Labor Market Shocks and Monetary Policy

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Workshop on Methods and Applications for Dynamic Equilibrium Models
NBER SI
July 2025

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- U.S. employer-to-employer (EE) transition rate is procyclical and persistent.
  - Important driver of wage and productivity growth.

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- Relative strength of wage vs productivity growth over the business cycle affects inflation.
  - Potential implications for monetary policy.

Questions

1. **Positive:** How do fluctuations in EE flows affect macro outcomes and inflation dynamics?

2. **Normative:** How should monetary policy respond to fluctuations in EE flows?

This Paper

- Develop HANK model with frictional labor market and on-the-job search (OJS).
  - Income risk cyclicality and correlation with MPC. Acharya and Dogra (2020), Patterson (2022)
    - stylized on "supply block" and labor income process.
  - Labor market frictions, job ladder, and Phillips curve. Moscarini and Postel-Vinay (2019)
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- **Normative analysis:** Optimal monetary policy (MP) within a class of Taylor rules.
  - Solve for optimal unemployment and EE gap coefficients under job mobility dynamics.
- Show that accounting for imperfect self-insurance is quantitatively relevant.
  - RANK model generates different macro responses and optimal MP to changes in EE flows.

Literature

Roadmap

Motivation

Simple TANK model with frictional labor market and OJS

HANK model with frictional labor market and OJS

Calibration of model, transitional dynamics, estimation of shocks

Quantitative results

List of Simplifying Assumptions: ALL Relaxed in HANK

I Self-insurance is independent of labor income fluctuations: either full or no self-insurance.

II All jobs (worker-firm matches) are identical in productivity.

III All workers are identical in productivity.

IV Wages are exogenously set according to a predetermined rule.

- No bargaining, all outside offers lead to EE transitions with wage gains.

V No fiscal policy.

Overview: TANK + Labor Search with OJS

- Infinitely-lived individuals belong to one of two types of households:
  - Hand-to-mouth (HtM): does not hold assets, consumes real labor income.
  - Permanent-income (PIH): saves in risk-free asset, receives labor and dividend income.

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- Three firm types:
  - Labor service: hire workers in a frictional labor market and produce labor services.
  - Intermediate goods: use labor services and produce differentiated goods.
  - Final good: assemble differentiated goods into final consumption good.

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- Monetary authority controls nominal interest rate through Taylor rule.

Timing

Model Details: TANK

New Keynesian Components

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Intermediate goods firms:

- Firms are monopolistically competitive.
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- Pricing subject to quadratic costs $\Rightarrow$ New Keynesian Phillips Curve: Rotemberg (1982)

$$\frac{\log\left(1+\pi_t-\pi^*\right)\left(1+\pi_t\right)}{1+\pi_t-\pi^*} = \vartheta\left(p_t^l - \frac{\eta-1}{\eta}\right) + \frac{1}{1+r_{t+1}}\frac{\log\left(1+\pi_{t+1}-\pi^*\right)\left(1+\pi_{t+1}\right)}{1+\pi_{t+1}-\pi^*}\frac{Y_{t+1}}{Y_t}.$$

Model Details: TANK

Households and the Labor Market

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where $q_{t+s} = \frac{1}{1+r_{t+1}} \times \cdots \times \frac{1}{1+r_{t+s}}$ and Z_t is total real income of PIH household.

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- Aggregate demand $C_t = (1 - \mu)\, c_t^{PIH} + \mu c_t^{HtM}$.

The Labor Market

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- Search:
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  - Employed search with on-the-job search efficiency ν: contact rate $\nu f(\theta)$.
  - Later: ν shocks to break down negative correlation between unemployment and EE rates.

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  - Employed search with on-the-job search efficiency ν: contact rate $\nu f(\theta)$.
  - Later: ν shocks to break down negative correlation between unemployment and EE rates.
- **Labor service firms** hire in a frictional labor market:
  - Pay a flow cost κ to post vacancies.
  - Produce labor services sold at real price p_t^l.
  - Pay wages to individuals according to a predetermined rule.

Household Income

- Workers hired out of unemployment receive a fraction $\alpha \in (0, 1)$ of match revenue p_t^l.
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- Aggregate real profits $\Gamma_t = \Gamma_t^I + \Gamma_t^S$, where Γ_t^I and Γ_t^S are profits of two firm types. Details
- Per-capita real income of PIH household is $Z_t = W_t + \Gamma_t/(1-\mu)$.

Labor Service Firms and Monetary Authority

Real value of matched firm: Details

$$J_t = (1-\alpha)p_t^l + \frac{1}{1+r_{t+1}}(1-\delta)\Big(1-\nu_{t+1}f(\theta_{t+1})\Big)J_{t+1}.$$

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Value of posting vacancy:

$$V_t = -\kappa + q(\theta_t)\overbrace{\frac{u_{t-1}+\delta(1-u_{t-1})}{u_{t-1}+\delta(1-u_{t-1})+\nu_t(1-\delta)(1-u_{t-1})}}^{\mathbb{E}J_t}J_t\,.$$

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- composition effect
- shorter match duration effect

