Consensus New Keynesian DSGE Model

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Overview

- A 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)

- Construct the consensus models based on SVAR results.
  - Christiano, Eichenbaum and Evans JPE (2005)
  - Smets and Wouters, AER (2007)

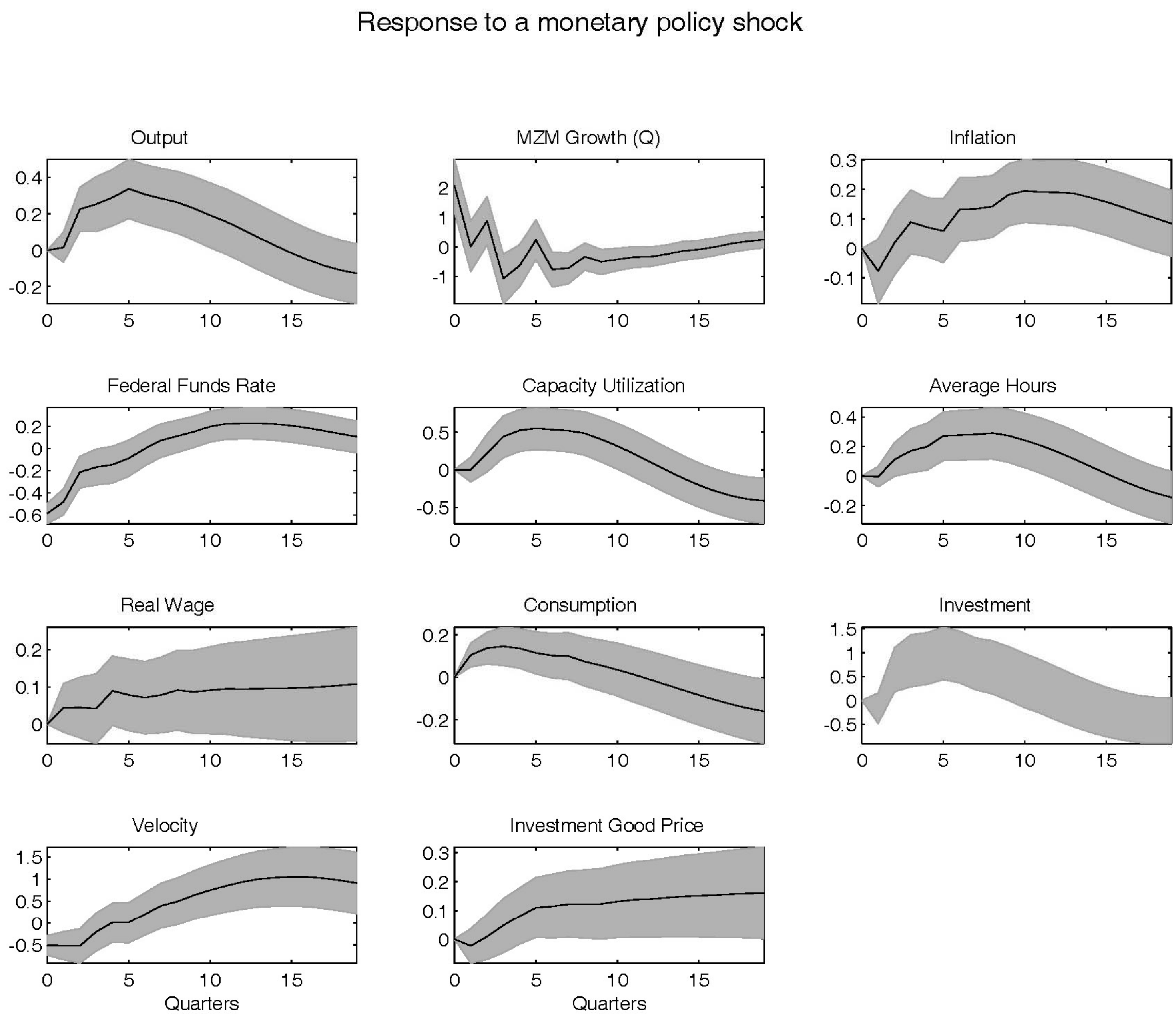
- Very brief review of SVARs.

Identifying Monetary Policy Shocks

- Rule that relates Fed's actions to state of the economy.

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

  - f is a linear function
  - Ω_t: set of variables that Fed looks at.
  - e_t^R: time t policy shock, orthogonal to Ω_t



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

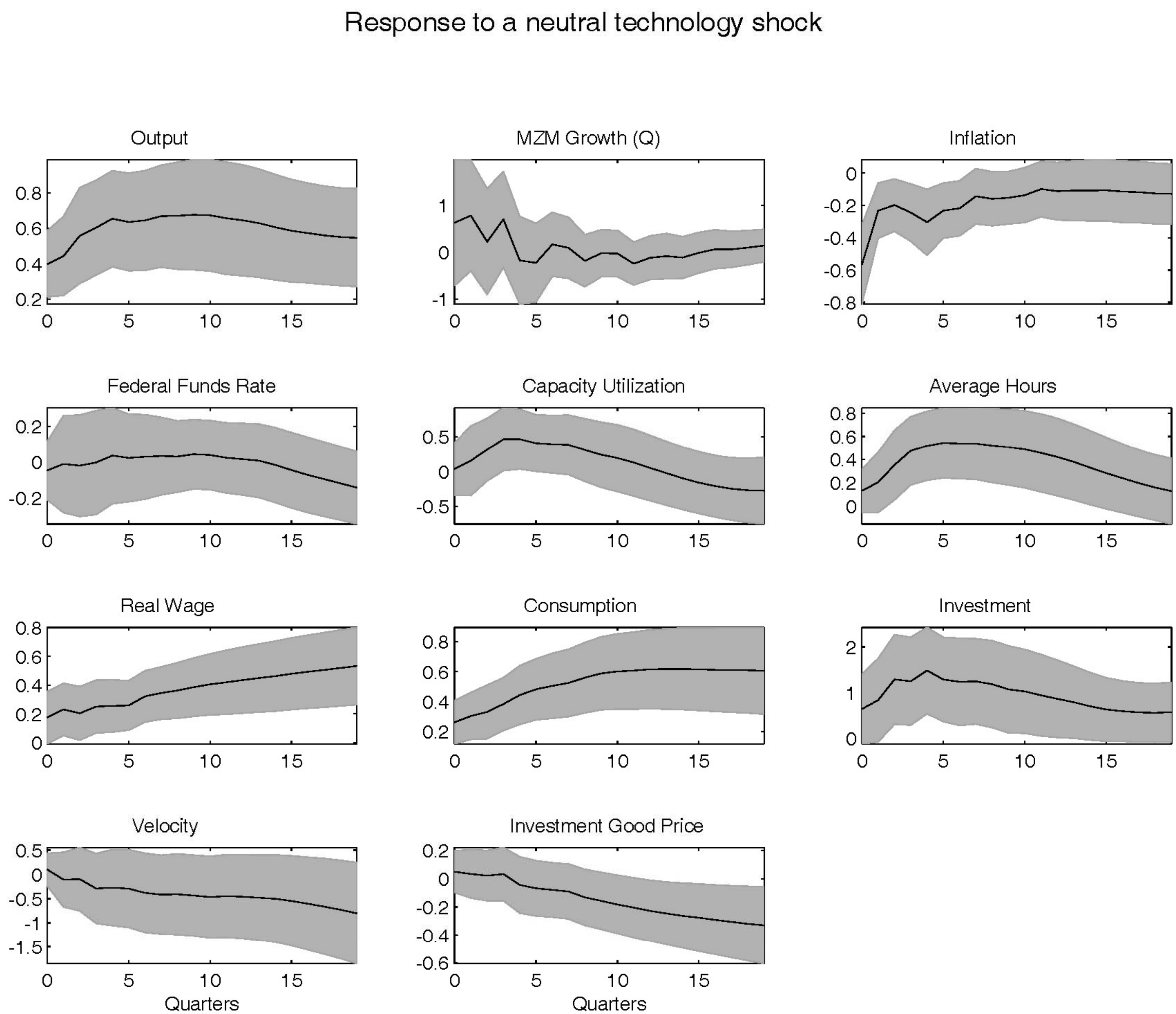
Interesting Properties of Monetary Policy Shocks

- 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

Identification of Technology Shocks

- Two technology shocks:
  - One perturbs price of investment goods
  - One perturbs total factor productivity

- Identification assumptions:
  - They are the only two shocks that affect labor productivity in the long run
  - Only the shock to investment good prices have an impact on investment good prices in the long run.



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

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.

Importance of Three Shocks

- According to VAR analysis, they account for a large part of economic fluctuations.

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]

Next

- Use Impulse Responses to Estimate a DSGE Model
  - Motivate the Basic Model Features.
  - Model Estimation.
- Determine if there is a conflict regarding price behavior between micro and macro data.
  - Macro Evidence:
    - Inflation responds slowly to monetary shock
    - Single equation estimates of slope of Phillips curve produce small slope coefficients.
  - Micro Evidence:
    - Bils-Klenow, Nakamura-Steinsson report evidence on frequency of price change at micro level: 5-11 months.
- Finding: no micro macro puzzle, as long as we suppose that capital used by firms is ‘firm-specific’.

