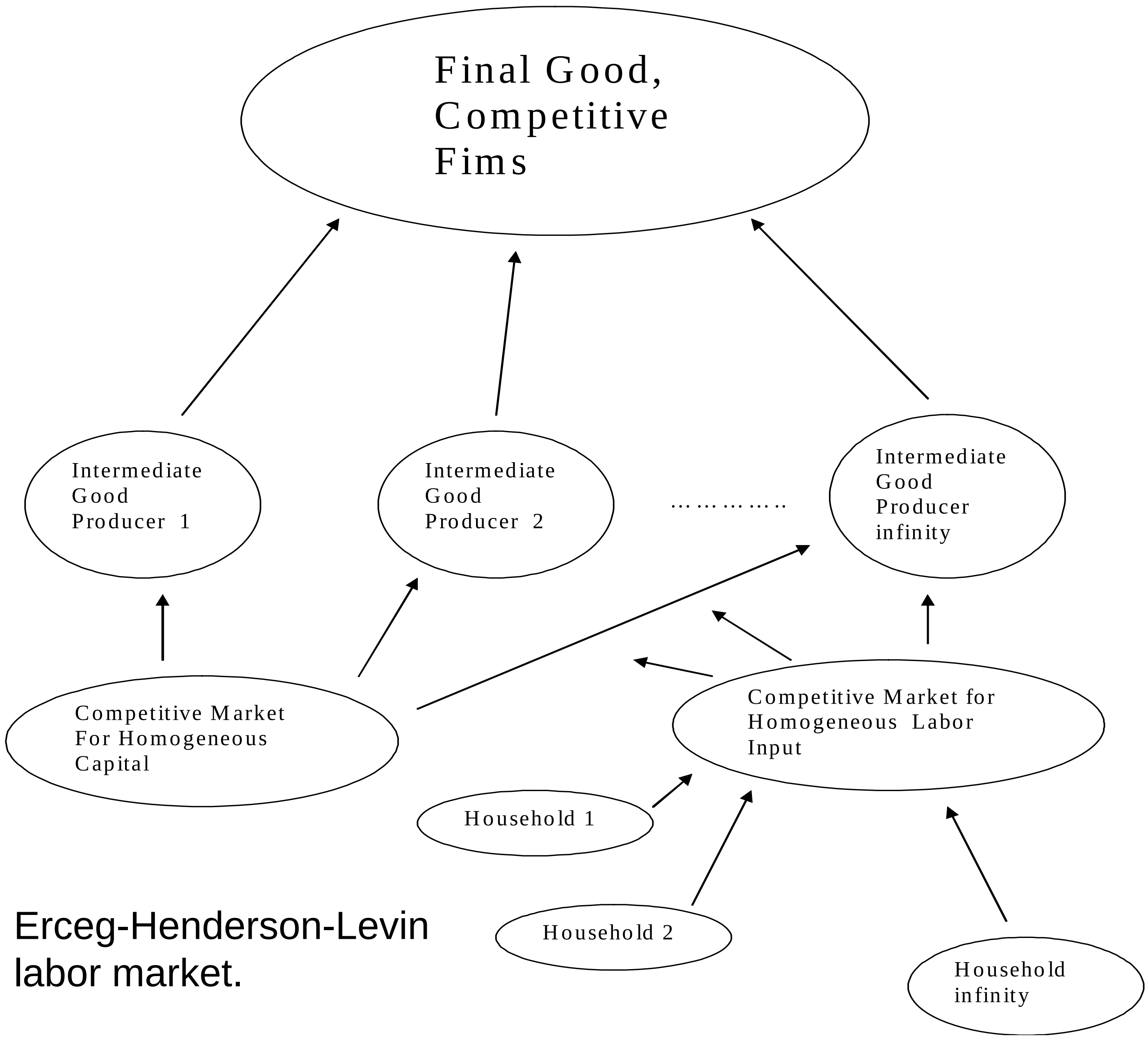
Description of Model

- Timing Assumptions
- Firms
- Households
- Monetary Authority
- Goods Market Clearing and Equilibrium

Timing

- Technology Shocks Realized.
- Agents Make Price/Wage Setting, Consumption, Investment, Capital Utilization Decisions.
- Monetary Policy Shock Realized.
- Household Money Demand Decision Made.
- Production, Employment, Purchases Occur, and Markets Clear.
-
- Note: Wages, Prices and Output Predetermined Relative to Policy Shock.

Firm Sector



Erceg-Henderson-Levin
labor market.

Firms

Final Good Firms

- Technology:

$$Y_t = \left[\int_0^1 Y_{it}^{\frac{1}{\lambda_f}} di\right]^{\lambda_f},\ 1 \leq \lambda_f < \infty$$

- Objective:

$$\max P_t Y_t - \int_0^1 P_{it} Y_{it} di$$

- Foncs and Prices:

$$\left(\frac{P_t}{P_{it}}\right)^{\frac{\lambda_f}{\lambda_f - 1}} = \frac{Y_{it}}{Y_t},\ P_t = \left[\int_0^1 P_{it}^{\frac{1}{1-\lambda_f}} di\right]^{(1-\lambda_f)}.$$

Intermediate Good Firms -

- Each Y_{it} Produced by a Monopolist, With Demand Curve:

$$\left(\frac{P_t}{P_{it}}\right)^{\frac{\lambda_f}{\lambda_f - 1}} = \frac{Y_{it}}{Y_t}.$$