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The central bank controls short-term nominal interest rate following a Taylor rule:

$$i_t = i^* + \Phi_\pi\,(\pi_t - \pi^*) + \Phi_u\,(u_t - u^*).$$

Equilibrium DAG Solution: SSJ

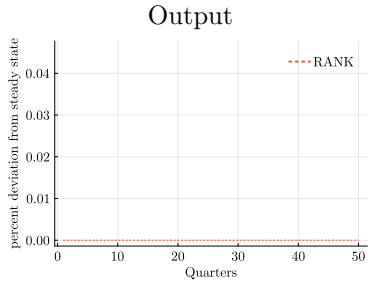
Results from the TANK Model

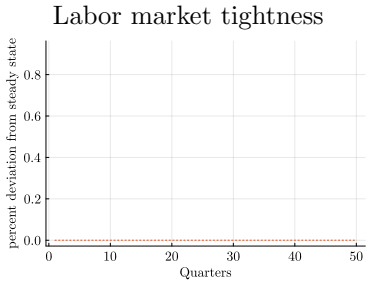
1. How do changes in job mobility affect macro outcomes?
2. Understanding mechanisms: TANK vs RANK

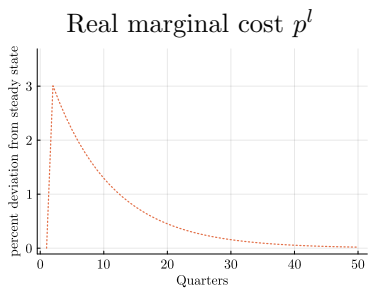
Main Exercise

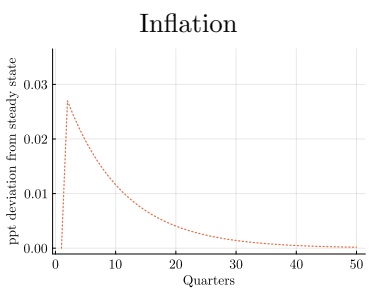
- Introduce exogenous variation in job mobility dynamics:
  - Positive OJS efficiency shock: 1 percent increase in ν that gradually reverts back to mean.
- Study IRFs in TANK ($\mu > 0$) vs RANK ($\mu = 0$) model.
- Analyze mechanisms:
  - How does accounting for imperfect self-insurance shape aggregate outcomes?
  - Differentiate between mechanisms: composition vs shorter match duration. Results

IRFs to OJS Efficiency Shock: Constant Real Rate



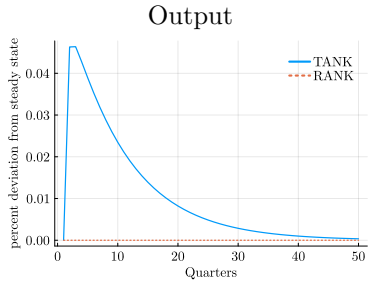


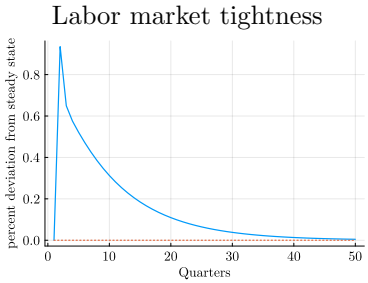


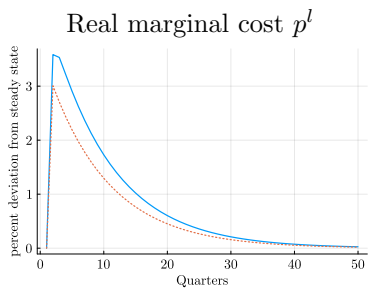


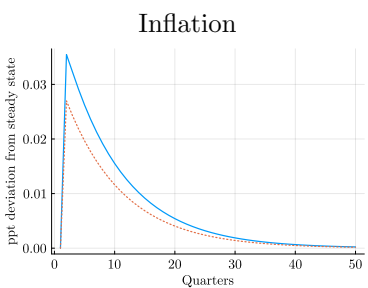
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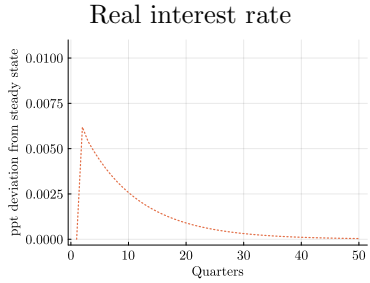


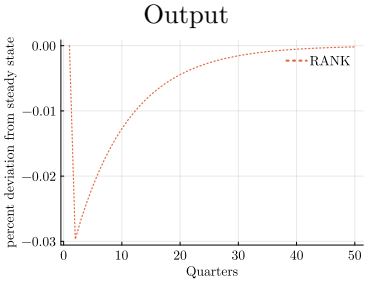


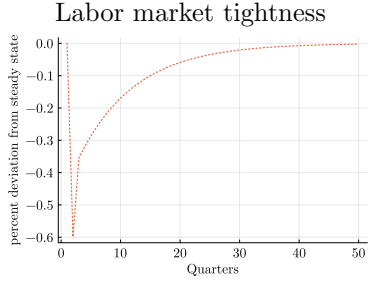


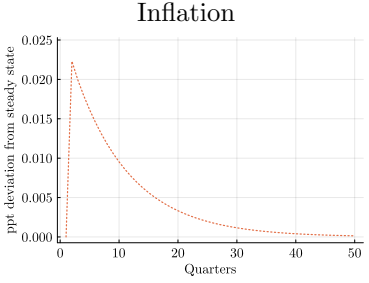
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IRFs to OJS Efficiency Shock: Real Rate Response