Outline

- Model
- Econometric Estimation of Model
  - Fitting Model to Impulse Response Functions
- Model Estimation Results (is there a micro/macro puzzle?)

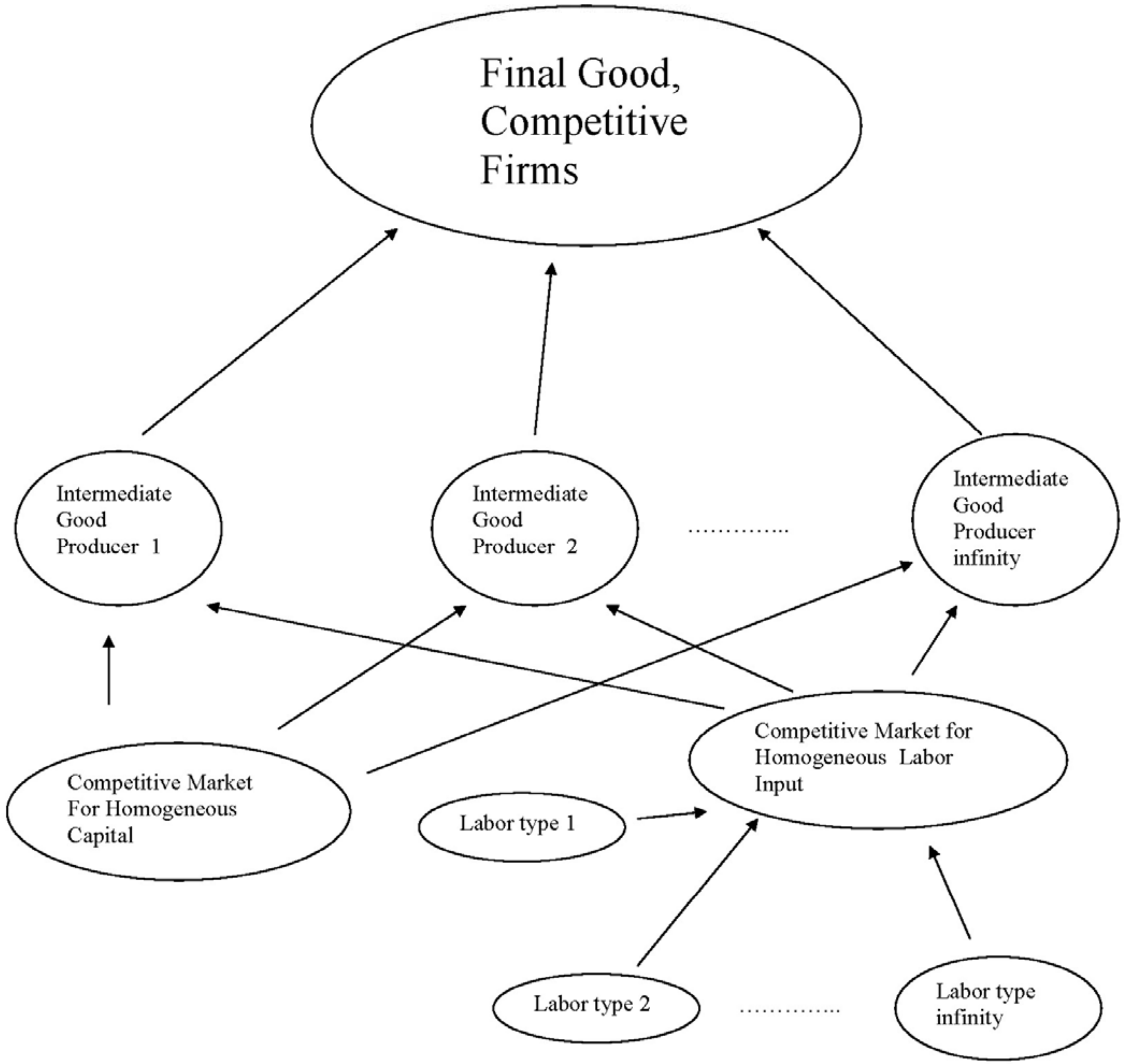
Description of Model

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

Timing

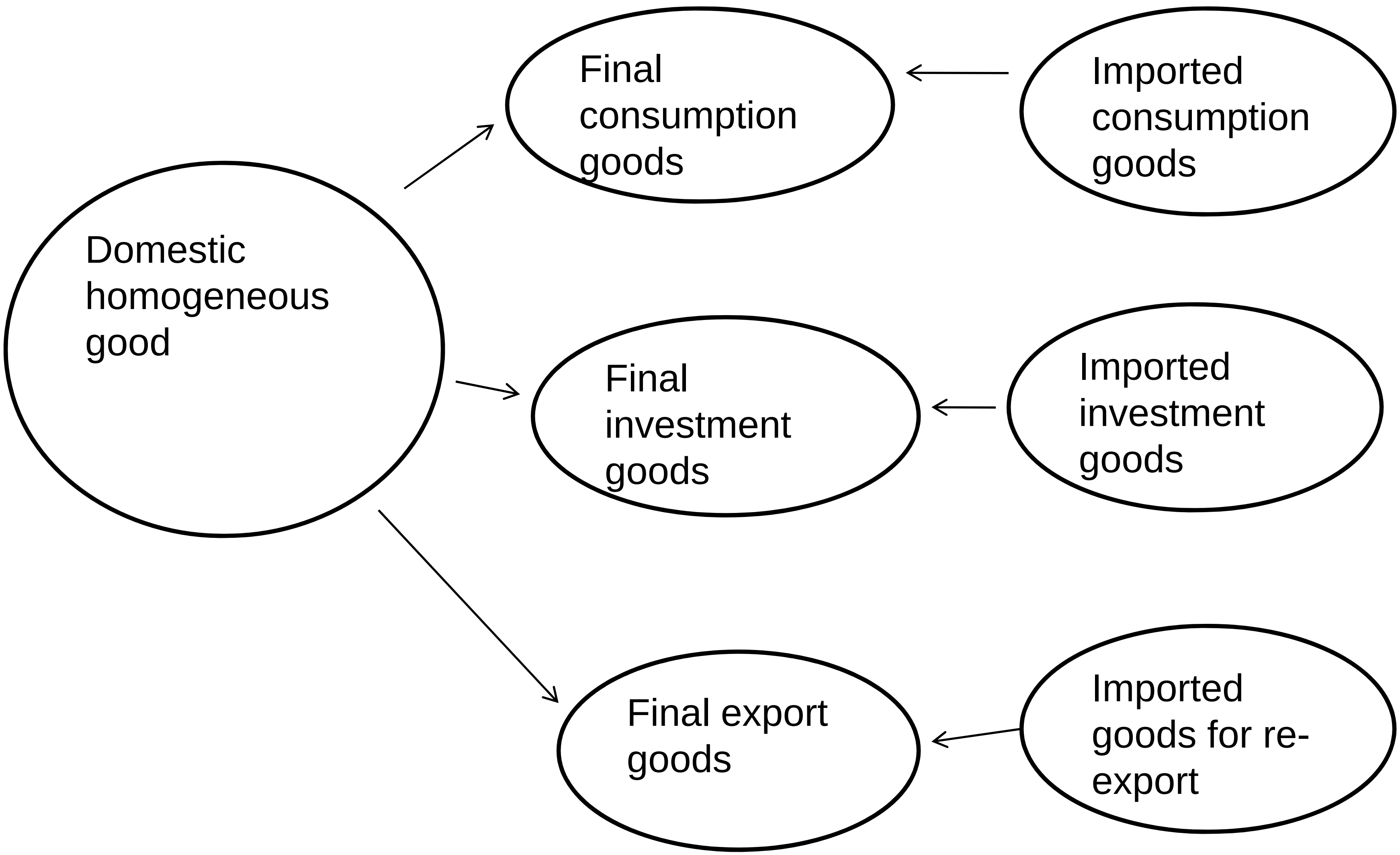
- Technology Shocks Realized.
- Agents Make Price/Wage Setting, Consumption, Investment, Capital Utilization Decisions.
- Monetary Policy Shock Realized.
- Household Money Demand Decision Made.
- Production, Employment, Purchases Occur, and Markets Clear.
- Note: Wages, Prices and Output Predetermined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

Firm Sector



Final Good, Competitive Firms
Intermediate Good Producer 1
Intermediate Good Producer 2
…………..
Intermediate Good Producer infinity
Competitive Market For Homogeneous Capital
Competitive Market for Homogeneous Labor Input
Labor type 1
Labor type 2
…………..
Labor type infinity

Extension to small open economy
(Christiano, Trabandt, Walentin (2009))



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:

$$\max_{Y_t, \{y_{it}, 0 \leq i \leq 1\}} P_t Y_t - \int_0^1 P_{it} y_{it} di$$

  - Foncs and prices:

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

Firms, cont'd

- Intermediate good firms
  - Each y_{it} produced by a monopolist with demand curve:

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

  - Technology:

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

  - Law of motion of technology shock:

$$\mu_{z,t} \equiv \log z_t - \log z_{t-1},\ \hat{\mu}_{z,t} \equiv \frac{\mu_{z,t} - \mu_z}{\mu_z},\ \mu_z = E\mu_{z,t}$$

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

  - consistent with identifying assumption on technology.