- Technology:

$$Y_{it} = K_{it}^{\alpha}\left(z_t L_{it}^{1-\alpha}\right),\ 0 < \alpha < 1,$$

- Here, z_t is a technology shock:

$$\mu_{z,t} = \log z_t - \log z_{t-1},\ \hat{\mu}_{z,t} = \rho_{\mu_z}\hat{\mu}_{z,t-1} + \varepsilon_{\mu_z,t}$$

- Calvo Price Setting:
  - With Probability $1-\xi_p$, i^{th} Firm Sets Price, P_{it}, Optimally, to $\tilde{P}_t$.
  - With Probability ξ_p,

$$P_{it} = \pi_{t-1} P_{i,t-1},\ \pi_t = \frac{P_t}{P_{t-1}}.$$

  - Standard Approach in Literature:

$$\begin{aligned} P_{it} &= \bar{\pi} P_{i,t-1},\ \text{or} \\ P_{it} &= P_{i,t-1}. \end{aligned}$$

  - Stand on Indexing Matters

    Determines Extent of 'Front-Loading'

What Price Optimizers Do

- What they do *not* do:
  - Firms with the opportunity to set price today, do *not* do the usual thing of setting price as a markup of today's marginal cost.
  - This is because they understand there is a chance that they will be stuck in the future with the price they pick today.

What Price Optimizers Do, cont'd

- Optimizers set price today based on expected current *and future* marginal costs.

$$\text{marginal cost} = \frac{1}{z_t}\left(\frac{R_t W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{P_t r_t^k}{\alpha}\right)^{\alpha}$$

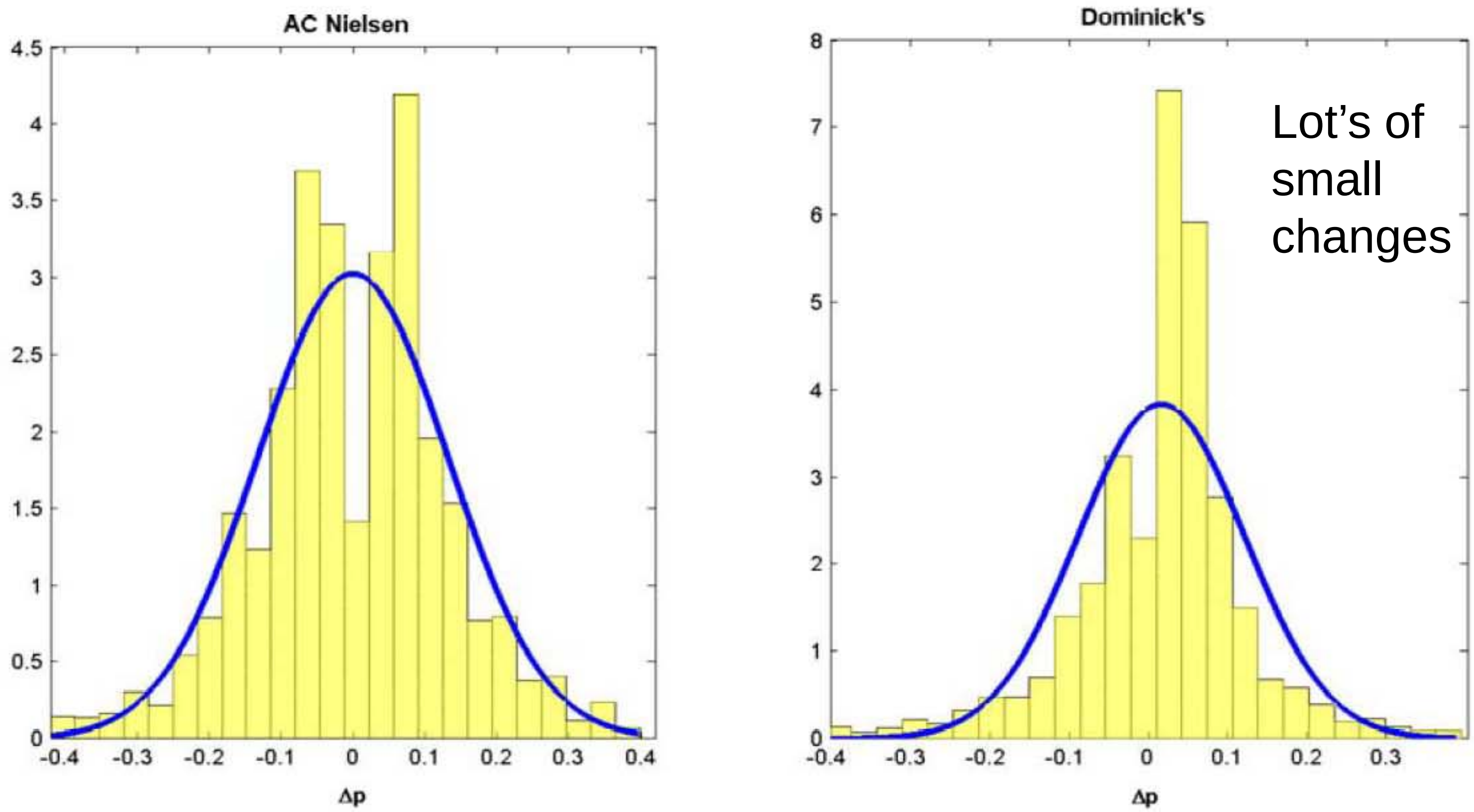
- Note:
  - marginal cost involves interest rate, because firms are assumed to have to borrow to pay the wage bill.
  - High supply elasticities limit rise in factor prices in an expansion and so limit the rise in marginal costs and, hence, prices.

Is Calvo a Good Reduced Form Model of Sticky Prices?

