Monetary Policy in Incomplete Market Models: Theory and Evidence

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INTRODUCTION

- Workhorse model in public economics:
  Bewley-Imrohoroglu-Huggett-Aiyagari incomplete markets model.
  - Matches joint distribution of earnings, consumption and wealth
  - Generates realistic distribution of MPCs
  - Can generate realistic consumption responses to transitory income and transfers.

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  - Matches joint distribution of earnings, consumption and wealth
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  - Can generate realistic consumption responses to transitory income and transfers.
- Workhorse model in monetary economics:
  Representative-Agent New-Keynesian model.
  - Nominal rigidities allow output to be demand determined.
  - Meaningful role for monetary policy.
  - Can match the data.

Introduction

- Research frontier: Combine
  - Representative-Agent New-Keynesian model.
  - Aiyagari model.

    $\hookrightarrow$ AiyaGalí
    - Allows for demand determined output *and*
    - Consumption responses in line with the data

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- Our Objective: Estimate the new model.
  - Incomplete Markets (No Ricardian Equivalence):

  Shocks $\rightarrow$ Government budget $\rightarrow$ Fiscal Policy $\rightarrow$ Prices, ...
    - Consequence I:
      Need to estimate the response of fiscal policy.
    - Consequence II:
      Re-estimate other parameters (Price-rigidity, ...)

Methodology: IRF-Matching

- Methodology: Impulse Response Function Matching.
  1. Use identified technology shocks. Need to take into account:
     - Monetary policy response (FFR).
     - Fiscal policy response (Govt. Spending, Revenue, Transfers, Debt).
  2. Use identified monetary policy shocks. Need to take into account:
     - Fiscal policy response (Govt. Spending, Revenue, Transfers, Debt).
- Model Impulse Response Functions.
  1. Compute non-linear IRF to MIT shock
     - Following Boppart, Krusell & Mitman (2018) can treat as numerical derivative in sequence space to provide a linearized solution to the model with aggregate risk.
  2. Pick parameters to minimize distance between model & data IRF.

Neutral Technology Shocks

- Bocola et al (2016).
- Identified innovations to labor-augmenting technology. ▸ Details
- Series extends back to 1947.

Monetary Policy Shocks

- Romer-Romer (2004) extended by Wieland-Yang (2017).
- These are residuals from a regression of the target federal funds rate on lagged values and the Federal Reserve's information set based on Greenbook forecasts.
- Series extends back to 1969.
- Results are qualitatively similar when we use monetary policy shocks measured with high frequency identification, but those series are much shorter.

Construction of Fiscal Variables

- Measure government Spending, Revenue, and Transfers in the data.
- Source: NIPA
- Coverage: Federal, State and Local government.
- Ensure that variables are defined consistently with their meaning in the model and that the budget constraint holds.

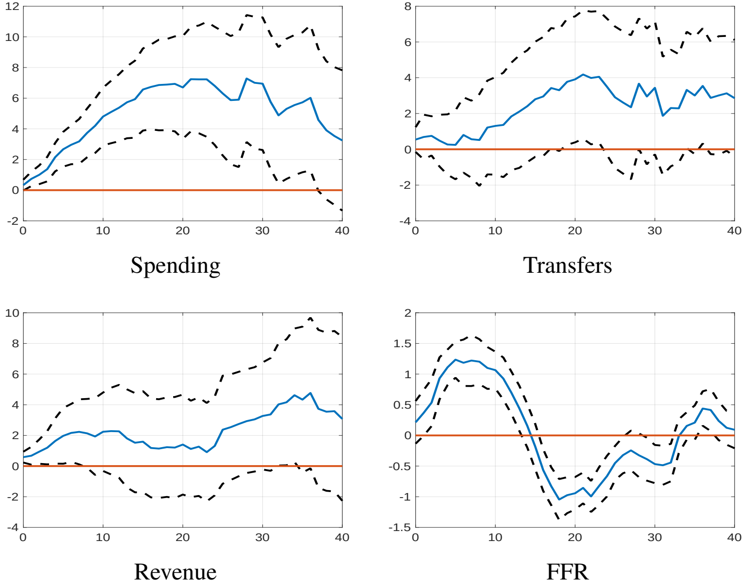
▸ Variable Construction Details

Estimating IRFs

- Outcome variable X.
- Identified shock ξ.
- Estimated IRF:

$$100 * (\log(X_{t+k}) - \log(X_{t-1})) = \beta_k \log(\xi_t) + \varepsilon_t$$

What Happens after a Technology Shock?



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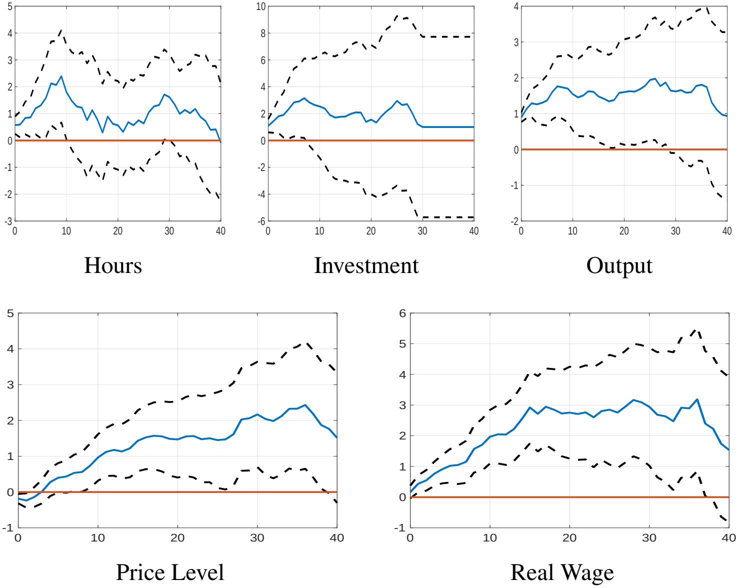