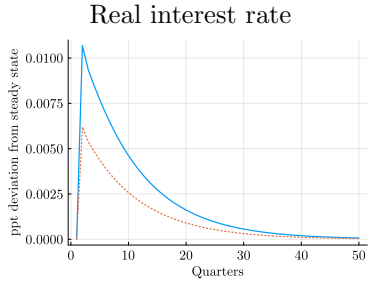


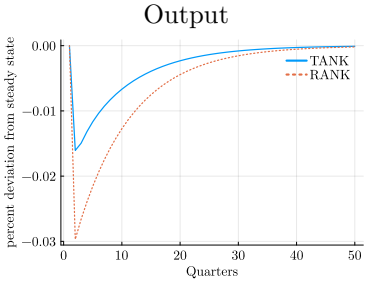


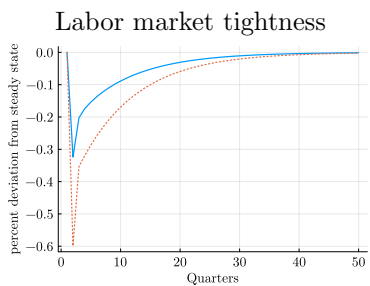


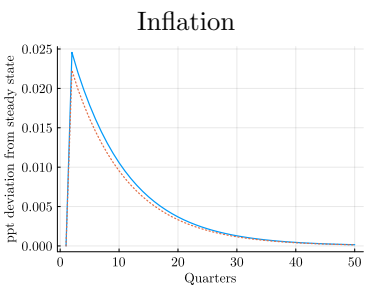
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Taking stock and motivations for HANK

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  - Higher job mobility leads to a decline in output and tightness, and to an increase in inflation.
  - Imperfect self-insurance is relevant for the responses of macro outcomes and conduct of MP.
- Motivations for a richer HANK model:
  1. Interaction between self-insurance (MPC heterogeneity) and labor income risk.
     ⇒ Endogenous wealth distribution. relax Assumption I
  2. Productivity-enhancing effects of job mobility.
     ⇒ Heterogeneity in match productivity in the labor services sector. relax Assumption II
  3. Wage dynamics for job switchers, job stayers, and job losers.
     ⇒ Wage bargaining and human capital dynamics. relax Assumptions III, IV
  4. Realistic fiscal policy
     ⇒ Government transfers funded by taxes and debt. relax Assumption V

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- Mutual fund owns firms, holds government debt, issues shares, pays dividends. Details
- Fiscal authority uses taxes and debt to finance spending and transfers. Details GBC Taxes

Timing

Employed Worker

Value of employment:

$$V_t^E(s,h,x,\alpha,\beta) = \max_{s'\geq 0,\ c} u(c) + \beta(1-\psi^R)\mathbb{E}_{h'|h}\left\{(1-\delta)\Omega_{t+1}^E(s',h',x,\alpha,\beta) + \delta\Omega_{t+1}^U(s',h',\beta)\right\}$$
$$+ \beta\psi^R V_{t+1}^R(s',\beta)$$
$$\text{s.t.} \quad P_t c(1+\tau_c) + P_t^s s' = P_t\tau_t w(h,x,\alpha)^{1-\Upsilon} + (P_t^s + D_t)s$$

- δ: Probability of match separation
- ν: On-the-job search efficiency

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$$\text{s.t.} \quad P_t c(1+\tau_c) + P_t^s s' = P_t\tau_t w(h,x,\alpha)^{1-\Upsilon} + (P_t^s + D_t)s$$

Value of on-the-job search:

$$\Omega_t^E(s,h,x,\alpha,\beta) = \overbrace{\nu_t f(\theta_t)}^{\text{Offer}}\mathbb{E}_{\widetilde{x}}\left[\max\left\{\overbrace{V_t^E(s,h,\widetilde{x},x/\widetilde{x},\beta)}^{\text{Switch}}, \overbrace{V_t^E(s,h,x,\max\{\alpha,\widetilde{x}/x\},\beta)}^{\text{Stay–Discard offer or rebargain}}\right\}\right]$$
$$+ \underbrace{(1-\nu_t f(\theta_t))}_{\text{No offer}} V_t^E(s,h,x,\alpha,\beta)$$

- δ: Probability of match separation
- ν: On-the-job search efficiency

Labor Service Firms

Value of matched firm:

$$J_t(h,x,\alpha) = p_t^l F(h,x) - w(h,x,\alpha) + \frac{1}{1+r_{t+1}}(1-\psi^R)(1-\delta)$$
$$\times \mathbb{E}_{h'|h}\left\{(1-\nu_t f(\theta_{t+1}))\, J_{t+1}(h',x,\alpha) + \nu_t f(\theta_{t+1}) \int_{\underline{x}}^{x} J\left(h',x,\max\{\alpha,\widetilde{x}/x\}\right) d\Gamma^x(\widetilde{x})\right\}$$

- p_t^l: Price of labor services
- r_t: Real interest rate
- κ: Cost of posting vacancy
- $F(h,x) = hx$: Match output
- S_t: Aggregate search effort
- Γ^x: Sampling distribution for match productivity

Details Equilibrium

Labor Service Firms

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Value of posting vacancy:

$$V_t = -\kappa + q(\theta_t)\frac{1}{S_t}\left[\int_{s,h,\beta}\int_{\widetilde{x}} J_t\left(h,\widetilde{x},\underline{x}/\widetilde{x}\right) d\Gamma^x(\widetilde{x})\, d\mu_t^U(s,h,\beta)\right.$$
$$\left. + \nu_t \int_{s,h,x,\alpha,\beta}\int_{x}^{\overline{x}} J_t\left(h,\widetilde{x},x/\widetilde{x}\right) d\Gamma^x(\widetilde{x})\, d\mu_t^E(s,h,x,\alpha,\beta)\right]$$

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Free-entry implies $V_t = 0$.