Firms, cnt'd

Nominal wage

Real rental rate of capital services

- Intermediate good firm marginal cost

$$MC\$ = [\psi + (1-\psi)R_t]\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{P_t r_t^k}{\alpha}\right)^{\alpha}\frac{1}{z_t^{1-\alpha}}$$

Fraction of wage and capital rental bill that must be borrowed in advance at gross nominal rate of interest, *R*

ψ < 1 creates 'working capital channel' for the interest rate, *R,* on the supply side of the economy.

Helps keep prices from rising after monetary injection (actually, may Even help explain the 'price puzzle'.

Firms, cnt'd

- Intermediate good firm marginal cost

$$MC\$ = [\psi + (1-\psi)R_t]\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{P_t r_t^k}{\alpha}\right)^{\alpha}\frac{1}{z_t^{1-\alpha}}$$

- Marginal cost divided by final good price:

$$s_t \equiv \frac{MC\$}{P_t} = [\psi + (1-\psi)R_t]\left(\frac{W_t/P_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t^k}{\alpha}\right)^{\alpha}\frac{1}{z_t^{1-\alpha}}$$

Calvo price frictions in intermediate good firms

- With probability, $1-\xi_p$, firms may optimize price:

$$P_{it} = \tilde{P}_t$$

- With probability, ξ_p ,

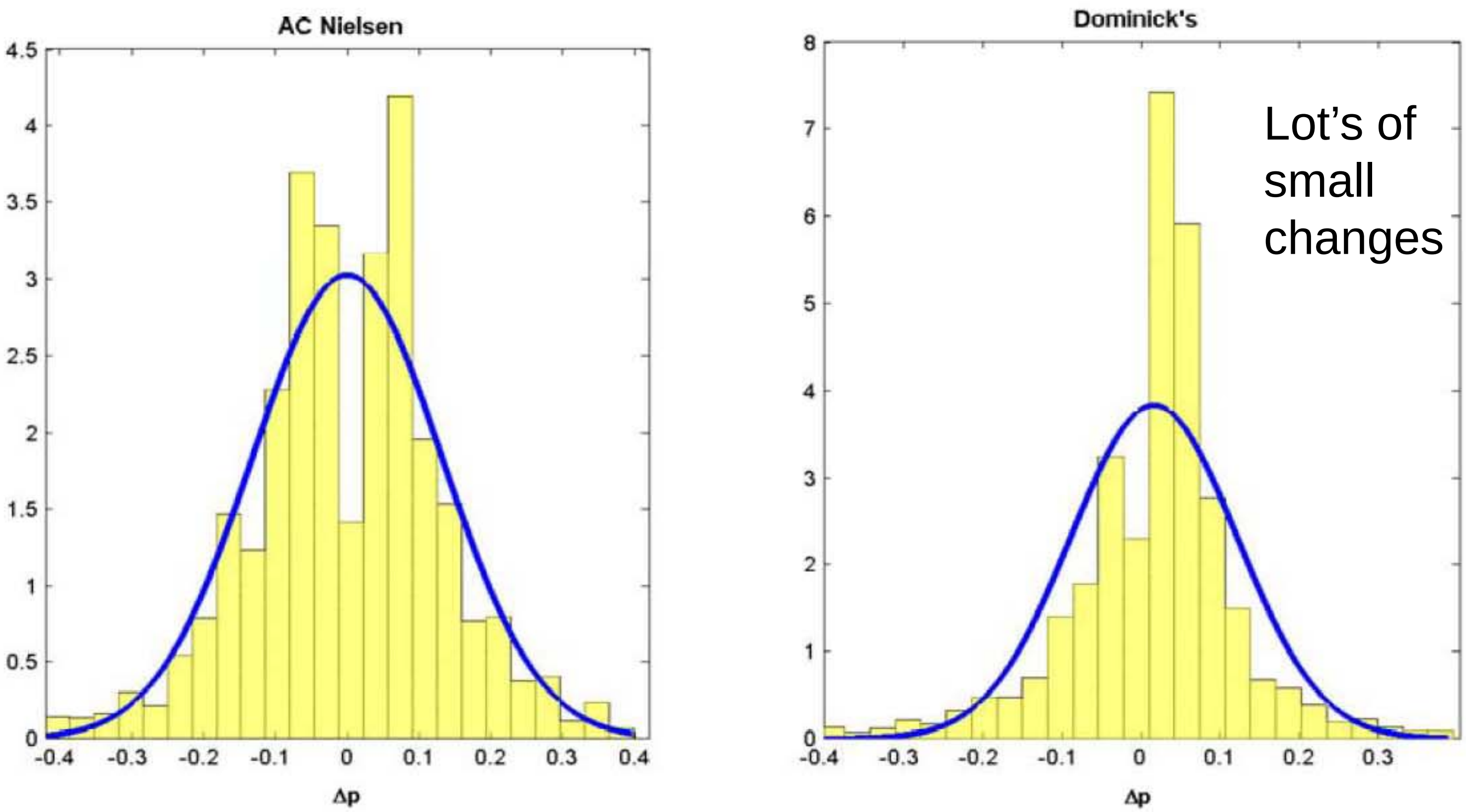
$$P_{it} = \bar{\pi}^{\nu}\pi_{t-1}^{1-\nu}P_{i,t-1},\ 0 < \nu < 1$$

- Alternative is that with probability ξ_p ,

$$P_{it} = P_{i,t-1}$$

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:

$$\Delta\hat{\pi}_t = \beta E_t \Delta\hat{\pi}_{t+1} + \frac{(1-\beta\xi_p)(1-\xi_p)}{\xi_p} E_t \hat{s}_t, \qquad \nu = 0$$

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

Households: Sequence of Events

- Technology shock realized.
- Decisions: Consumption, Capital accumulation, Capital Utilization.
- 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

- Each household is identical
- Each household supplies each of many different varieties of labor, $j \in (0,1)$
  - Quantity of *j*-type labor: $h_{j,t}$
- Quantity of consumption: C_t
- Household preferences:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\log(C_t - bC_{t-1}) - \frac{\psi_L}{1+\sigma} \int_0^1 h_{j,t}^{1+\sigma} dj \right]$$

Household and Labor Market
Erceg-Henderson-Levin Model

- Each type of labor, *j*, in the household joins a union of all *j*-type labor from all other households.

- The union for *j*-type labor behaves as a monopolist on behalf of its members, setting the wage $W_{j,t}$ subject to a demand curve for *j*-type labor.

- With probability ξ_w the union may not reoptimize the wage, and with probability $1-\xi_w$ it may reoptimize.

Labor market, cnt'd

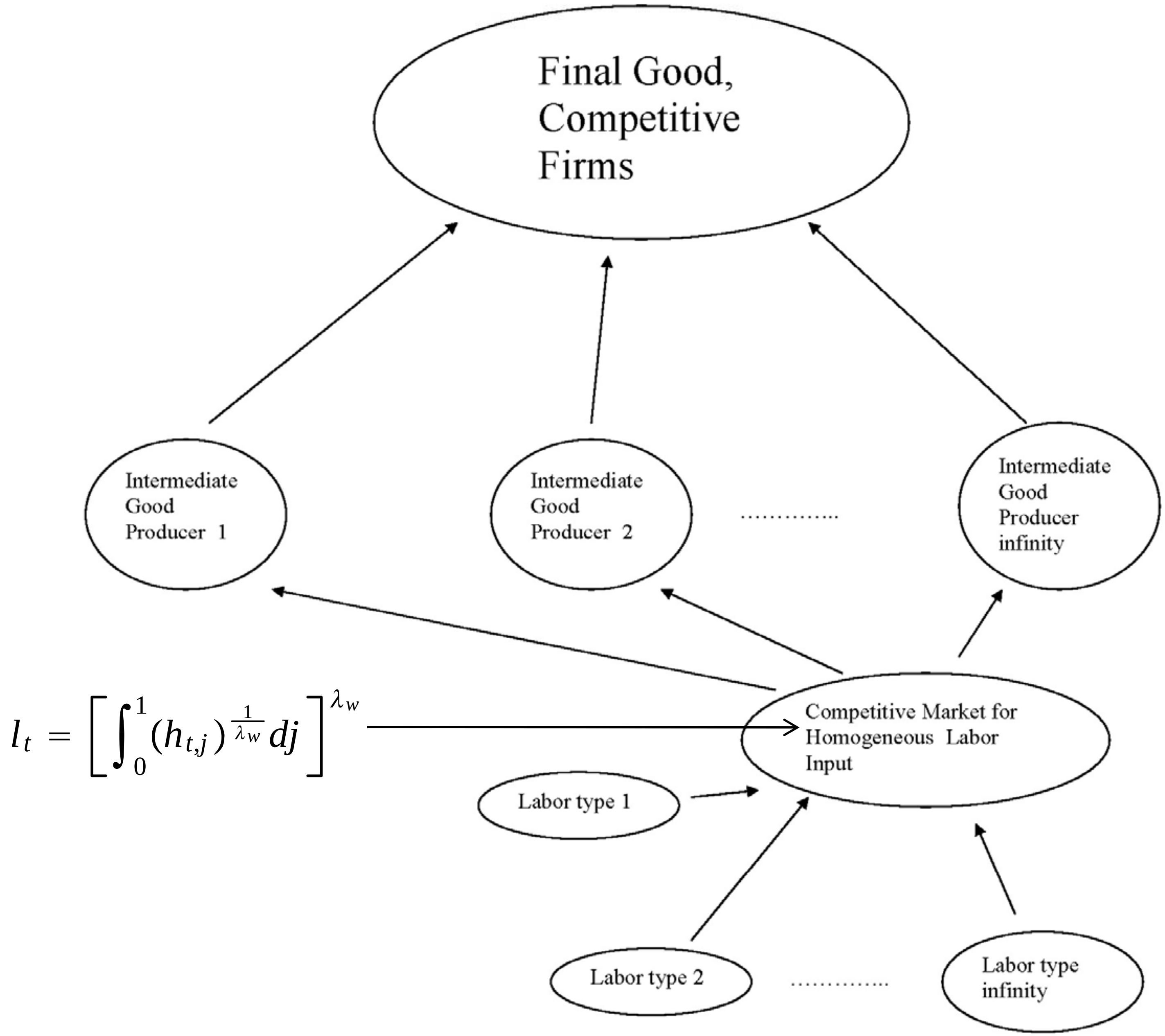
- Given the specified wage, *j*-type workers supply whatever quantity of labor is demanded.