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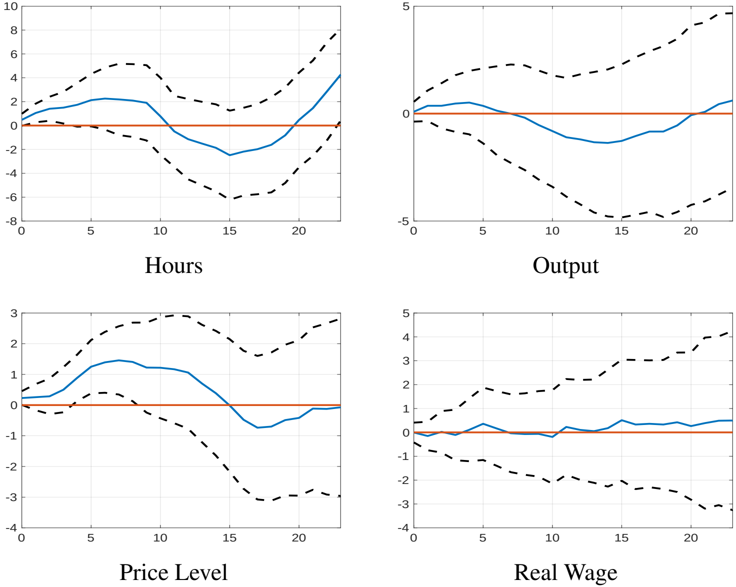

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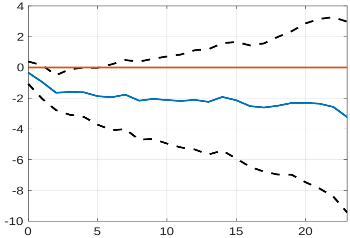
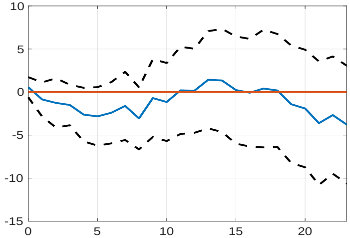


Spending



Transfers

Model: Households

- Continuum of ex-ante identical households
- Preferences over consumption and leisure
- Stochastic (uninsured) labor productivity
- Can save in one-period uncontingent assets
- No borrowing
- HH budget constraint:

$$Pc + a' = (1 + r^a)a + P(1 - \tau)whs + T$$

where P: price level, c: consumption, a: nominal savings, r^a: return on savings, τ: tax, w: real wage, h: hours, s: productivity, T: transfers

Model, Detailed Exposition

Model: Production and Prices

- Hours and Wages:
  - Recruiting firms aggregate differentiated HH labor services
  - Sell to intermediate goods produces
  - Union sets nominal wages as if subject to Rotemberg (1982) adjustment costs

Model: Production and Prices

- Hours and Wages:
  - Recruiting firms aggregate differentiated HH labor services
  - Sell to intermediate goods produces
  - Union sets nominal wages as if subject to Rotemberg (1982) adjustment costs
- Output and Prices:
  - Final good produces aggregate continuum of intermediates
  - Intermediate production Cobb-Douglas in capital and labor
  - Intermediate firms set prices as if subject to Rotemberg (1982) adjustment costs

Model: Government

Government taxes labor income and provides nominal transfers:

$$\tilde{T}(wsh) = -T + \tau Pwsh$$

- Government fully taxes firm profits $P_t d_t$
- Government taxes capital income at rate τ_k
- Government issues nominal bonds B^g
- Exogenous unvalued expenditures G_t
- Government budget constraint given by:

$$B^g_{t+1} = (1+i_t)B^g_t + G_t - P_t d_t - \tau_k(r^k_t - \delta)K_t - \int \tilde{T}_t(w_t s_t h_t)d\Omega$$

Monetary Policy in Complete Markets

The complete markets economy arises as a special case when there is no idiosyncratic risk:

$$
\begin{aligned}
Y_t^{CM} = Z_t H_t^{CM} &= C_t^{CM} + g_t + F + \frac{\theta}{2}\left(\pi_t^{CM} - \overline{\Pi}\right)^2 Y_t^{CM} \\
w_t^{CM}(1-\tau_t)(C_t^{CM})^{-\sigma} &= D(H_t^{CM})^{\phi} \\
u_c(C_t^{CM}) = (C_t^{CM})^{-\sigma} &= \beta \frac{1+i_{t+1}}{1+\pi_{t+1}^{CM}} u_c(C_{t+1}^{CM}) = \beta(1+r_{t+1}^{CM})(C_{t+1}^{CM})^{-\sigma} \\
(1-\varepsilon) + \frac{\varepsilon}{1-\alpha}\frac{w_t^{CM}}{Z_t} &= \theta\left(\pi_t^{CM} - \overline{\Pi}\right)\pi_t^{CM} - \frac{1}{1+r_t^{CM}}\theta\left(\pi_{t+1}^{CM} - \overline{\Pi}\right)\pi_{t+1}\frac{Y}{Y}
\end{aligned}
$$

Note that output is linear in hours, $Y = ZH$, and that the function describing the disutility of labor is $g(h)$

Theory: MP in (In)Complete Markets

- Complete Markets:
  - Steady state in CM: $C_{ss}^{CM}, H_{ss}^{CM}, Y_{ss}^{CM}, w_{ss}^{CM}$
  - Monetary Policy shock:

$$i_0 = i^*, i_1, i_2, \ldots, i_t, \ldots i^*$$

  - Consumption/Hours/Output/Wages Responses:

$$\text{Consumption:} \qquad \gamma_t^C = \frac{C_t^{CM}}{C_{ss}^{CM}}$$

$$\text{Hours/Output:} \qquad \gamma_t^H = \gamma_t^Y = \frac{H_t^{CM}}{H_{ss}^{CM}} = \frac{Y_t^{CM}}{Y_{ss}^{CM}},$$

$$\text{Wages:} \qquad \gamma_t^w = \frac{w_t^{CM}}{w_{ss}^{CM}},$$

Theory: MP in (In)Complete Markets

- Incomplete Markets:
  - Steady state in IM: $C_{ss}^{IM}, H_{ss}^{IM}, Y_{ss}^{IM}, w_{ss}^{IM}$
  - Take scaled CM Monetary Policy shock:

$$1+i_0^{IM} = 1+i_{ss}^{IM}, 1+i_1^{IM} = (1+i_{ss}^{IM})\frac{1+i_1}{1+i^*},$$
$$1+i_2^{IM} = (1+i_{ss}^{IM})\frac{1+i_2}{1+i^*}, \ldots, 1+i_t^{IM} = (1+i_{ss}^{IM})\frac{1+i_t}{1+i^*}, \ldots$$

  - Households receive real transfers in addition to labor earnings:

$$\Gamma_t^{IM} = d_t^{IM} + \tau w_t^{IM} H_t^{IM} + \frac{B_{t+1}^{IM} - B_t^{IM}(1+i_t^{IM})}{P_t^{IM}} - g_t^{IM},$$
$$\Gamma^{IM,ss} = d^{IM,ss} + \tau w^{IM,ss} H_{ss}^{IM,ss} + \frac{B^{IM,ss} - B^{IM,ss}(1+i^{IM,ss})}{P^{IM,ss}} - g^{IM,ss}.$$

    Each household i receives a share $\lambda_{i,t}$ of the transfer at time t, such that $\int \lambda_{i,t} di = 1$. We denote $\gamma_t^{\Gamma} = \Gamma_t^{IM}/\Gamma_{ss}^{IM}$.