- p_t^l: Price of labor services
- r_t: Real interest rate
- κ: Cost of posting vacancy
- $F(h,x) = hx$: Match output
- S_t: Aggregate search effort
- Γ^x: Sampling distribution for match productivity

Details Equilibrium

Roadmap

Motivation

Simple TANK model with frictional labor market and OJS

HANK model with frictional labor market and OJS

Calibration of model, transitional dynamics, estimation of shocks

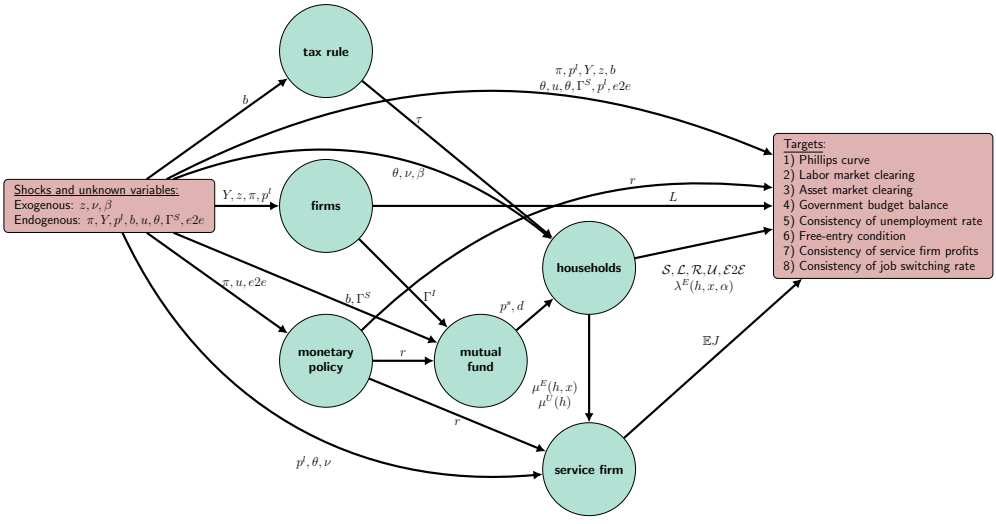
Quantitative results

Internally Calibrated Parameters

Parameter	Explanation	Value	Target	Data	Model
$\bar{\beta}$	Middle value of discount factor	0.939	Income-weighted average MPC	0.20	0.20
$\Delta\beta$	Gap between discount factor values	0.050	Average wealth/annual income	4.10	4.89
κ	Vacancy creation cost	0.636	Unemployment rate	0.051	0.049
δ	Job separation probability	0.102	EU rate	0.038	0.033
ν	Search efficiency of employed	0.097	EE rate	0.020	0.019
π^U	Skill depreciation probability	0.107	Earnings drop upon job loss	-0.35	-0.35
σ_x	Standard deviation of productivity	0.068	Wage growth of job switchers	0.09	0.10
ϕ^E	Maximum share of output as wages	0.822	Labor share	0.67	0.73
ϕ^U	UI replacement rate	0.406	UI replacement rate	0.40	0.46
ϕ^R	Retirement benefit amount	0.412	Retirement income/labor income	0.34	0.38

External parameters

Dynamics: DAG Representation



Solution: Sequence-space Jacobian method (Auclert et al., 2021) + worker distribution

Details | Estimation off agg. shocks | Estimated parameters | Variance decomposition

Roadmap

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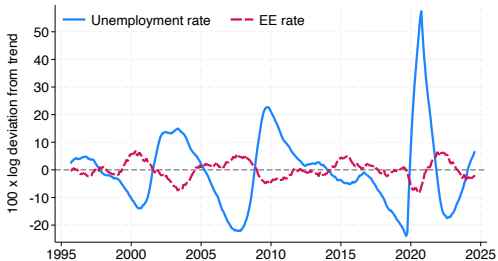
Quantitative results

Positive Analysis

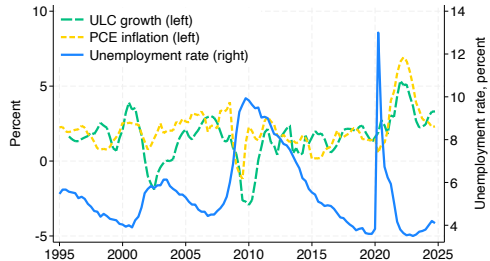
1. Post-Great Recession Case Study
2. COVID-19 Recovery Case Study

UR, EE and ULC dynamics: Post GR vs COVID-19

Cyclical components of unemployment and EE rates



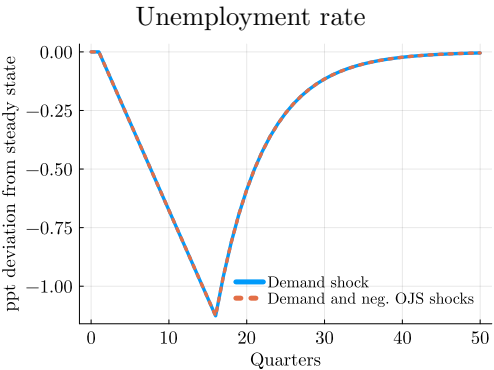
ULC, PCE inflation, unemployment rate



Differential EE and ULC dynamics despite same magnitude of UR recovery in 2016-19 vs 21-22.