- Labor is demanded by competitive 'labor contractors', who aggregate different labor services into a homogeneous labor input that they rent to intermediate good producers.

- Labor contractors use the following technology:

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

Firm Sector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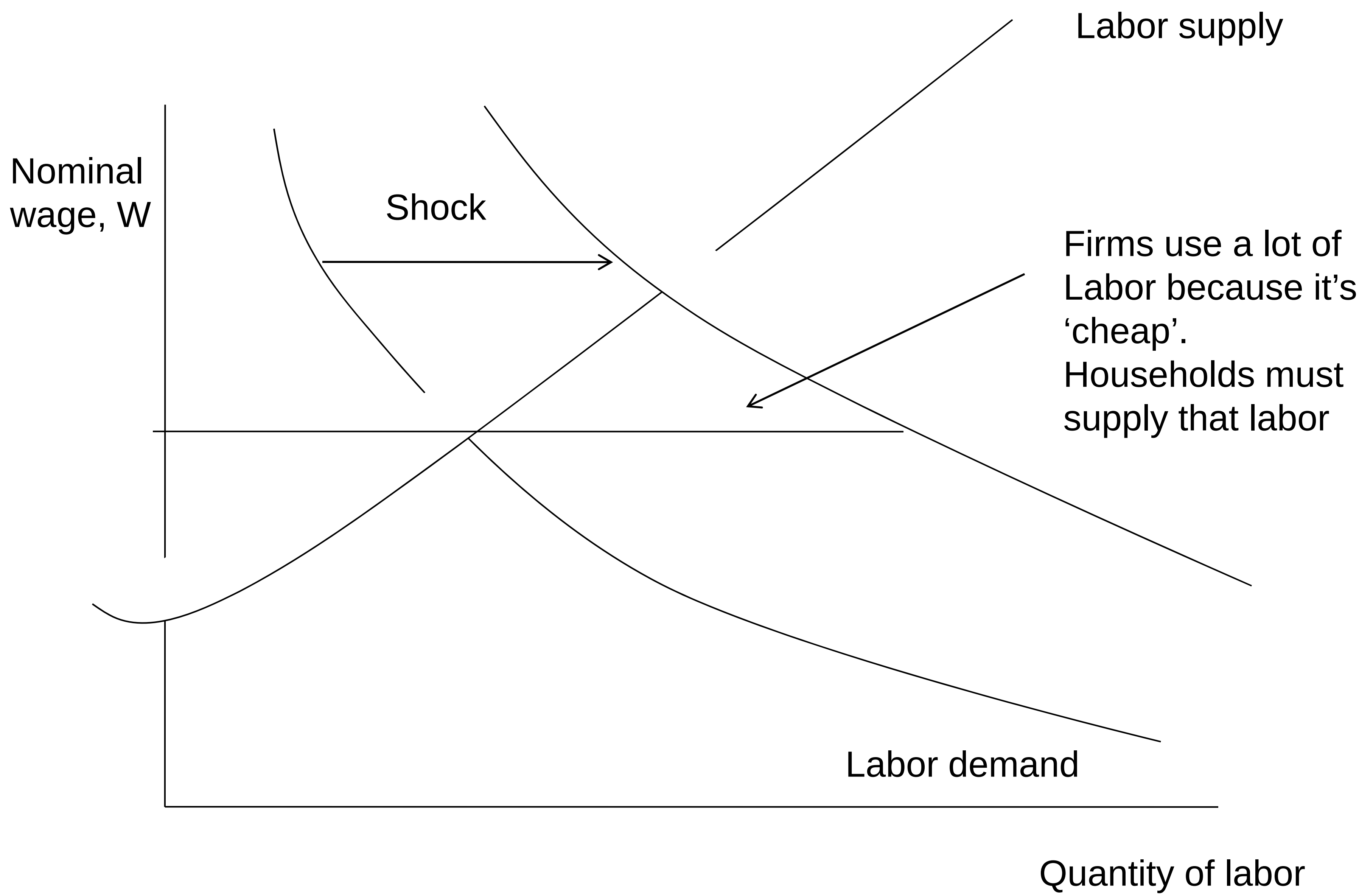
$l_t = \left[\int_0^1 (h_{t,j})^{\frac{1}{\lambda_w}} dj \right]^{\lambda_w}$
Competitive Market for Homogeneous Labor Input
Labor type 1
Labor type 2
…………..
Labor type infinity

What's the point of the wage setting frictions?

- They help the model account for the response of inflation and output to a monetary policy shock.

  – Sticky wage in effect makes labor supply highly elastic.

  – Positive monetary policy shock leads to:
    - Big increase in employment and output.
    - Small increase in cost and, hence, inflation.


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

Extensions of Labor Market

- Jordi Gali (2009) shows how to derive a theory of unemployment from the EHL model.

- Christiano-Trabandt-Walentin (2010) extend the model to obtain ‘involuntary’ unemployment.

- Gertler-Trigari, Gertler-Sala-Trigari show how to introduce Mortensen-Pissarides-style search and matching approach

  – see Christiano-Ilut-Motto-Rostagno and Christiano-Trabandt-Walentin for empirical applications to closed and small open economies.

Why Habit Persistence in Preferences?

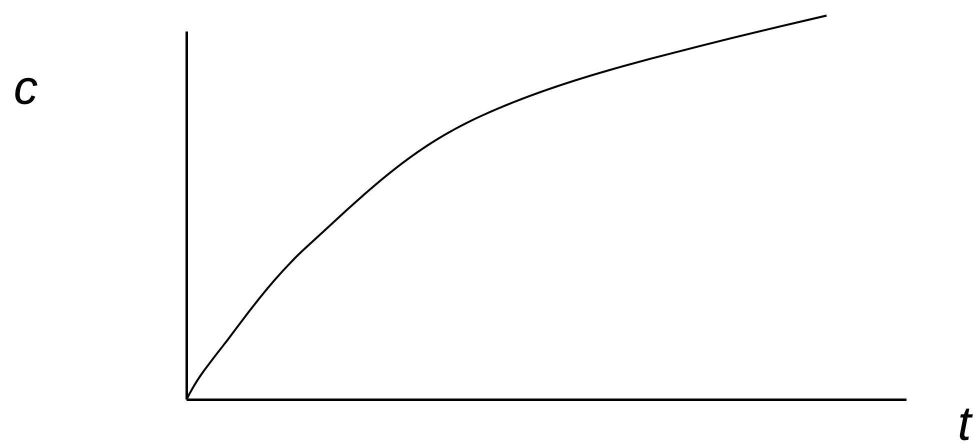
- They help resolve the ‘consumption puzzle’ in monetary economics…..
- With standard preferences, hard to understand the way consumption responds to monetary policy shock.