- Evidence on relative frequency of large and small price changes suggests ‘yes’
- Evidence of probability of price change conditional on time since last change suggests ‘yes’

Evidence from Midrigan, 'Menu Costs, Multi-Product Firms, and Aggregate Fluctuations'

Figure 1: Distribution of price changes conditional on adjustment



Note: superimposed is the pdf of a Gaussian distribution with equal mean and variance

Histograms of $\log(P_t/P_{t-1})$, conditional on price adjustment, for two data sets pooled across all goods/stores/months in sample.

- Combining Optimal Price and Aggregate Price Relation:

$$\Delta\hat{\pi}_t = \beta E_t \Delta\hat{\pi}_{t+1} + \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p} E_t \hat{s}_t,$$

- Under Standard Price-Updating Scheme:

$$P_{it} = \bar{\pi} P_{i,t-1}.$$

Associated Reduced Form:

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p} E_t \hat{s}_t.$$

Households: Sequence of Events

- Technology shock realized.
- Decisions: Consumption, Capital accumulation, Capital Utilization.
- Insurance markets on wage-setting open.
- Wage rate set.
- Monetary policy shock realized.
- Household allocates beginning of period cash between deposits at financial intermediary and cash to be used in consumption transactions.

Households...

- Monopoly supplier of differentiated labor
  - Sets wage subject to Calvo style frictions like firms
- Preferences of j^{th} household

$$E_t^j \sum_{l=0}^{\infty} \beta^{l-t} \left[\log \left(C_{t+l} - bC_{t+l-1} \right) - \psi_L \frac{h_{j,t+l}^2}{2} \right]$$

- E_t^j : expectation operator, conditional on aggregate and household j idiosyncratic information.
- C_t : consumption
- h_{jt} : hours worked.

Households...

- Asset Evolution Equation:

$$\begin{aligned} M_{t+1} &= R_t\left[M_t - Q_t + (x_t - 1)M_t^a\right] + A_{j,t} + Q_t + W_{j,t}h_{j,t} \\ &\quad + P_t r_t^k u_t \bar{K}_t + D_t - P_t\left[\left(1 + \eta\left(V_t\right)\right)C_t + \Upsilon_t^{-1}\left(I_t + a(u_t)\bar{K}_t\right)\right] \end{aligned}$$

  – M_t : Beginning of Period Base Money; Q_t : Transactions Balances

- Velocity:

$$V_t = \frac{P_t C_t}{Q_t},$$

Households...

- Asset Evolution Equation:

$$\begin{aligned} M_{t+1} &= R_t \left[M_t - Q_t + (x_t - 1) M_t^a \right] + A_{j,t} + Q_t + W_{j,t} h_{j,t} \\ &\quad + P_t r_t^k u_t \bar{K}_t + D_t - P_t \left[\left(1 + \eta \left(V_t \right) \right) C_t + \Upsilon_t^{-1} \left(I_t + a(u_t) \bar{K}_t \right) \right] \end{aligned}$$

  - M_t : Beginning of Period Base Money; Q_t : Transactions Balances
  - x_t : Growth Rate of Base; u_t : Utilization Rate of Capital
    - $u_t = 1$ in steady state, $a(1) = 0$, $a'(1) > 0$, $\sigma_a = a''(1)/a'(1)$.

Households...

- Asset Evolution Equation:

$$
\begin{aligned}
M_{t+1} &= R_t \left[M_t - Q_t + (x_t - 1) M_t^a \right] + A_{j,t} + Q_t + W_{j,t} h_{j,t} \\
&\quad + P_t r_t^k u_t \bar{K}_t + D_t - P_t \left[\left(1 + \eta\left(V_t\right)\right) C_t + \Upsilon_t^{-1} \left(I_t + a(u_t) \bar{K}_t \right) \right]
\end{aligned}
$$

  - M_t : Beginning of Period Base Money; Q_t : Transactions Balances
  - x_t : Growth Rate of Base; u_t : Utilization Rate of Capital
    - $u_t = 1$ in steady state, $a(1) = 0$, $a'(1) > 0$, $\sigma_a = a''(1)/a'(1)$.
  - Υ_t^{-1}: (Real) Price of investment goods, $\mu_{\Upsilon,t} = \Upsilon_t / \Upsilon_{t-1}$,

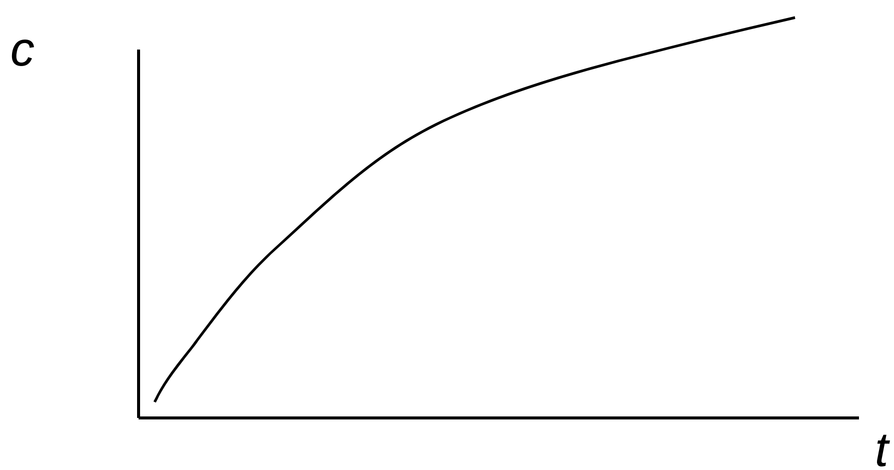
$$
\hat{\mu}_{\Upsilon,t} = \rho_{\mu_\Upsilon} \hat{\mu}_{\Upsilon,t-1} + \varepsilon_{\mu_\Upsilon,t}
$$