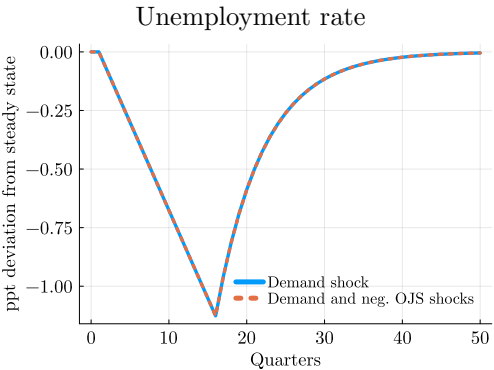
More

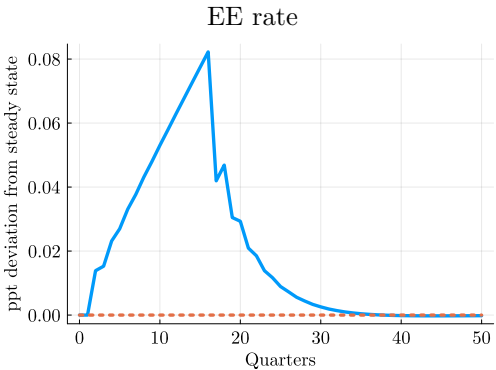
1. Model Simulation of Post-Great Recession



Common unemployment path,

1. Model Simulation of Post-Great Recession

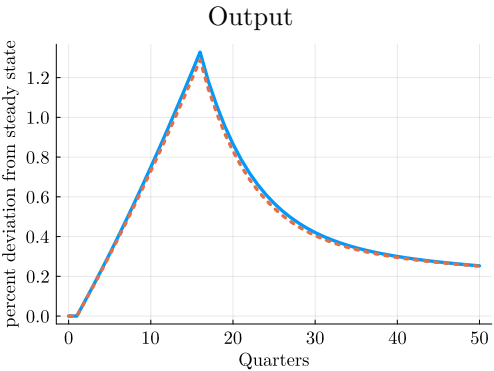




Common unemployment path, but different EE dynamics.

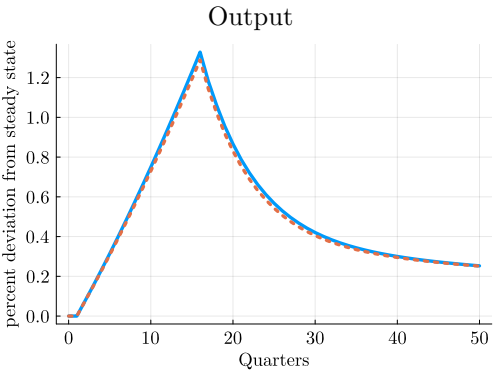
Details More Shocks

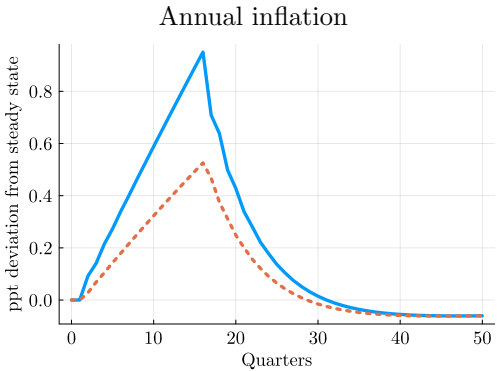
1. Model Simulation of Post-Great Recession



Identical unemployment and similar output dynamics,

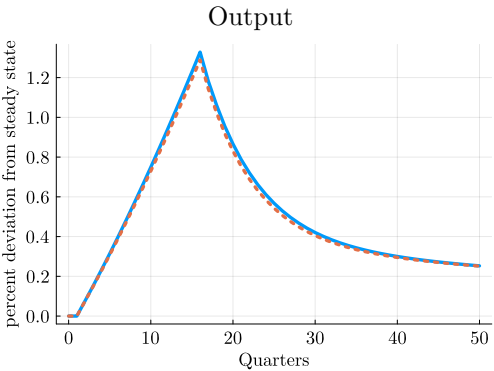
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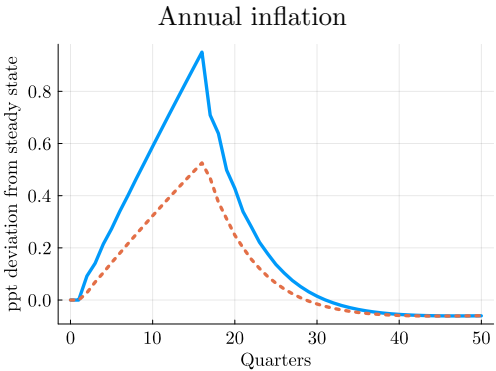




Identical unemployment and similar output dynamics, but muted inflation response.

1. Model Simulation of Post-Great Recession

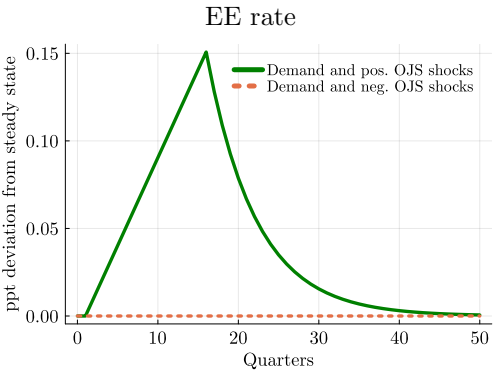


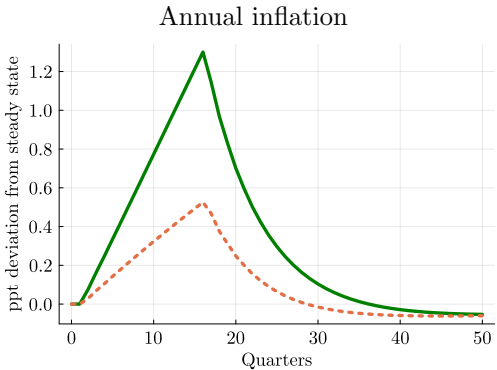


Identical unemployment and similar output dynamics, but muted inflation response.
Annual inflation rate 0.42pp lower due to lower EE.

x vs α More

2. Model Simulation of COVID-19 Recovery





Higher EE rate leads to larger inflation during recovery from COVID-19 recession.