Consumption 'Puzzle'

- In Estimated Impulse Responses:
  - Real Interest Rate Falls

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

  - Consumption Rises in Hump-Shape Pattern:



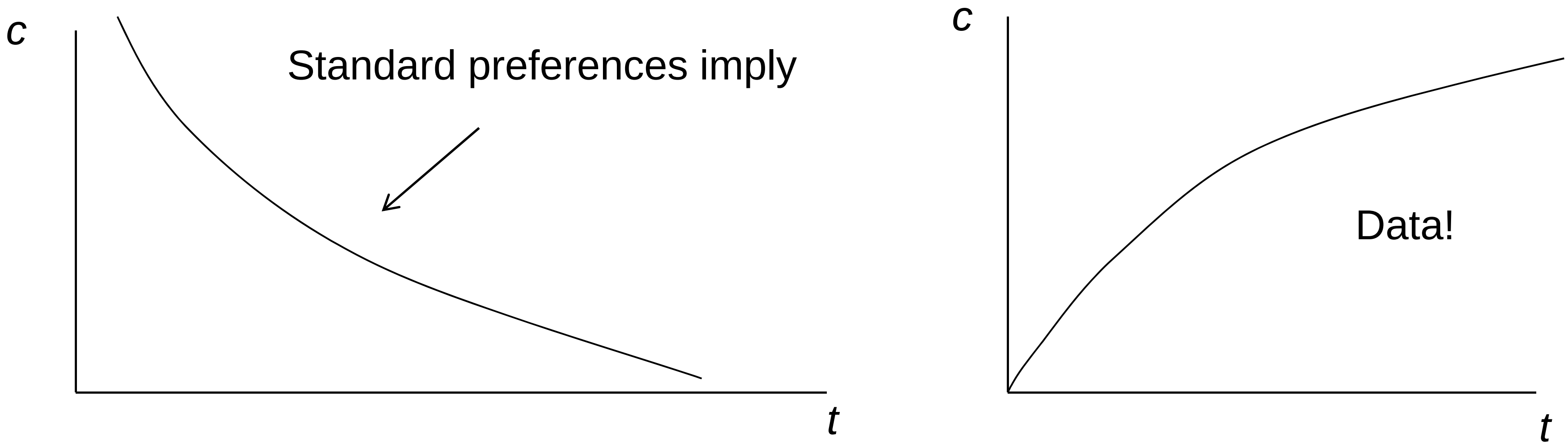
- Standard preferences inconsistent with above

Consumption ‘Puzzle’

- Intertemporal First Order Condition:

‘Standard’ Preferences →

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



A Solution to the 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*

Households...

- Asset Evolution Equation:

$$M_{t+1} = R_t[M_t - Q_t + (x_t - 1)M_t^a] + Q_t + \int_0^1 W_{j,t}h_{j,t}dj$$
$$+ P_t r_t^k u_t \bar{K}_t + D_t - P_t\Big[(1+\eta(V_t))C_t + \frac{1}{\Upsilon_t}(I_t + a(u_t)\bar{K}_t)\Big]$$

  - 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, $\mu_{\Upsilon,t} = \Upsilon_t/\Upsilon_{t-1}$,

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

- Velocity:

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

Money Demand

- Asset Evolution Equation:

$$M_{t+1} = R_t[M_t - Q_t + (x_t - 1)M_t^a] + Q_t + \int_0^1 W_{j,t}h_{j,t}dj$$
$$+ P_t r_t^k u_t \bar{K}_t + D_t - P_t\left[(1 + \eta(V_t))C_t + \frac{1}{\Upsilon_t}(I_t + a(u_t)\bar{K}_t)\right]$$

- Increase in Q_t :
  - Marginal Cost of Interest Foregone: R_t
  - Marginal Benefit:

$$1 - P_t \eta'(V_t) C_t \frac{dV_t}{dQ_t}$$

$$= \overbrace{1}^{\text{addititional cash available at end of period}} + \overbrace{\eta'\left(\frac{P_t C_t}{Q_t}\right)\left(\frac{P_t C_t}{Q_t}\right)^2}^{\text{reduction in transactions costs due to extra cash}}$$

- Money Demand: Equate Marginal Benefits and Costs of Q_t-

$$R_t = 1 + \eta' \left(\frac{P_t C_t}{Q_t}\right) \left(\frac{P_t C_t}{Q_t}\right)^2.$$

- Properties of Money Demand:
  - Unit Consumption Elasticity of Money Demand
    - Increase C_t 1 percent and Hold R_t, P_t Fixed $\Rightarrow$ Desired Q_t increases 1 percent
  - $R_t \uparrow$ Implies $Q_t \downarrow$
    - To Induce Households to Hold Additional Q, Must Have Lower R
    - Money Demand Elasticity is Bigger, the Bigger is η''

- Quantitative Analysis of Money Demand
  - Consider the Following Parametric Function for η

$$\eta = AV_t + \frac{B}{V_t} - 2\sqrt{AB}$$

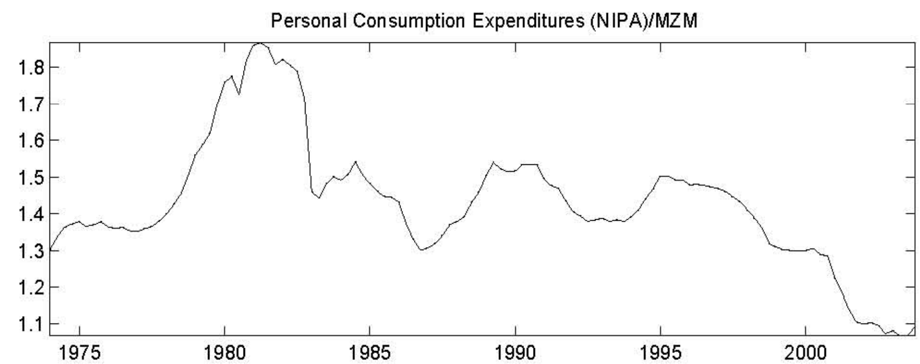
$$\Rightarrow$$

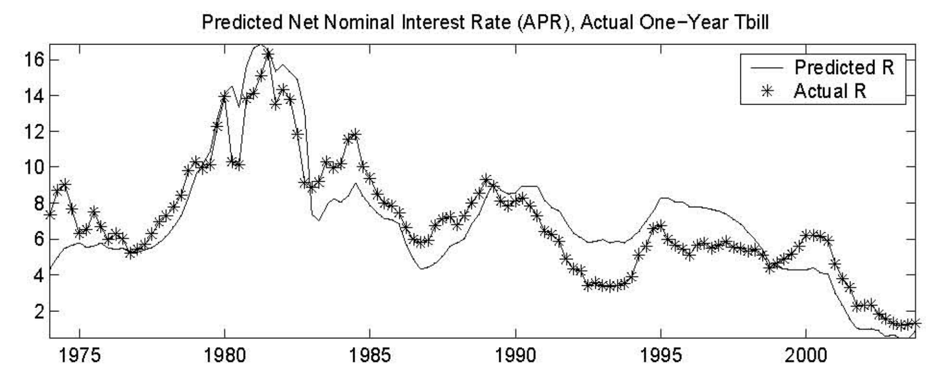
$$R = 1 + \eta'(V) \times V^2 = 1 + \left[A - BV^{-2}\right] V^2 = 1 - B + AV^2$$

  - Data:
    - Money - St. Louis Fed's MZM, 1974-2004
    - Consumption - NIPA Consumption of Services and Nondurables
    - Interest Rate - One Year T-Bills.
    - OLS Regression of V^2 on $R \Rightarrow A = 0.0174$ and $B = 0.0187$

Money Demand ...

- Top Graph: Velocity of Money
- Bottom Graph: Actual and Predicted Interest Rate

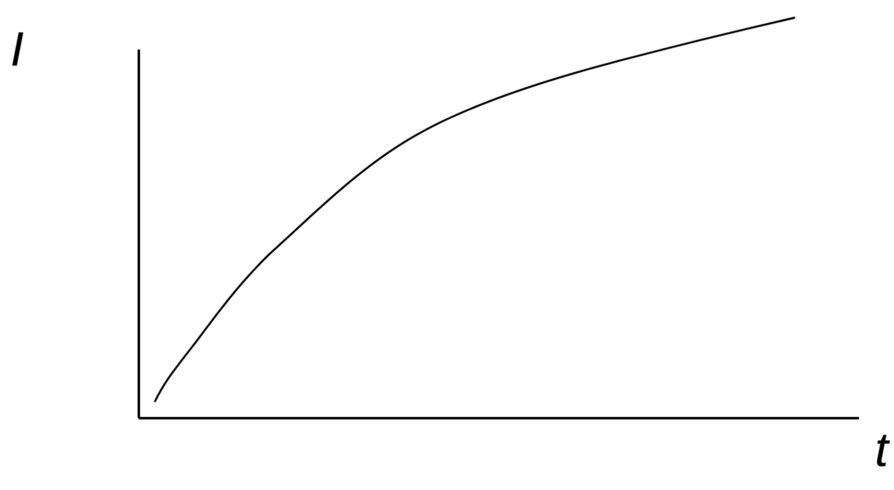




- Findings: Static Money Demand Equation Fits the Data Well!

Dynamic Response of Investment to Monetary Policy Shock

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



Investment 'Puzzle'

- Rate of Return on Capital

$$R_t^k = \frac{MP_{t+1}^k + P_{k',t+1}(1-\delta)}{P_{k',t}},$$

$$P_{k',t} \sim \text{consumption price of installed capital}$$

$$MP_t^k \sim \text{marginal product of capital}$$

$$\delta \in (0,1) \sim \text{depreciation rate.}$$

- Rough 'Arbitrage' Condition:

$$\frac{R_t}{\pi_{t+1}} \approx R_t^k.$$

- Positive Money Shock Drives Real Rate:

$$R_t^k \downarrow$$

- Problem: Burst of Investment!