Dynamic Response of Consumption to Monetary Policy Shock

- In Estimated Impulse Responses:
  - Real Interest Rate Falls

$$R_t/\pi_{t+1}$$

  - Consumption Rises in Hump-Shape Pattern:



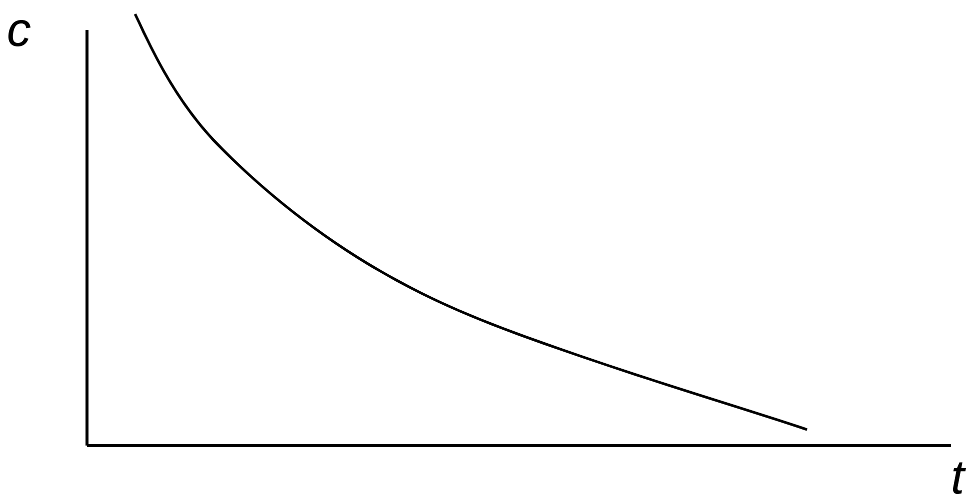
Consumption 'Puzzle'

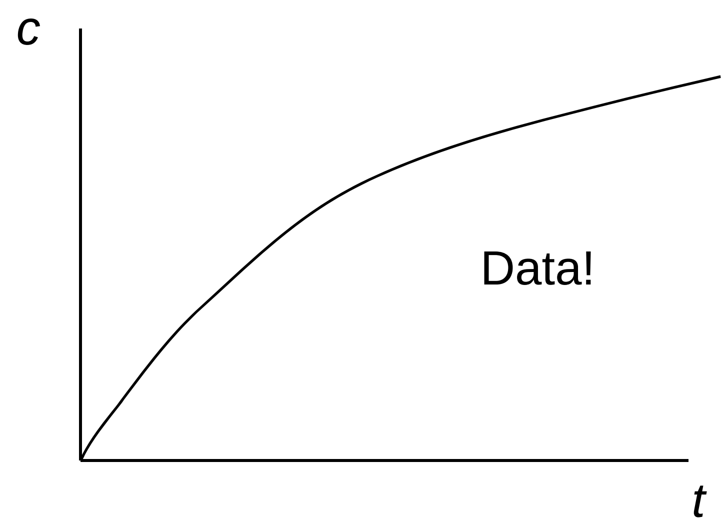
- Intertemporal First Order Condition:

'Standard' Preferences →

$$\frac{c_{t+1}}{\beta c_t} = \frac{MU_{c,t}}{\beta MU_{c,t+1}} \approx R_t/\pi_{t+1}$$

- With Standard Preferences:





One Resolution to Consumption Puzzle

- Concave Consumption Response Displays:
  - Rising Consumption (problem)
  - Falling Slope of Consumption

Habit parameter

- Habit Persistence in Consumption

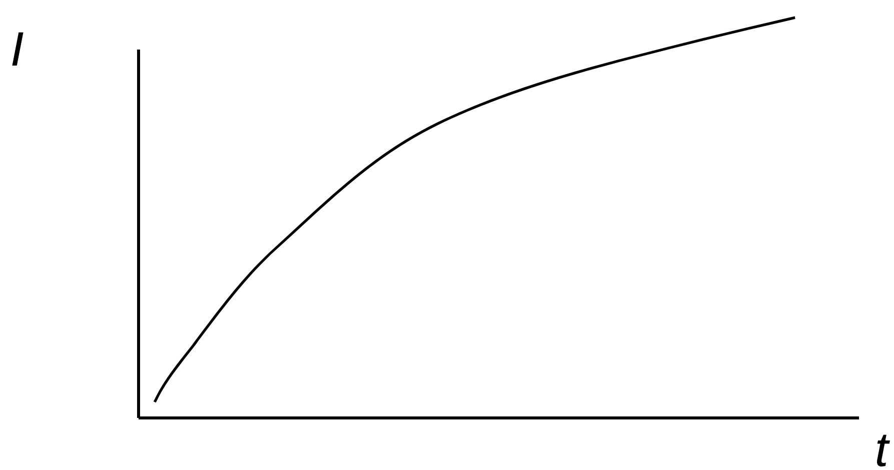
$$U(c) = \log(c - b \times c_{-1})$$

  - Marginal Utility Function of *Slope* of Consumption
  - Hump-Shape Consumption Response Not a Puzzle

- Econometric Estimation Strategy Given the Option, *b>0*

Dynamic Response of Investment to Monetary Policy Shock

- In Estimated Impulse Responses:
  - Investment Rises in Hump-Shaped Pattern:



One Solution to Investment Puzzle…

- Cost-of-Change Adjustment Costs:

$$k' = (1 - \delta)k + F\left(\frac{I}{I_{-1}}\right)I$$

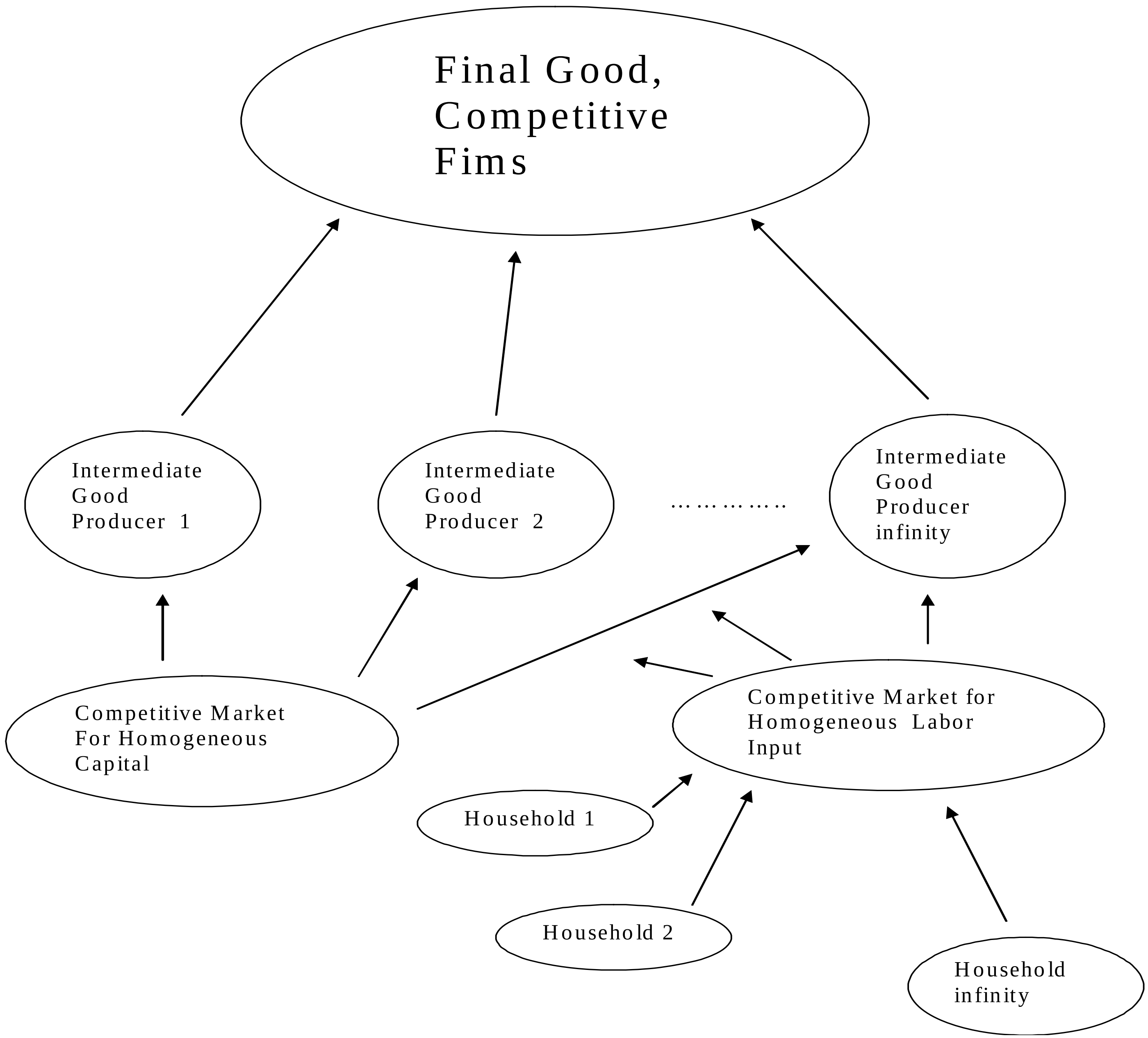
- This Does Produce a Hump-Shape Investment Response
  - Other Evidence Favors This Specification
  - Empirical: Matsuyama, Smets-Wouters.
  - Theoretical: Matsuyama, David Lucca