HOUSEHOLD PROBLEM

Solve the following dynamic program in response to the monetary policy shock:

$$
\begin{aligned}
V_t(a_{i,t}, s_{i,t}) = & \max_{c_{i,t}^{IM}, a_{i,t+1} \geq 0} u(c_{i,t}^{IM}, h_{i,t}) + \beta \mathbb{E}_{s_{t+1}} V_{t+1}(a_{i,t+1}, s_{i,t+1}) \\
\text{subj. to} \quad & c_{i,t}^{IM} + a_{i,t+1} = \frac{(1+i_t^{IM})}{(1+\pi_t^{IM})} a_{i,t} + (1-\tau)\gamma_t^w \gamma_t^H w_{ss}^{IM} h_{i,ss}^{IM} s_{i,t} \\
& + \lambda_{i,t} \gamma_t^\Gamma \Gamma_{ss}^{IM} + \Delta_{i,t}
\end{aligned}
$$

Note: $\Delta_{i,t}$ does not depend any subsequent choices.

THEORY: MP IN (IN)COMPLETE MARKETS

- Define an individual specific time t transfer $\Delta_{i,t}$:

$$
\begin{aligned}
& \Delta_{i,t} \\
= \; & (\gamma_t^C - 1)c_{i,t}^{IM,ss} - \left(\gamma_t^H \gamma_t^w - 1\right) w_{ss}^{IM}(1-\tau_{ss}) s_{it} h_{i,t}^{IM,ss} \\
- \; & \lambda_{i,t}(\gamma_t^\Gamma - 1)\Gamma^{IM,ss} + a_{it}\left(\frac{1+i^{IM,ss}}{P^{IM,ss}} - \frac{P_{t-1}^{IM}}{P^{IM,ss}} \frac{1+i_t^{IM}}{P_t^{IM}}\right)
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- The total transfer received by a household is then given by:

$$\begin{aligned} & \Delta_{i,t}^{Total} = \Delta_{i,t} + \lambda_{i,t} (\gamma_t^\Gamma - 1) \Gamma^{IM,ss} \\ = \quad & (\gamma_t^C - 1) c_{i,t}^{IM,ss} - \left(\gamma_t^H \gamma_t^w - 1\right) w_{ss}^{IM} (1 - \tau_{ss}) s_{it} h_{i,t}^{IM,ss} \\ + \quad & a_{it} \left(\frac{1 + i^{IM,ss}}{P^{IM,ss}} - \frac{P_{t-1}^{IM}}{P^{IM,ss}} \frac{1 + i_t^{IM}}{P_t^{IM}} \right) \end{aligned}$$

Theory: MP in (In)Complete Markets

- By comparison define the rep. agent counterpart of Δ is:

$$\begin{aligned}\overline{\Delta}_t &= (\gamma_t^C - 1)C_{ss}^{IM} - \left(\gamma_t^H \gamma_t^w - 1\right) w_{ss}^{IM}(1-\tau_{ss})H_{ss}^{IM} \\ &- (\gamma_t^\Gamma - 1)\Gamma_{ss}^{IM} + A\left(\frac{1+i_{ss}^{IM}}{P_{ss}} - \frac{P_{t-1}^{IM}}{P_{ss}}\frac{1+i_t^{IM}}{P_t^{IM}}\right),\end{aligned}$$

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- so that the difference makes the various redistributions clear:

$$\begin{aligned} \tilde{\Delta}_{i,t} &= \Delta_{i,t} - \overline{\Delta}_t \\ &= \underbrace{(\gamma_t^C - 1)(c_{i,t}^{IM,ss} - C_{ss}^{IM})}_{\text{Redistributes toward high } c \text{ if } \gamma_t^C > 1} \\ &- \left(\gamma_t^H \gamma_t^w - 1\right) w_{ss}^{IM} (1 - \tau_{ss})(s_{it} h_{i,t} - H_{ss}^{IM}) \\ &- (\lambda_{i,t} - 1)(\gamma_t^\Gamma - 1)\Gamma_{ss}^{IM} \\ &+ (a - A)\left(\frac{1 + i_{ss}^{IM}}{P_{ss}} - \frac{P_{t-1}^{IM}}{P_{ss}} \frac{1 + i_t^{IM}}{P_t^{IM}}\right) \end{aligned}$$

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Equivalence Between IM and CM

Theorem

Consider the CM economy $\{C_t^{CM}, H_t^{CM}, w_t^{CM}, \pi_t^{CM}, 1+i_t\}$. *The IM economy with transfers* $\Delta_{i,t}$ *as above and taking* $1+i_t = (1+i_{ss}^{IM})\frac{1+i_t}{1+i^*}$ *has the same aggregate consumption, hours, wages and inflation rates as the complete markets case. Furthermore, individual consumption, hours, and savings satisfy*

$$\begin{aligned} c_{i,t}^{IM} &= \gamma_t^C c_{i,t}^{IM,ss} \\ h_{i,t}^{IM} &= \gamma_t^H h_{i,t}^{IM,ss} \\ a_{i,t+1}^{IM} &= \frac{P_t}{P_{ss}} a_{i,t+1}^{IM,ss}, \end{aligned}$$

for a price sequence P_t. *Real bonds are unchanged,* $B_t = \frac{P_t}{P_{ss}} B_{ss}$ *and transfers are adjusted to balance the government period-budget constraint.*

EQUIVALENCE (SPECIAL CASE)

- Consumption = Output, $\gamma_t^C = \gamma_t^Y$
  (No fixed costs, no adjustments costs (as-if), $G = 0$, $\tau = 0$)
- Profits distributed proportional to wages: $w_t s h_t + \lambda(s)\Gamma_t = Z_t s h_t$.