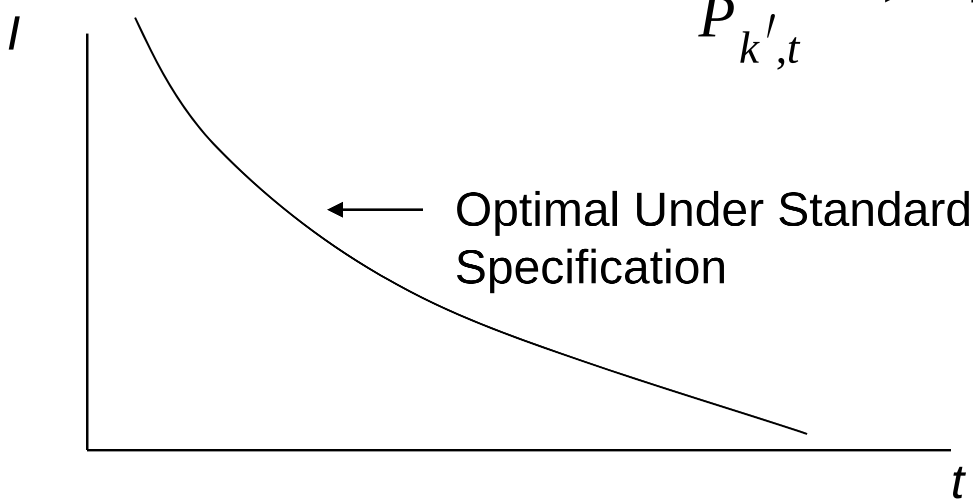
Investment Puzzle: a failed approach

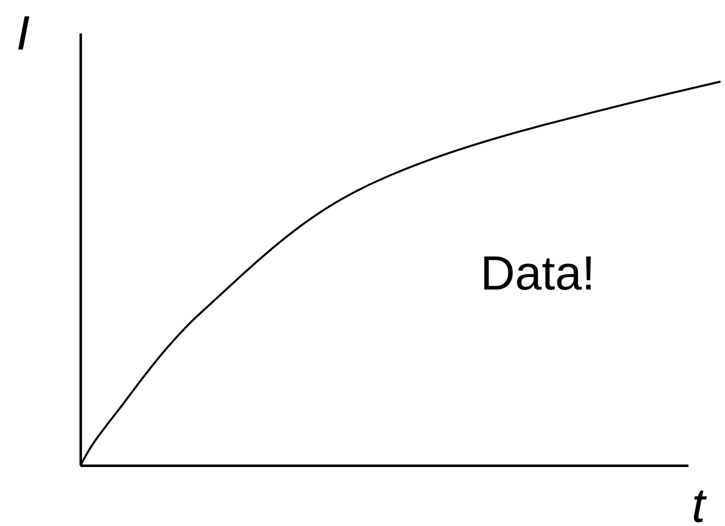
- Adjustment Costs in Investment
  - Standard Model (Lucas-Prescott)

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

  - Problem:
    - Hump-Shape Response Creates Anticipated Capital Gains

$$\frac{P_{k',t+1}}{P_{k',t}} > 1$$





A Solution to the 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, Sherwin Rosen
  - Theoretical: Matsuyama, David Lucca

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

- Variant of limited information strategy used in CEE (2004).
  - Impose a subset of assumptions made in equilibrium model to estimate impulse response functions of ten key macroeconomic variables to the three shocks in our model.
  - Neutral technology shocks, capital embodied technology shocks and monetary policy shocks.
- Choose values for key parameters of structural model to minimize difference between estimated impulse response functions and analogous objects in model.

Estimating Parameters in the Model

We estimate γ, the slope of the Phillips curve, rather than ξ_p .

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

$$\zeta_1 = [\xi_w, \gamma, \sigma_a, b, S'', \epsilon]$$

  - 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.

Classical Perspective

- Impulse response functions have the following asymptotic distribution:

$$\sqrt{T}\left(\hat{\Psi} - \Psi^0\right) \overset{a}{\sim} N(0, \tilde{V})$$

  – or,

$$\hat{\Psi} \overset{a}{\sim} N\left(\Psi^0, \frac{\tilde{V}}{T}\right) = \left(\frac{1}{2\pi}\right)^{\frac{n}{2}} \left|\frac{\tilde{V}}{T}\right|^{-\frac{1}{2}} \exp\left[-\frac{1}{2}\left(\hat{\Psi} - \Psi^0\right)'\left(\frac{\tilde{V}}{T}\right)^{-1}\left(\hat{\Psi} - \Psi^0\right)\right]$$

- Estimation criterion:

$$L(\zeta, \hat{\Psi}) \equiv (\hat{\Psi} - \Psi(\zeta))' V^{-1} (\hat{\Psi} - \Psi(\zeta))$$

- Estimator: $L_1(\hat{\zeta}, \hat{\Psi}) = 0 \rightarrow \hat{\zeta} = f(\hat{\Psi})$

- Asymptotic distribution (delta function method):

$$\sqrt{T}\left(\hat{\zeta} - \zeta^0\right) \overset{a}{\sim} N\left(0, f'(\Psi^0)\tilde{V}[f'(\Psi^0)]^{\text{transpose}}\right)$$

Bayesian Perspective

- Suppose that the estimation criterion used the actual asymptotic variance-covariance of $\hat{\Psi}$, $\tilde{V}/T$:

$$L(\zeta,\hat{\Psi}) \equiv -\frac{1}{2}(\hat{\Psi}-\Psi(\zeta))'\left(\frac{\tilde{V}}{T}\right)^{-1}(\hat{\Psi}-\Psi(\zeta))$$

- Suppose that the model is true, with parameter values, ζ .

- Then, the likelihood of the observed impulse response functions, conditional on ζ is (for large *T*):

$$\text{likelihood}(\hat{\Psi}|\zeta) \propto e^{L\left(\zeta,\hat{\Psi}\right)}$$

- Bayesian posterior of model parameters

$$\text{posterior}\left(\zeta|\hat{\Psi}\right) \propto e^{L\left(\zeta,\hat{\Psi}\right)} \times \text{prior}(\zeta)$$

Chernozhukov and Hong, 2003, JME, vol. 115, pp. 293-346

- Parameter estimates

Estimated Parameter Values, ς_1

Model	λ_f	ξ_w	γ	σ_a	b	S''
Benchmark	1.01	0.78 (0.08)	0.014 (0.007)	11.42 (6.86)	0.76 (0.08)	1.50 (0.83)

↑

Markup parameter goes to unity in estimation, and estimation criterion is very flat.

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Estimated Parameter Values, ς_1

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Point estimate

Calvo parameter on wage ‘reasonable’

$$\text{Mean time between wage reoptimization} = \frac{1}{1-\xi_w} = (2.63,\ 4.55,\ 16.7)$$

Point estimate plus/minus 2 standard deviations

- Parameter estimates

Estimated Parameter Values, ς_1

Model	λ_f	ξ_w	γ	σ_a	b	S''
Benchmark	1.01	0.78	0.014	11.42	0.76	1.50
		(0.08)	(0.007)	(6.86)	(0.08)	(0.83)

↑

A big number, implying capital utilization hardly varies

- Parameter estimates

Estimated Parameter Values, ς_1

Model	λ_f	ξ_w	γ	σ_a	b	S''
Benchmark	1.01	0.78	0.014	11.42	0.76	1.50
		(0.08)	(0.007)	(6.86)	(0.08)	(0.83)

Habit parameter value similar to others reported in the literature

- Parameter estimates

Estimated Parameter Values, ς_1

Model	λ_f	ξ_w	γ	σ_a	b	S''
Benchmark	1.01	0.78	0.014	11.42	0.76	1.50
		(0.08)	(0.007)	(6.86)	(0.08)	(0.83)

- Slope of Phillips curve *very* small.

$$\gamma = \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p} = 0.014 \rightarrow \xi_p = 0.89$$

$$\text{average amount of time a price remains unchanged} = \frac{1}{1-\xi_p} = 9 \text{ quarters!}$$

- Apparently, a major failure!

Not a Failure…

- The standard model assumes capital is homogeneous
  - traded freely in homogeneous markets.
  - assumption made for simplicity, not realism.
  - hope: it does not matter.
  - in fact: it matters a lot!

- In reality, much capital is firm-specific
  - once in place, cannot easily be converted to another use.