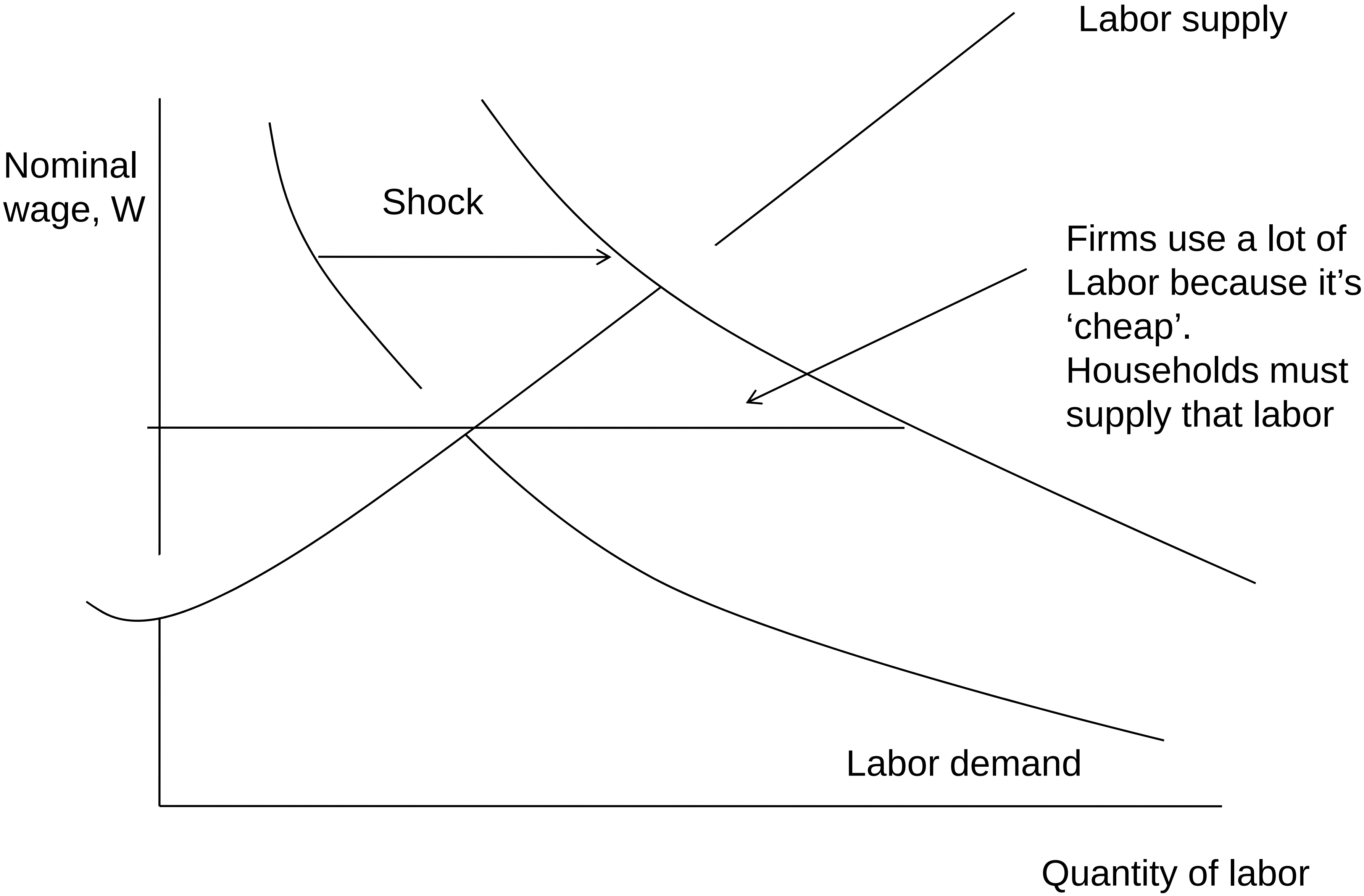
Wage Decisions

- Each household is a monopoly supplier of a specialized, differentiated labor service.
  - Sets wages subject to Calvo frictions.
  - Given specified wage, household must supply whatever quantity of labor is demanded.
- Household differentiated labor service is aggregated into homogeneous labor by a competitive labor 'contractor'.

$$l_t = \left[\int_0^1 (h_{t,j})^{\frac{1}{\lambda_w}} dj \right]^{\lambda_w}, \; 1 \leq \lambda_w < \infty.$$

Firm Sector


Final Good,
Competitive
Fims
Intermediate
Good
Producer 1
Intermediate
Good
Producer 2
……………
Intermediate
Good
Producer
infinity
Competitive Market
For Homogeneous
Capital
Competitive Market for
Homogeneous Labor
Input
Household 1
Household 2
Household
infinity


Labor supply
Nominal
wage, W
Shock
Firms use a lot of
Labor because it's
'cheap'.
Households must
supply that labor
Labor demand
Quantity of labor

Monetary and Fiscal Policy

$$x_t = M_t/M_{t-1}$$

$$\begin{aligned}
\hat{x}_{M,t} &= \rho_M \hat{x}_{M,t-1} + \varepsilon_{M,t} \\
\hat{x}_{z,t} &= \rho_{xz} \hat{x}_{z,t-1} + c_z \varepsilon_{z,t} + c_z^p \varepsilon_{z,t-1} \\
\hat{x}_{\Upsilon,t} &= \rho_{x\Upsilon} \hat{x}_{\Upsilon,t-1} + c_\Upsilon \varepsilon_{\Upsilon,t} + c_\Upsilon^p \varepsilon_{\Upsilon,t-1}
\end{aligned}$$

- $\hat{x}_{M,t}$: response of monetary policy to a monetary policy shock, $\varepsilon_{M,t}/$
- $\hat{x}_{z,t}$: response of monetary policy to an innovation in neutral technology, $\varepsilon_{z,t}$.
- $\hat{x}_{\Upsilon,t}$: response of monetary policy to an innovation in capital embodied technology, $\varepsilon_{\Upsilon,t}$.
- Government has access to lump sum taxes, pursues a Ricardian fiscal policy.

Loan Market and Final Good Market Clearing Conditions, Equilibrium

- Financial intermediaries receive $M_t - Q_t + (x_t - 1)\, M_t$ from the household.
  - Lend all of their money to intermediate good firms, which use the funds to pay for H_t.
- Loan market clearing
$$W_t H_t = x_t M_t - Q_t.$$
- The aggregate resource constraint is
$$(1 + \eta(V_t))C_t + \Upsilon_t^{-1}\left[I_t + a(u_t)\bar{K}_t\right] \ \leq\ Y_t.$$
- We adopt a standard sequence-of-markets equilibrium concept.