RESULT

Then the IM economy with transfers:

$$\Delta_{i,t} = (\gamma_t^Y - 1)(c_{i,t}^{IM,ss} - Z_t s_{it} h_{i,t}^{IM,ss})$$

has the same aggregate consumption, hours, wages and inflation rates as the complete markets case. Furthermore, individual consumption, hours, and savings satisfy

$$c_{i,t}^{IM} = \gamma_t^C c_{i,t}^{IM,ss} \quad (1)$$

$$h_{i,t}^{IM} = \gamma_t^H h_{i,t}^{IM,ss} \quad (2)$$

$$a_{i,t+1}^{IM} = \frac{P_t}{P_{ss}} a_{i,t+1}^{IM,ss}, \quad (3)$$

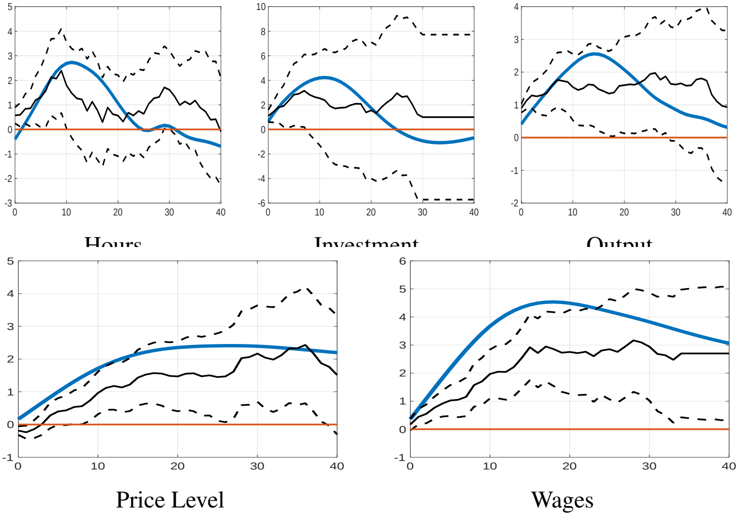
Other Policies

- Redistribute Profits Lump-Sum
  - Redistributes towards low-productivity hhs
  - $\Delta C^{IM} > \Delta C^{CM}$ if profits go up.
  - Tighten Monetary policy $\rightarrow$ profits go up.
    $\hookrightarrow$ IM-consumption responses muted
  - Loosen Monetary policy $\rightarrow$ profits go down.
    $\hookrightarrow$ IM-consumption increase smaller
- Effect of undone wealth redistribution.
  - Prices increase $\rightarrow$ Distributes towards low asset hhs
  - Prices decrease $\rightarrow$ Distributes towards high asset hhs

Calibration Overview

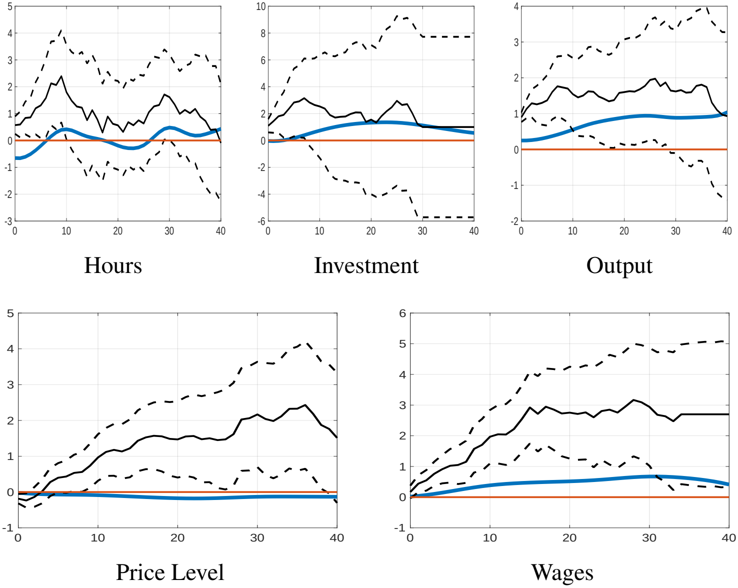
- Household side follows Krueger, Mitman and Perri (2016)
- Frisch elasticity of 1
- Markup of 10%
- G 17% of SS Output
- Transfers 12% of SS Output
- Debt / GDP 0.63
- Profits 0% of SS Output
- Tax τ 32%
- Steady state nominal interest rate 4%, inflation 2.7%
- To be estimated:
  - Slope of NK Price Philips Curve
  - Slope of NK Wage Philips Curve
  - Elasticity of investment to q

RESULTS, TECHNOLOGY SHOCK

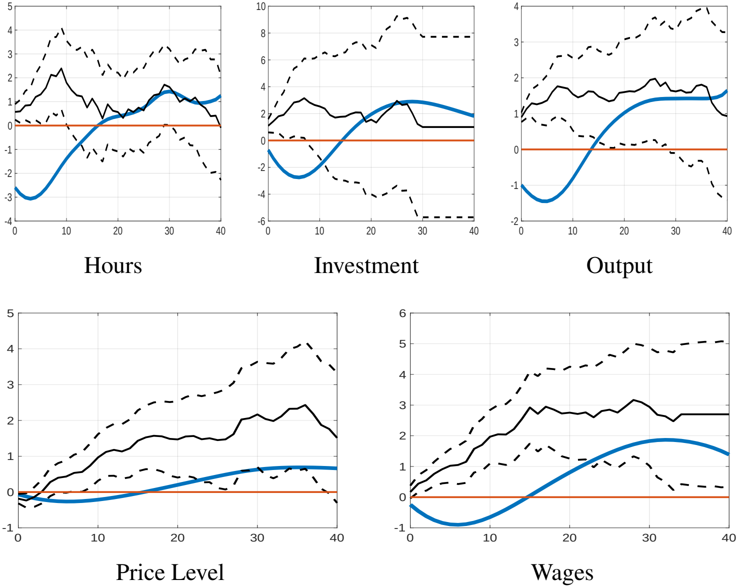


- Slope of NK Price Philips Curve : 0.0055.
- Slope of NK Wage Philips Curve: 0.0055.
- Elasticity of investment to q: 0.35.