Annual inflation rate 0.77pp higher due to Great Reallocation.

$\Rightarrow$ 15 percent of 5.5 ppts total rise in annual inflation was due to Great Reallocation.

Normative Analysis

Optimal Monetary Policy

Optimal Monetary Policy (MP)

Questions:

- How should monetary policy respond to the fluctuations in EE flows?
- Does accounting for EE flows as an additional proxy of slack matter for the conduct of MP?

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Implementation:

- Under a dual-mandate loss function Yellen (2012), Debortoli et al. (2019)

$$\mathcal{W} = \text{var}(\pi_t - \pi^*) + \Psi \text{var}(Y_t - Y^*),$$

evaluate loss function using a generalized Taylor rule for Φ_u, Φ_{EE} combinations:

$$i_t = i^* + \Phi_\pi (\pi_t - \pi^*) + \Phi_u (u_t - u^*) + \Phi_{EE} (EE_t - EE^*).$$

Optimal Monetary Policy (MP)

Taylor rule coefficients	Baseline	Optimal	Optimal (low MPC)
Inflation (π)	1.5	1.5	1.5
Unemployment rate (u)	-0.25	-0.125	-0.125
EE rate (EE)	0	1.125	0.625
Nominal interest rate i^*	2.13	2.22	2.11

- Optimal MP: Less aggressive response to u gap, but strong positive response to EE gap.
  - Despite similar u during 2016-19 and 2021-22, optimal MP raises i^* by more during 2021-22.

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  - Despite similar u during 2016-19 and 2021-22, optimal MP raises i^* by more during 2021-22.
  - 0.4 pp higher annual rate i^* under optimal MP when inflation peaked during 2022:Q2.
- Accounting for imperfect self-insurance also matters for optimal MP.
  - Optimal MP in RANK model with low MPC: Less strong positive response to EE gap. More
  - Lower elasticity of demand to real rate among high-MPC $\Rightarrow$ aggressive response in HANK.

Conclusion

- Develop a HANK model featuring a frictional labor market with on-the-job search.
- Analyze the macroeconomic implications of an EE shock.
  - Quantify effect of EE on inflation during post-GR and COVID-19 recoveries.
- Evaluate monetary policy under a dual-mandate objective function.
  - Solve for optimal unemployment and EE gap coefficients under job mobility dynamics.
- Show that accounting for imperfect self-insurance is quantitatively relevant.
  - RANK model generates different macro responses and optimal MP to changes in EE flows.
- **Future work**:
  - Estimate model with and without labor market shocks and evaluate its performance.
  - Fiscal and monetary policy interactions accounting for rich labor market dynamics.

EXTRA SLIDES

Related Literature

1. **Monetary policy transmission in HANK**:
   Kaplan, Moll, Violaten (2018), Auclert, Rognlie, Straub (2020), Auclert, Rognlie, Straub (2023)
   This paper: HANK with endogenous income process with job ladder and skill evolution.

2. **Computational methods**: Auclert, Bardoczy, Rognlie, and Straub (2021)
   This paper: Incorporate discretized worker distribution into SSJ method.

3. **HANK with labor search**:
   Ravn and Sterk (2016), Gornemann, Kuester, and Nakajima (2021)
   This paper: Incorporate job mobility dynamics.

4. **Effects of job mobility on inflation**:
   RANK: Moscarini and Postel-Vinay (2019), Faccini and Melosi (2022); *HANK*: Alves (2021)
   This paper: Rich labor market heterogeneity, decomposition, and optimal MP.

Timing: TANK

1. Aggregate and job destruction shocks realize.
2. Labor search: Service firms post vacancies, workers search, new matches are formed.
3. Production: Labor services, intermediate goods, and final goods are produced.
4. Monetary authority sets the nominal rate given unemployment rate and inflation.
5. Intermediate and service firms realize their profits, service firms pay wages.
6. Households pool income across their members and decide consumption.

Problem of PIH

Problem of PIH household is:

$$\max_{c_t^{PIH}} \sum_{t=0}^{\infty} \beta^t u(c_t^{PIH}) \quad \text{s.t.} \quad c_t^{PIH} + a_t = (1 + r_t)a_{t-1} + Z_t.$$

Intertemporal budget constraint (IBC) from t onward is

$$\sum_{s=0}^{\infty} q_{t+s} c_{t+s}^{PIH} = (1 + r_t)a_{t-1} + \sum_{s=0}^{\infty} q_{t+s} Z_{t+s}.$$

Euler equation to tie period 0 consumption to s-periods ahead consumption is

$$c_s^{PIH} = \beta^{s/\sigma} q_s^{-1/\sigma} c_0^{PIH}.$$

Plugging this to IBC yields consumption function for PIH households.