Homogeneous versus firm-specific capital

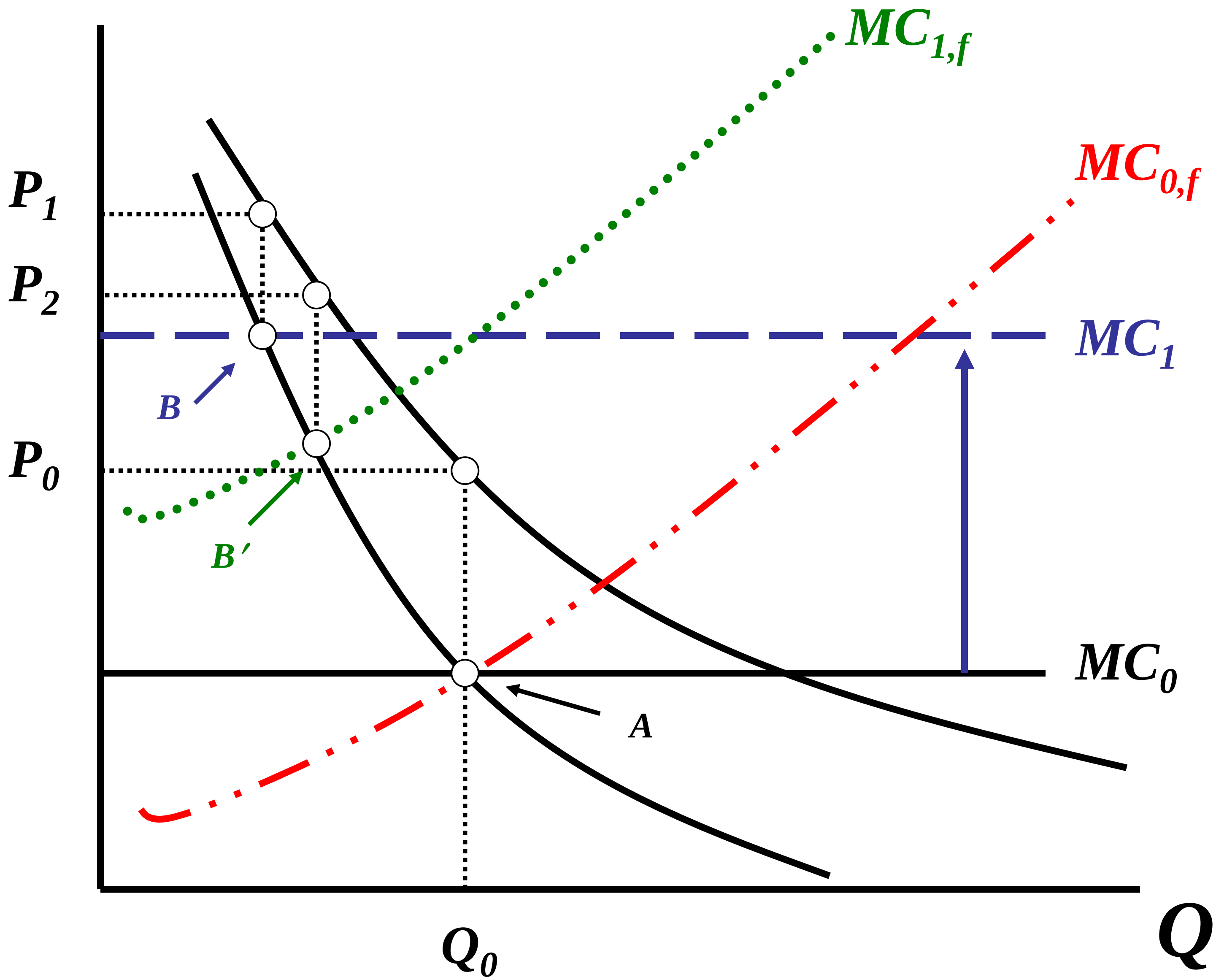
- Homogeneous capital:
  - Marginal cost is independent of firm output.

$$Y_{it} = (u_t \bar{K}_{it})^{\alpha} (z_t L_{it})^{1-\alpha}$$

- Firm-specific capital:
  - Marginal cost is increasing in firm output.
    - Requires that capital utilization not be variable.
  - As firm expands output, cannot simultaneously increase capital so incur diminishing returns in labor.

Homogeneous versus firm-specific capital, cnt'd…

- When firms have rising marginal cost, a given shock to marginal cost has smaller impact on price.



MC1,f
MC0,f
P1
P2
MC1
B
P0
B′
MC0
A
Q0
Q

More Intuition: Rising Marginal Cost and Incentive to Raise Price

- A Firm Contemplates Raising Price
  - This Implies Output Falls
  - Marginal Cost Falls
  - Incentive to Raise Price Falls
- Effect Quantitatively Important When:
  - Marginal Cost Steep (capital firm-specific; no variable utilization, σ_a large)
  - Demand Elastic (elasticity of demand, $\frac{\lambda_f}{\lambda_f - 1}$)

Observational Equivalence Property of Model

- Firm-Specificity of Capital Irrelevant for All Aggregate Equilibrium Conditions, Except One
- Aggregate Inflation Dynamics:

$$\pi_t = \beta E_t \pi_{t+1} + \gamma s_t,\ s_t = \text{marginal cost}$$

$$\gamma = \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p}\chi$$

$$\chi = \begin{cases} 1 & \text{standard, homogeneous capital model} \\ f(\text{slope of marginal cost and demand}) & \text{firm-specific capital model} \end{cases}$$

Degree of Price Stickiness in Model with Firm-specific Capital

IMPLIED AVERAGE TIME (Quarters) BETWEEN REOPTIMIZATION			
	$\frac{1}{1-\xi_P}$		elasticity of demand, $\frac{\lambda_f}{\lambda_f-1}$
Model	Firm-Specific Capital Model	Homogeneous Capital Model	demand: $Y_{it} = P_{it}^{\left(\frac{\lambda_f}{\lambda_f-1}\right)} \times$constant
Benchmark ($\lambda_f = 1.01$)	1.8	9.4	101
$\lambda_f = 1.05$	3.2	9.1	21
$\lambda_f = 1.10$	4.0	8.8	11
$\lambda_f = 1.20$	4.9	8.3	6

Plausible degree of price stickiness with assumption that capital is firm-specific consistent with the flat slope of the Phillips curve.

Full assessment requires an estimate of firm-level demand elasticity.

But, is the model consistent with evidence that inflation doesn't respond much to a monetary policy shock?

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

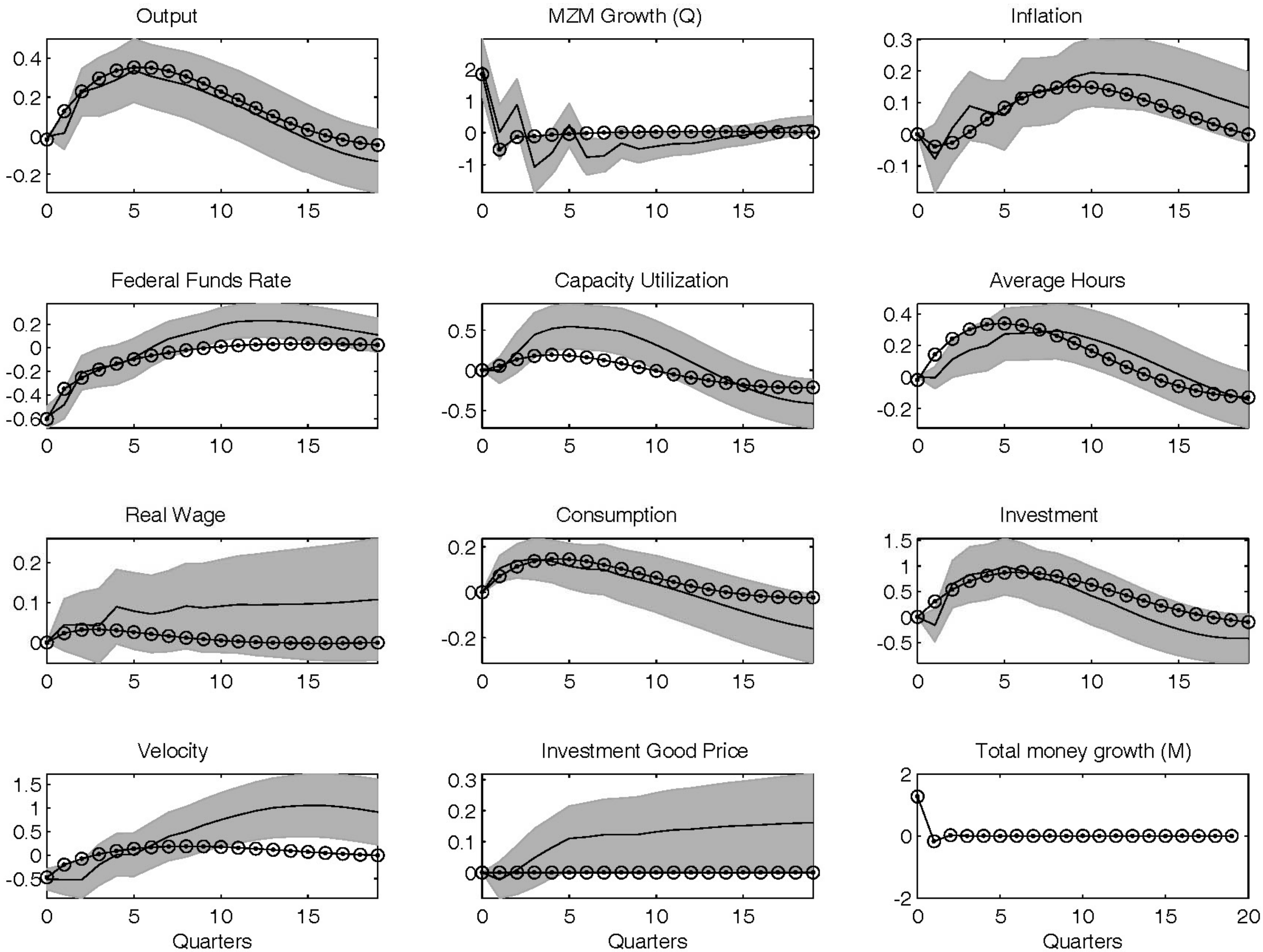


Figure 2: Response to a neutral technology shock (o - Model, - VAR, grey area - 95 % Confidence Interval)