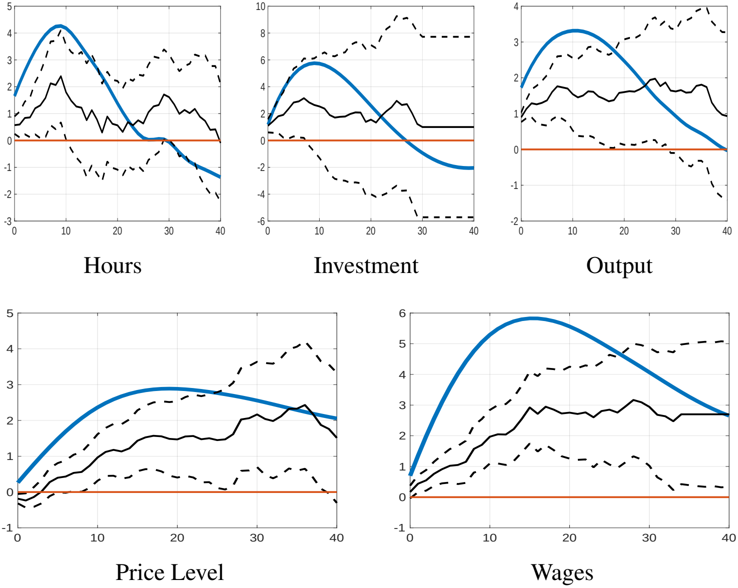
Technology Shock + No Policy Response



Technology Shock + Only MP response

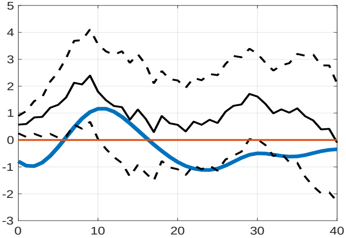


TECHNOLOGY SHOCK + ONLY FP RESPONSE

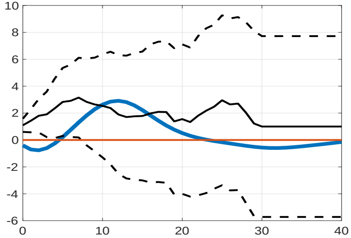


Comparison to Complete Markets

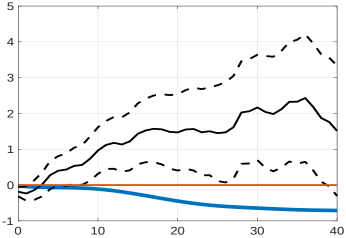
As-if complete markets (using IM model r_t):



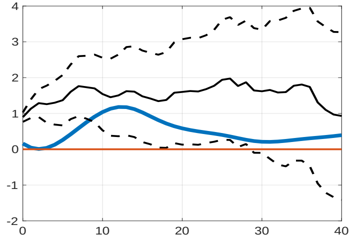
Hours



Investment



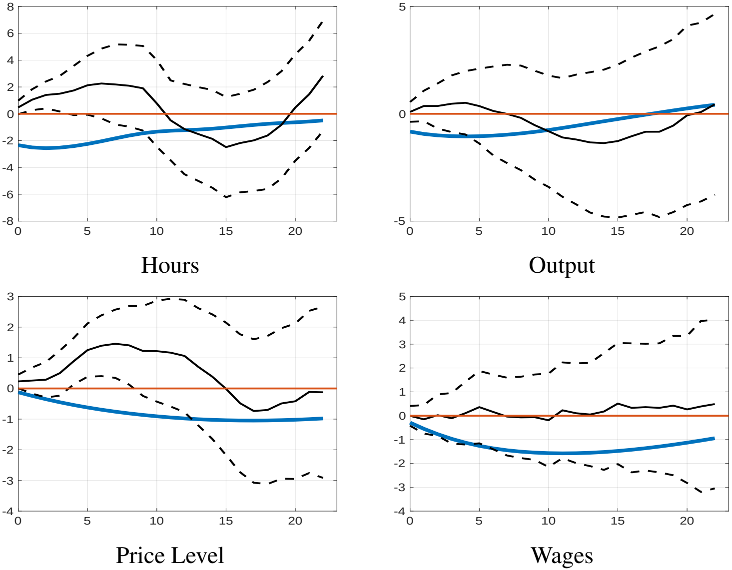
Price Level



Wages

Results, Monetary Policy Shock

Monetary policy shock: .25pp nominal interest rate increase (pers. .8)



Conclusions

- A simple AiyaGalí model generates impulse responses that are similar to those in the data.
  - Next step is to improve the estimation
- The effects of market incompleteness can be analyzed theoretically.
- Fiscal and monetary policies interact and should be studied jointly.

Thanks!

Additional Slides

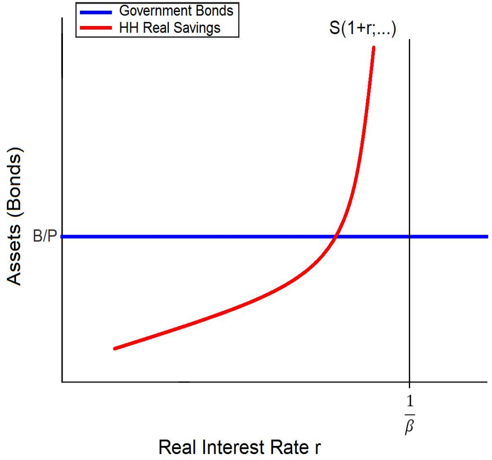
Price Level Determinacy in Incomplete Market Models

Price Level Indeterminacy

- Sargent and Wallace (1975):
  Interest rate target determines only expected inflation.
- Price level is left indeterminate.
- Next: Price level determinacy in a large class of incomplete market models.
- Government budget constraint is in nominal terms. Satisfied for all prices $\Rightarrow$ Not FTPL.

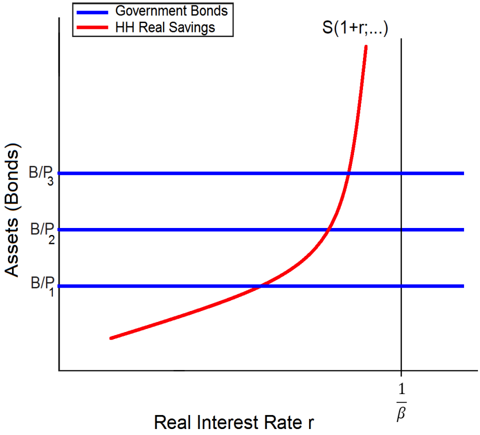
Steady State Price Level

Huggett Economy: Asset Market

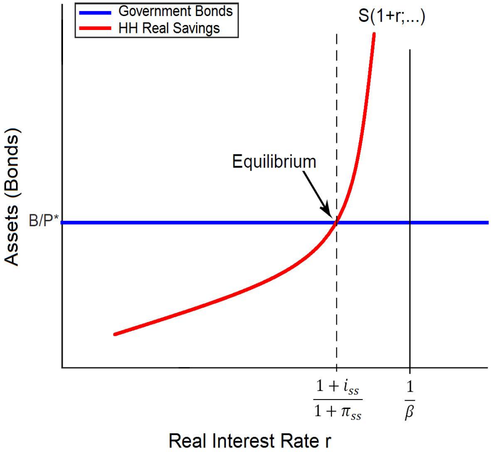


Steady State Price Level

Indeterminacy



Steady State Price Level



Real Interest Rate:

$$(1+r) = \frac{1+i}{1+\pi}$$

Monetary Policy:

Sets $1+i$

Fiscal Policy:

$$\pi = \frac{B'-B}{B} = \frac{G'-G}{G} = \frac{T'-T}{T}$$

i : nominal interest rate
r : real interest rate
π : inflation rate

B: nominal bonds
G: nominal government spending
T: nominal tax revenue

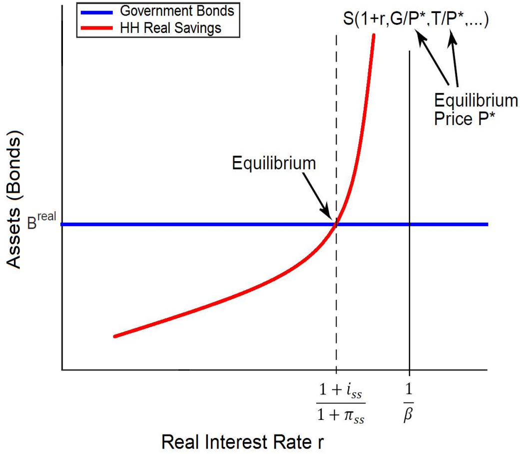
Precautionary Savings

- Failure of the permanent income hypothesis (Campbell and Deaton (1989), Attanasio and Davis (1996), Blundell, Pistaferri and Preston (2008), Attanasio and Pavoni (2011)):
  - Precautionary Savings: A permanent income gain does increase household consumption less than one-for-one.
  - A permanent decrease in government spending by one dollar and a simultaneous permanent tax rebate of the same amount to private households lowers real total aggregate demand - the sum of private and government demand.

Precautionary Savings and Steady State Prices

- Steady State (fixed real interest rate):
  - Higher steady state price level lowers real government consumption (given monetary and nominal fiscal policy).
  - Lowers the real tax burden for the private sector by the same amount.
  - Private sector demand does not substitute one-for-one for the drop in government consumption (Precautionary savings up).
  - Aggregate demand-price curve is downward sloping.
  - Steady state price level equates aggregate real demand and real supply.

STEADY STATE PRICE LEVEL: FULLY PRICE-INDEXED BONDS B^{real}



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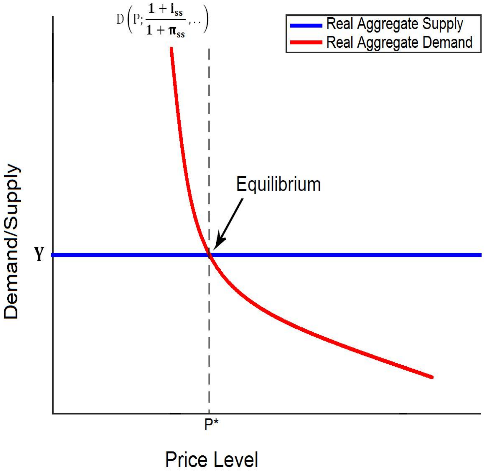
T: nominal tax revenue

Steady State Price Level: Aggregate (Goods) Demand



Real Interest Rate:

$$(1+r) = \frac{1+i}{1+\pi}$$

Monetary Policy:

Sets $1+i$

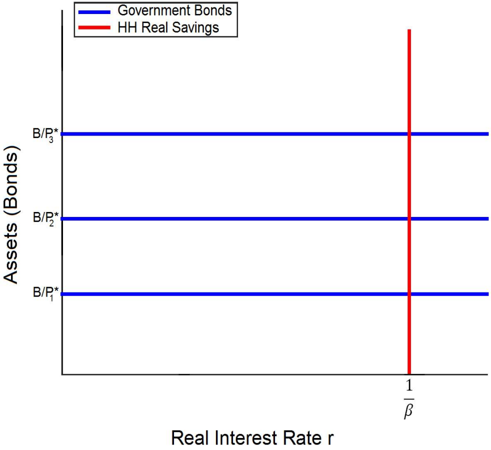
Fiscal Policy:

$$\pi = \frac{B'-B}{B} = \frac{G'-G}{G} = \frac{T'-T}{T}$$

i : nominal interest rate
r : real interest rate
π : inflation rate

B: nominal bonds
G: nominal government spending
T: nominal tax revenue

Steady State Price Level: Complete Markets



Real Interest Rate:

$$(1+r) = \frac{1+i}{1+\pi}$$

Monetary Policy:

Sets $1+i$

Fiscal Policy:

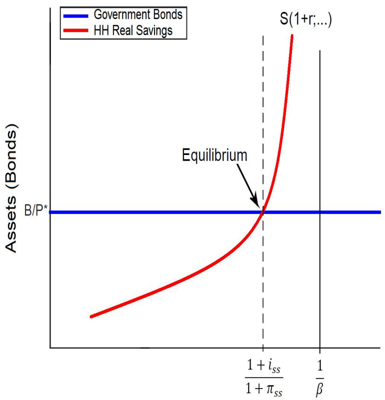
$$\pi = \frac{B'-B}{B} = \frac{G'-G}{G} = \frac{T'-T}{T}$$

i : nominal interest rate
r : real interest rate
π : inflation rate

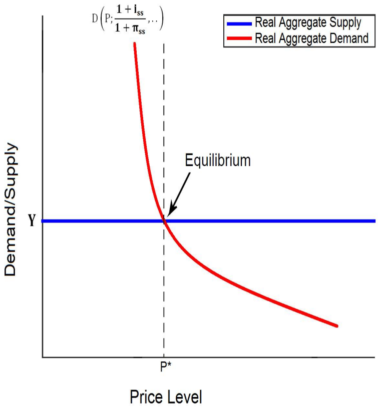
B: nominal bonds
G: nominal government spending
T: nominal tax revenue