Model

TANK Model: Details

- LOMs are given as follows: Wages

$$
\begin{aligned}
u_t &= (1 - f(\theta_t))u_{t-1} + \delta(1 - f(\theta_t))(1 - u_{t-1}) \\
e_t(\alpha) &= f(\theta_t)u_{t-1} + (1 - \delta)(1 - \nu_t f(\theta_t))e_{t-1}(\alpha) + \delta f(\theta_t)(1 - u_{t-1}) \\
e_t(1) &= (1 - \delta)e_{t-1}(1) + (1 - \delta)\nu_t f(\theta_t)e_{t-1}(\alpha).
\end{aligned}
$$

- Aggregate per-period real profits of intermediate and service firms: Wages

$$\Gamma_t^I = \left(1 - p_t^l - \frac{\eta}{2\vartheta}\log(1 + \pi_t - \pi^*)^2\right)Y_t.$$

$$\Gamma_t^S = (1 - \alpha)p_t^l e_t(\alpha).$$

- Tightness is $\theta_t = v_t/S_t$, where S_t is aggregate measure of job searchers: Service firm

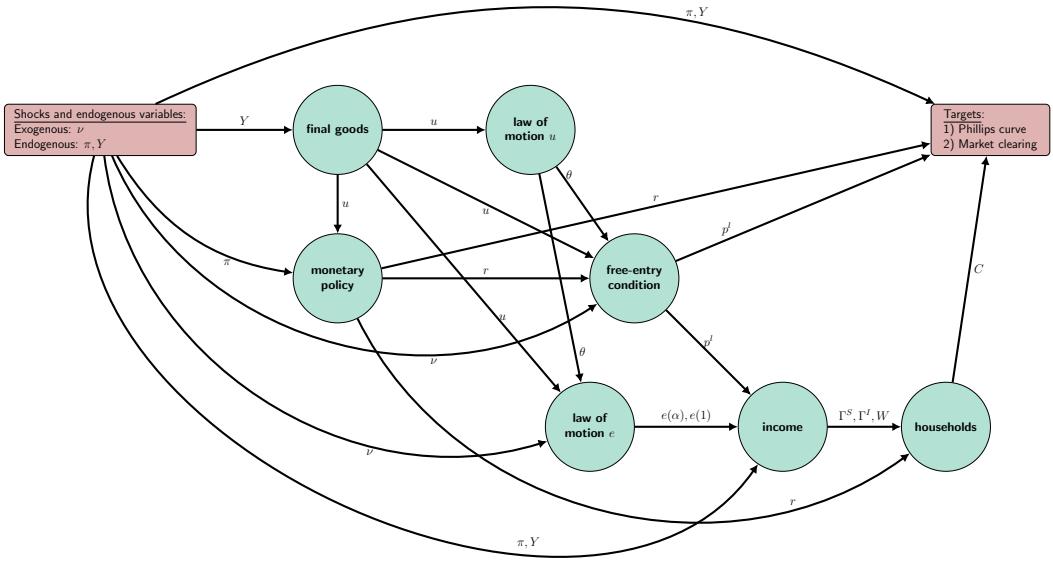
$$S_t = u_{t-1} + \delta(1 - u_{t-1}) + \nu_t(1 - \delta)(1 - u_{t-1}).$$

Equilibrium

1. Goods and labor market clearing requires $C_t = Y_t = 1 - u_t$.
2. Households consumption decisions are optimal.
3. Market tightness θ_t satisfies LOM for u: $u_t = (1 - f(\theta_t))u_{t-1} + \delta(1 - f(\theta_t))(1 - u_{t-1})$.
4. Employed masses $e_t(\alpha)$ and $e_t(1)$ evolve according to their LOMs.
5. The free-entry condition $V_t = 0$ yields real value of matched firm J_t.
6. Equation for J_t gives real price of labor services p_t^l.
7. Real interest rate r_t satisfies Fisher equation $1 + i_t = (1 + \pi_{t+1})(1 + r_{t+1})$.
8. Inflation π_t satisfies the NKPC.

Service firm

Directed Acyclic Graph Representation: TANK

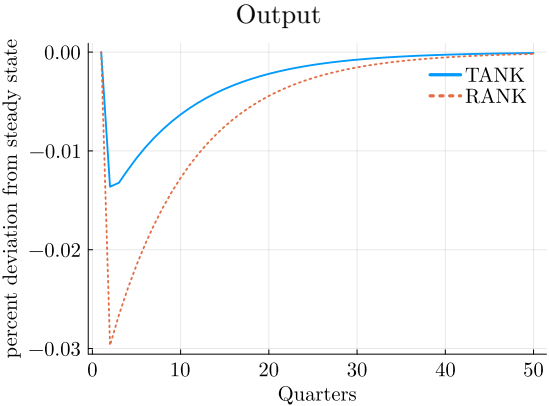


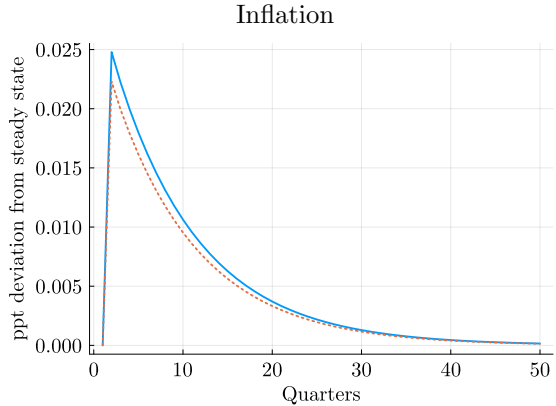
Solution of Model with Aggregate Shocks

Follow Auclert, Bardoczy, Rognlie, Straub (2021) to compute IRFs and model simulation.

1. Cast the model in sequence space for $t \in \{0, ..., T\}$ as a directed acylic graph (DAG).
   - + simple blocks only (no heterogeneous-agent (HA) block in this model)
2. For each block, compute partial Jacobians of each output with respect to each input.
   - ◦ Automatic differentiation for simple blocks.
3. Forward accumulate partials along topological sort of DAG to get total derivatives.
4. Use implicit function theorem to get the GE response of endogenous variables to shocks.
5. The GE Jacobian is sufficient to compute IRFs to aggregate shocks.
6. Simulate the model subject to aggregate shocks (IRF $\equiv$ MA).