Econometric Methodology

- Choose parameters of economic model, so that the dynamic response to shocks resembles as closely as possible the impulse responses estimated from SVARs.

- Make sure that identifying assumptions used in the SVAR are satisfied in the model.

Estimating Parameters in the Model

- Partition Parameters into Three Groups.
  - Parameters set a priori (e.g., β, δ,...)
  - ζ_1: remaining parameters pertaining to the nonstochastic part of model

$$\zeta_2 = [\xi_w, \gamma, \sigma_a, b, S'', \epsilon]$$

  - ζ_2: parameters pertaining to stochastic part of the model
- Number of parameters, $\zeta = (\zeta_1, \zeta_2)$, to be estimated - 18
- Estimation Criterion
  - $\Psi(\zeta)$: mapping from ζ to model impulse responses
  - $\hat{\Psi}$: 592 impulse responses estimated using VAR
  - Estimation Strategy:

$$\hat{\zeta} = \arg\min_{\zeta} \left(\hat{\Psi} - \Psi(\zeta)\right)' V^{-1} \left(\hat{\Psi} - \Psi(\zeta)\right).$$

  - V: diagonal matrix with sample variances of $\hat{\Psi}$ along the diagonal.

- Parameter estimates

TABLE 2: ESTIMATED PARAMETER VALUES ζ_1							
Model	λ_f	ξ_w	γ	σ_a	b	S''	ϵ
Benchmark	1.35 (0.17)	.75 (0.06)	.32 (0.32)	0.06 (0.18)	0.80 (0.04)	4.85 (2.15)	0.77 (0.27)

- Parameters are surprisingly consistent with estimates reported in JPE (2005) based on studying only monetary policy shocks

- Point estimates imply prices relatively flexible at micro level
  - At point estimates: $\xi_p = 0.58, \ \frac{1}{1-\xi_p} = 2.38$ quarters

- Other parameters 'reasonable': estimation results *really* want sticky wages!

- Combining Optimal Price and Aggregate Price Relation:

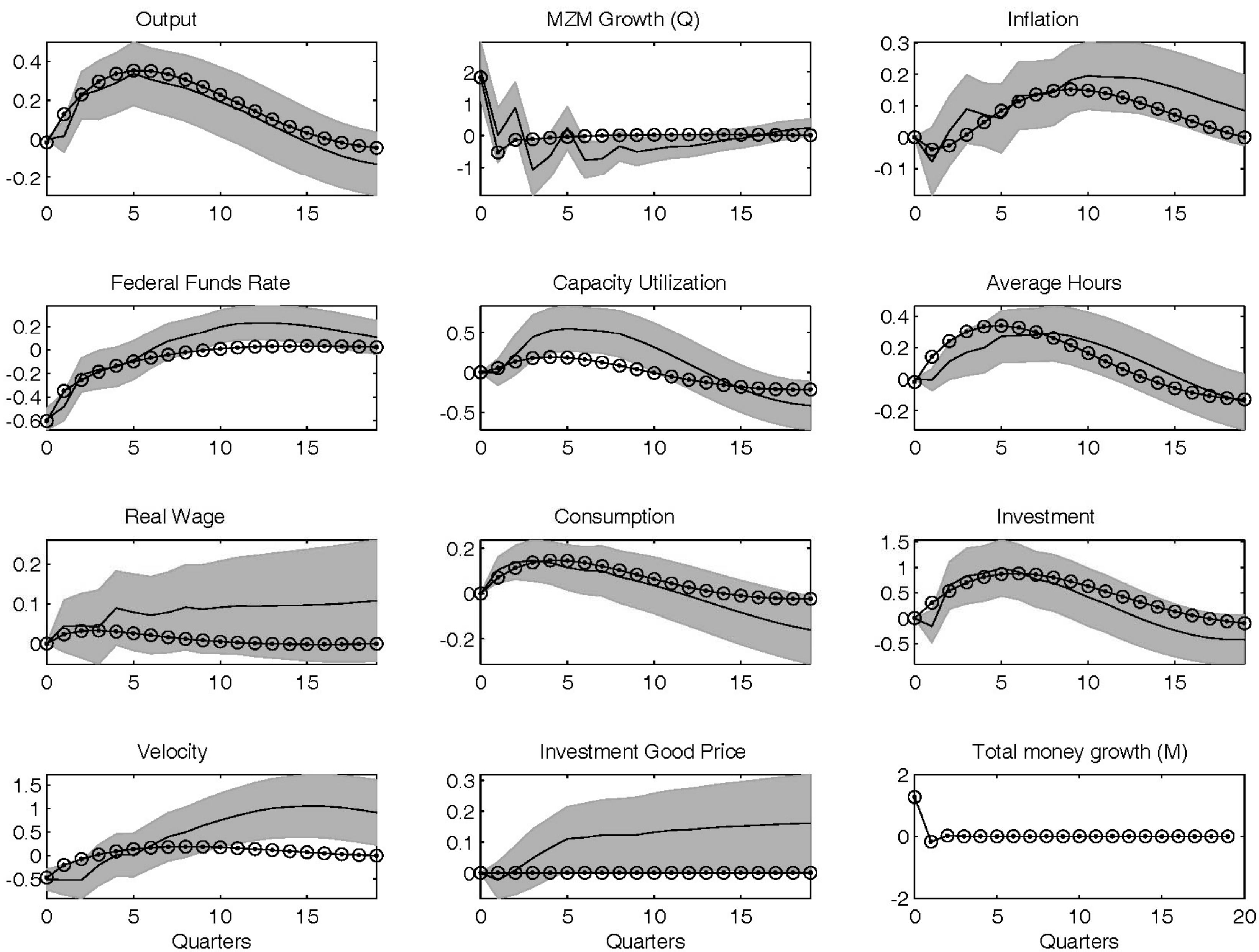
$$\Delta\hat{\pi}_t = \beta E_t \Delta\hat{\pi}_{t+1} + \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p} E_t \hat{s}_t,$$