Monetary and Fiscal Policy, Technology, Liquidity

Steady State Price Level: Asset and Goods Market

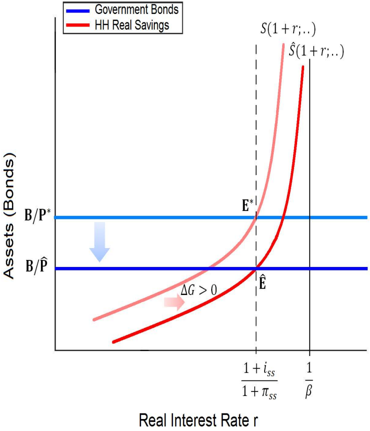


Asset Market

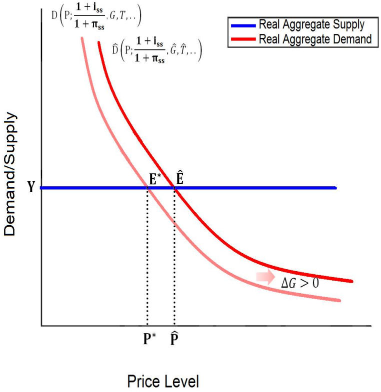


Goods Market

Steady State Price Level: Expansionary Fiscal Policy $\Delta G > 0$

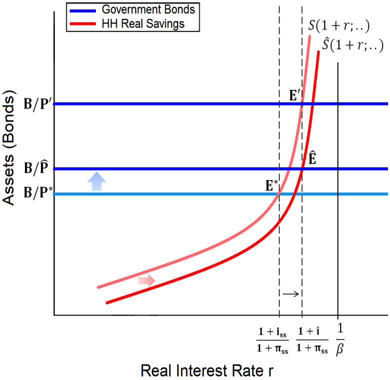


Asset Market

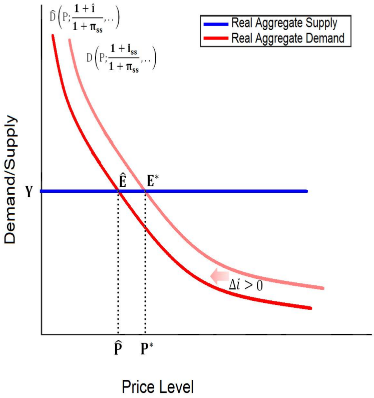


Goods Market

Steady State Price Level: Tighter Monetary Policy $\Delta i > 0$

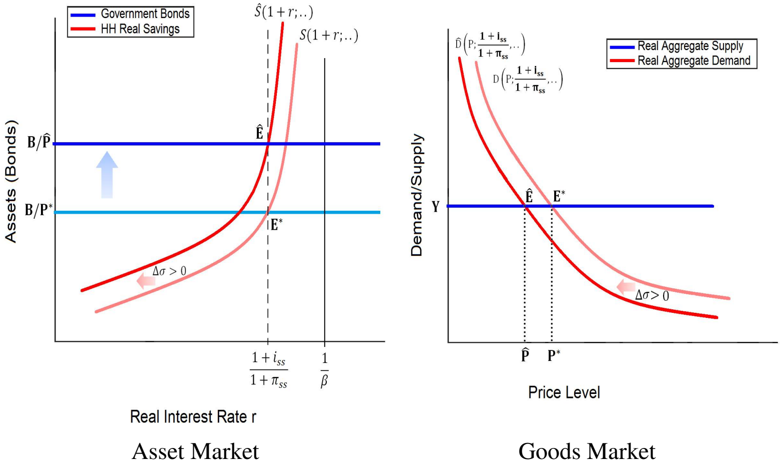


Asset Market

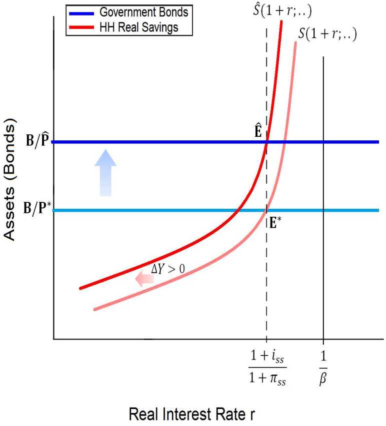


Goods Market

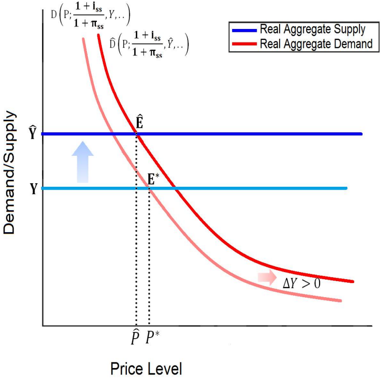
Steady State Price Level: Higher Liquidity Demand $\Delta\sigma > 0$



Steady State Price Level: Productivity Increase $\Delta Y > 0$



Asset Market



Goods Market

Model, Details

Model: Households

Continuum of ex-ante identical households with preferences:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \{u(c_t) - g(h_t)\}$$

where:

$$\begin{aligned} u(c) &= \log(c) \\ g(h) &= \psi \frac{h^{1+1/\varphi}}{1+1/\varphi} \end{aligned}$$

and $\beta \in (0,1)$ is the discount factor.

- Households' labor productivity $\{s_t\}_{t=0}^{\infty}$ is stochastic
- $s_t \in \mathscr{S} = \{s^1, \cdots, s^N\}$ with transition probability characterized by $p(s_{t+1}|s_t)$

Model: Recruiting Firms

A representative, competitive recruting firm aggregates a continuum of differentiated households labor services indexed by $j \in [0,1]$ and nominal wages per efficiency unit W_{jt}:

$$H_t = \left(\int_0^1 s_{jt} (h_{jt})^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dj \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}} .$$

Given a level of aggregate labor demand H, demand for the labor services of household j is given by:

$$h_{jt} = h(W_{jt}; W_t, H_t) = \left(\frac{W_{jt}}{W_t} \right)^{-\varepsilon_w} H_t.$$

where W_t is the (equilibrium) nominal wage,

$$W_t = \left(\int_0^1 s_{jt} W_{jt}^{1-\varepsilon_w} dj \right)^{\frac{1}{1-\varepsilon_w}} .$$

Model: Wage Setting

- A union sets a nominal wage $W_{jt} = \hat{W}_t$ for an effective unit of labor to maximize profits.
- Quadratic wage adjustment as in Rotemberg (1982):

$$s_{jt}\frac{\theta_w}{2}\left(\frac{\hat{W}_t}{\hat{W}_{t-1}} - 1\right)^2 H_t.$$

- Union's wage setting problem is to maximize

$$\begin{aligned}
& V_t^w\left(\hat{W}_{t-1}\right) \\
\equiv \quad & \max_{\hat{W}_t} \int \left(\frac{s_{jt}(1-\tau_t)\hat{W}_t}{P_t} h(\hat{W}_t; W_t, H_t) - \frac{g(h(\hat{W}_t; W_t, H_t))}{u'(C_t)} \right) dj \\
- \quad & \int s_{jt}\frac{\theta_w}{2}\left(\frac{\hat{W}_t}{\hat{W}_{t-1}} - 1\right)^2 H_t dj + \frac{1}{1+r_t} V_{t+1}^w\left(\hat{W}_t\right)
\end{aligned}$$

- Symmetry: $h_{jt} = H_t$ and $\hat{W}_t = W_t$. Real wage $w_t = \frac{W_t}{P_t}$. $C_t =$ aggregate consumption.