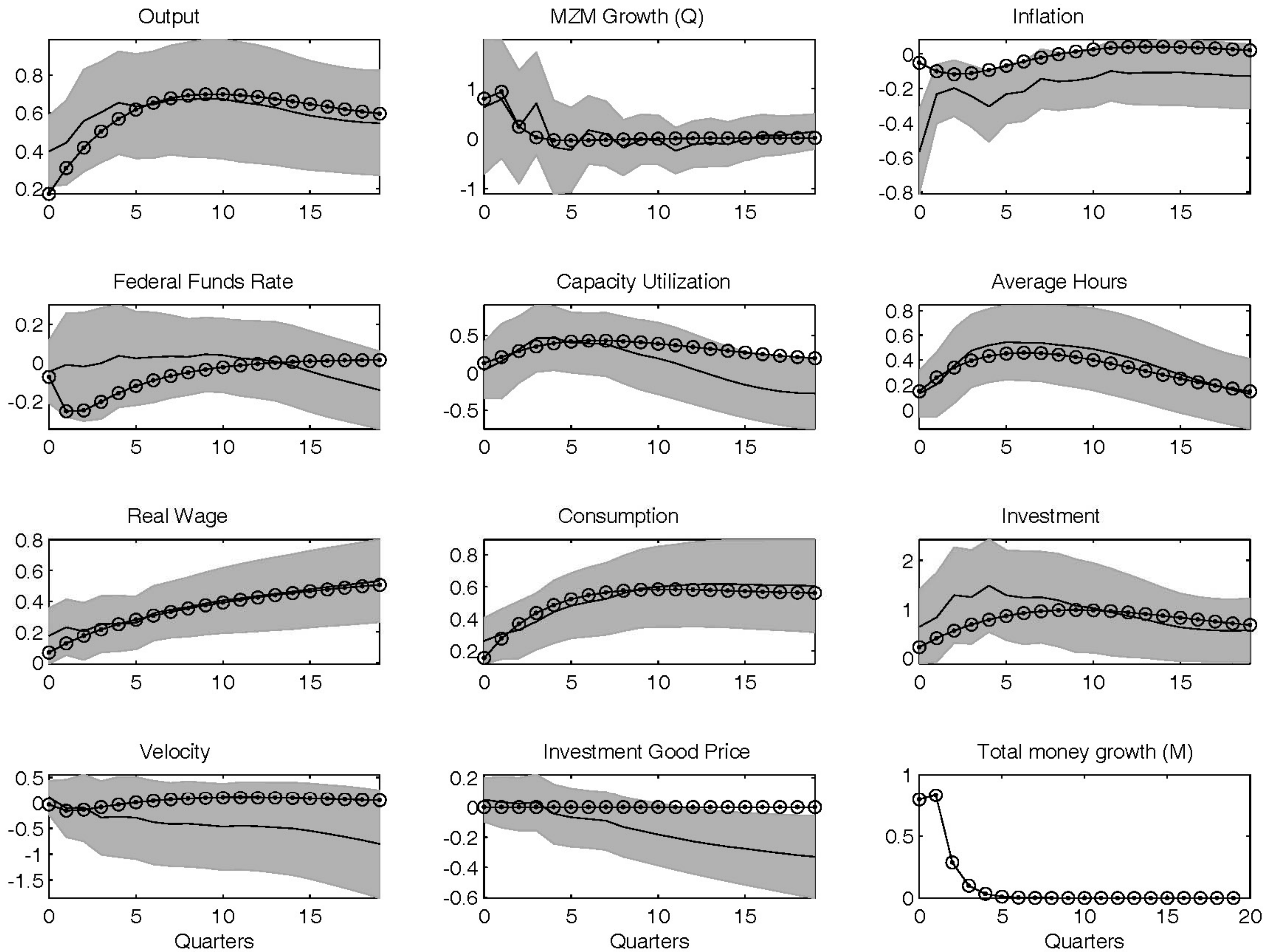
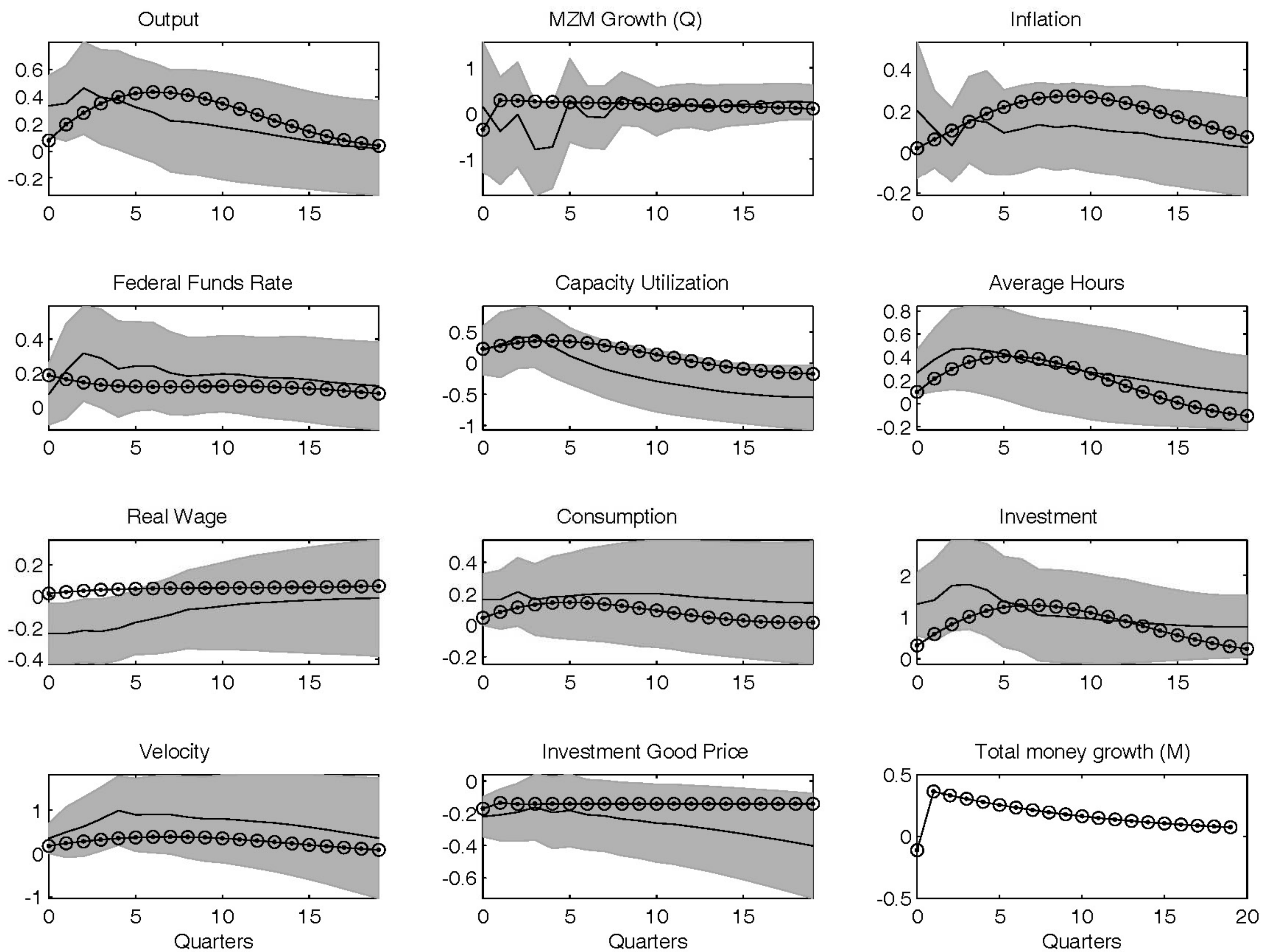


Figure 3: Response to an embodied technology shock (o - Model, - VAR, grey area - 95 % Confidence Interval)



Conclusion of Analysis of Standard Model

- Simple model with various frictions is capable of accounting well for key features of economic responses to monetary and technology shocks.

- But, model is missing financial frictions, and so cannot be used to address many of the policy questions arising from the financial crisis.