- Parameters of exogenous shocks:

TABLE 3: ESTIMATED PARAMETER VALUES ζ_2											
ρ_M	σ_M	ρ_{μ_z}	σ_{μ_z}	ρ_{xz}	c_z	c_z^p	ρ_{μ_Υ}	σ_{μ_Υ}	$\rho_{x\Upsilon}$	c_Υ	c_Υ^p
Benchmark Model											
-0.10	0.31	$.91$	0.05	0.36	3.68	2.49	-0.24	0.17	0.91	-0.10	0.63
(0.12)	(0.10)	(0.03)	(0.02)	(0.22)	(1.55)	(1.22)	(0.52)	(0.06)	(0.07)	(0.57)	(0.65)

- Neutral technology shock, ρ_{μ_z} ,is highly persistent.

Figure 1: Response to a monetary policy shock (o - Model, - VAR, grey area - 95 % Confidence Interval)



Monetary Policy Shock

- Key findings:
  - Can account for sluggish aggregate response to monetary policy shock without a lot of price stickiness
  - Can account for the observed effects of monetary policy on consumption, investment, output, etc.

Figure 2: Response to a neutral technology shock (o - Model, - VAR, grey area - 95 % Confidence Interval)

troublesome

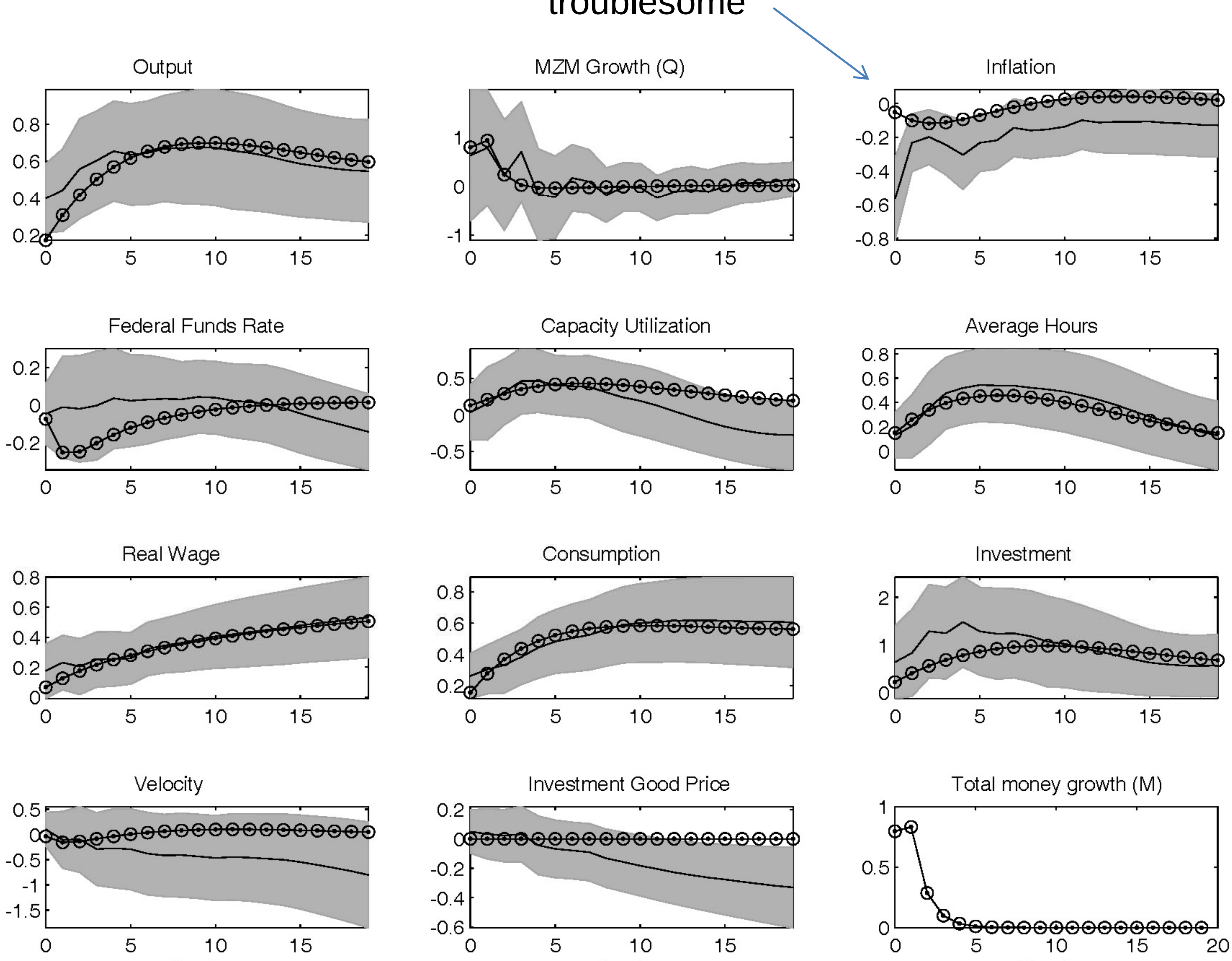


Figure 3: Response to an embodied technology shock (o - Model, - VAR, grey area - 95 % Confidence Interval)