Model: Worker Households

Can write their problem recursively:

$$V(a,s;\Omega) = \max_{c\geq 0, h\geq 0, a'\geq 0} u(c,h) + \beta \sum_{s\in\mathscr{S}} p(s'|s)V(a',s';\Omega')$$

subject to

$$Pc + a' = (1+i)a + P(1-\tau)whs + T$$

$$\Omega' = \Gamma(\Omega)$$

- $\Omega(a,s) \in \mathscr{M}$ is the distribution on the space $X = A \times S$.
- Γ equilibrium object determines evolution of Ω.

Model: Final Goods Production

A final good producer aggregates a continuum of intermediate goods indexed by $j \in [0,1]$ and with prices p_j:

$$Y_t = \left(\int_0^1 y_{jt}^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}} .$$

Given a level of aggregate demand Y, cost minimization for the final goods producer implies that the demand for the intermediate good j is given by

$$y_{jt} = y(P_{jt}; P_t, Y_t) = \left(\frac{P_{jt}}{P_t} \right)^{-\varepsilon} Y_t,$$

where P_t is the (equilibrium) price of the final good and can be expressed as

$$P_t = \left(\int_0^1 P_{jt}^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}} .$$

Model: Intermediate Goods Production

- Production technology is linear in labor:

$$y_{jt} = Z_t n_{jt},$$

  where Z_t is aggregate productivity.

- Marginal costs given by

$$mc_{jt} = \frac{w_t}{Z_t}.$$

- Price adjustment costs a la Rotemberg (1982):

$$\frac{\theta}{2}\left(\frac{P_{jt}}{P_{jt-1}} - 1\right)^2 Y_t.$$

- Fixed cost of production:

$$Z_t \Phi.$$

Model: Government

Government taxes labor income and provides nominal transfers:

$$\tilde{T}(wsh) = -T + \tau Pwsh.$$

- Government fully taxes firm profits $P_t d_t$
- Government issues nominal bonds B^g
- Exogenous unvalued expenditures G_t
- Government budget constraint given by:

$$B^g_{t+1} = (1 + i_t)B^g_t + G_t - P_t d_t - \int \tilde{T}_t(w_t s_t h_t) d\Omega.$$

Equilibrium

Definition: A monetary competitive equilibrium is a sequence of prices P_t, tax rates τ_t, nominal transfers T_t, nominal government spending G_t, bonds B_t^g, a value functions v_t, policy functions a_t and c_t, h_t, H_t, pricing functions r_t and w_t, and law of motion Γ, such that:

1. v_t satisfies the Bellman equation with corresponding policy functions a_t, c_t, h_T given price sequences r_t, w_t.
2. Prices are set optimally by firms.
3. Wages are set optimally by middlemen.
4. For all $\Omega \in \mathscr{M}$: Markets clear
5. Aggregate law of motion Γ generated by a' and p.

Focus on steady state equilibria where all real variables are constant, and constant rate of inflation.

Neutral Technology Shocks

Technology Shocks

- Need to compare impulse responses to *the same* shocks in the data and in the model.
- Labor-augmenting, or Harrod-neutral shocks are typically used among major stochastic disturbances in the model. Need to identify them in the data.
  - Arbitrary CRS aggregate production function:

    $$Y = F(K_1, ..., K_k, Z_t L_1, ..., Z_t L_n, t).$$

  - Solow residual $\frac{\dot{Z}}{Z} + \frac{\partial F / \partial t}{F}$ does not isolate neutral shocks.
  - Neither do SVARs. E.g., identification with long run restrictions pick up all shocks that have a long run effect on output per worker.
- Methodology to identify neutral shocks proposed in Bocola, Hagedorn and Manovskii (20xx).

BHM Identification Strategy

Identification Theorem: [Reformulation of Uzawa (1961)]
A permanent Harrod-neutral technology shock is the only shock with the following (balanced-growth) properties for some time T. An innovation which increases the level of the shock by x percent at time 0 *implies for all $t \geq T$*

- $\uparrow$ *in agg. output Y by x percent,*
- $\uparrow$ *in investment I_j by x percent,*
- $\uparrow$ *in capital K_j by x percent,*
- $\uparrow$ *in agg. consumption C by x percent,*
- *No effect on labor inputs L_m,*
- *No effect on the marginal product of capital F_{K_j},*
- $\uparrow$ *in the marginal product of labor F_{L_m} by x percent.*

BHM Implementation Strategy

Observe time series $\mathbf{D_t}$ of growth rates of n macroecon variables. Wlg:

$$\mathbf{D_t} = \Delta Z_t \mathbf{1_n} + \tilde{\boldsymbol{S}}_t,$$

where ΔZ_t is the growth rate of the neutral technology (in logs), and $\tilde{\boldsymbol{S}}_t$ is a vector of states. E.g.,

$$\Delta \log(Y_t) = \Delta Z_t + \Delta \log \left[F\left(\frac{K_{1,t}}{Z_t}, \ldots, \frac{K_{J,t}}{Z_t}, L_{1,t}, \ldots, L_{M,t}; \boldsymbol{\theta_t} \right) \right].$$

$F(\cdot)$ is unknown and unrestricted. $\tilde{\boldsymbol{S}}_t$ is unobserved.

Strategy:

1. Assume a time series model for the behavior of $[\Delta Z_t, \tilde{\boldsymbol{S}}_t]$, indexed by the vector of parameters Λ.
2. Estimate the parameters' vector Λ given identifying restrictions.
3. Conditional on the estimation of Λ and given a time series for $\mathbf{D_t}$, estimate the realization of ΔZ_t using smoothing techniques.

Fiscal Variables Construction

Construction of Fiscal Variables, Details

Source: NIPA Table 3.1, line numbers in brackets

Spending = Consumption expenditures [21]
+ Gross government investment [39]
+ Net purhases on nonproduced assets [41]
– Consumption of fixed capital [42]

Revenue = Total receipts [34]
– Subsidies [30]
– Current transfer receipts from the rest of the world [18]
+ Current surplus of government enterprises [19]

Transfers = Current transfer payments [22]
+ Capital transfer payments [40]
– Current transfer receipts from the rest of the world [18]

▸ Back