Mechanisms: No wage increases upon external offers



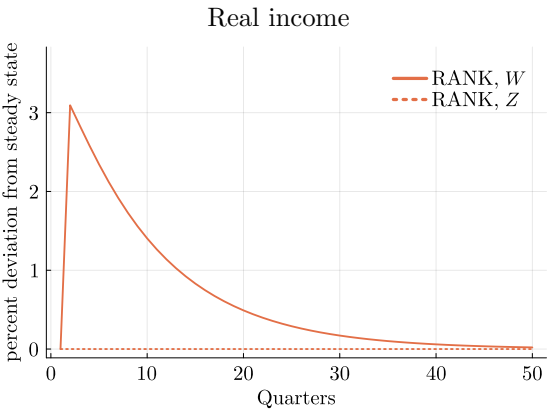


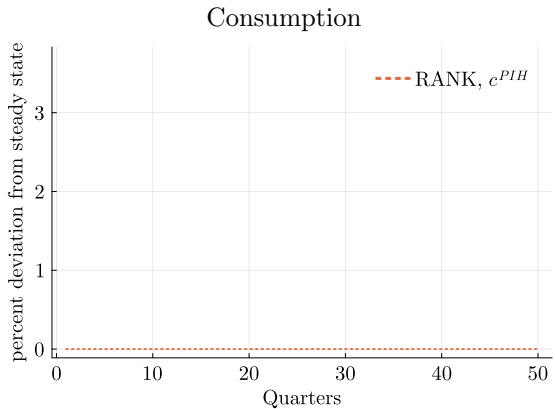
Shorter match duration channel is more important:

Intermediate firms still need to pay higher p^l to convince service firms to produce labor services under shorter expected match duration.

Results

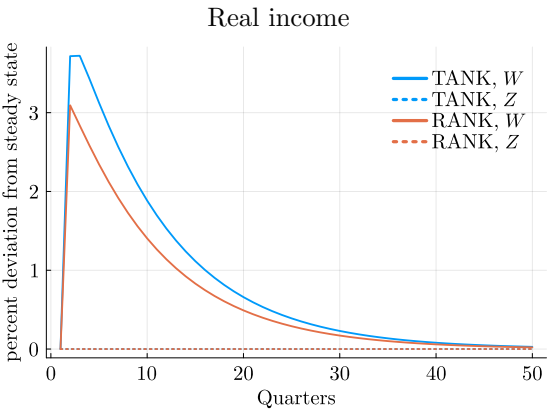
IRFs to OJS efficiency shock: Constant Real Rate

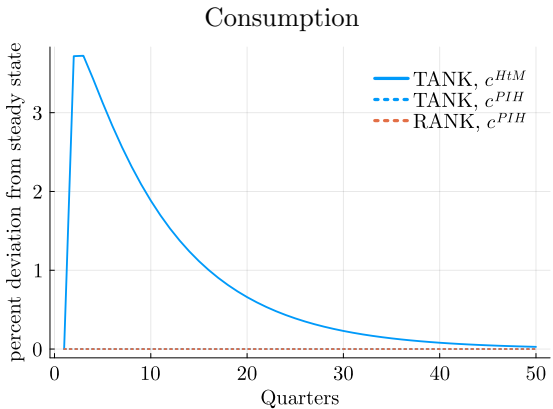




Results

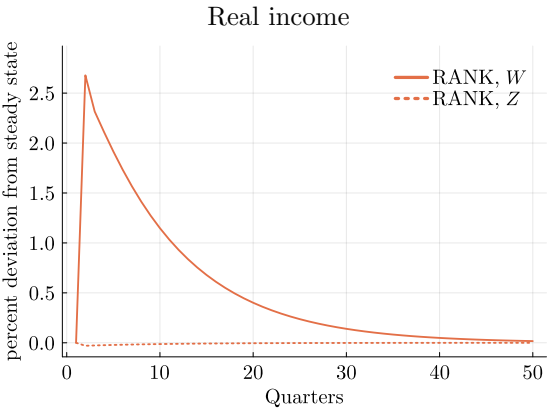
IRFs to OJS efficiency shock: Constant Real Rate

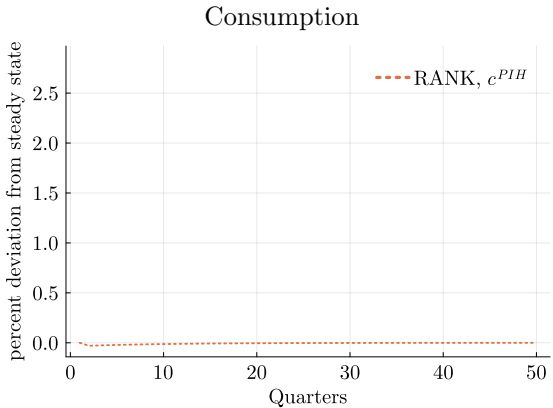




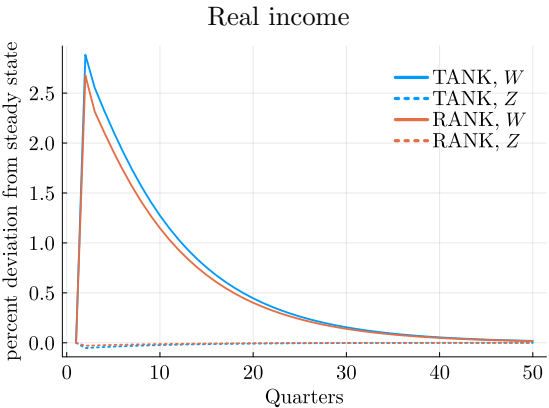
Results

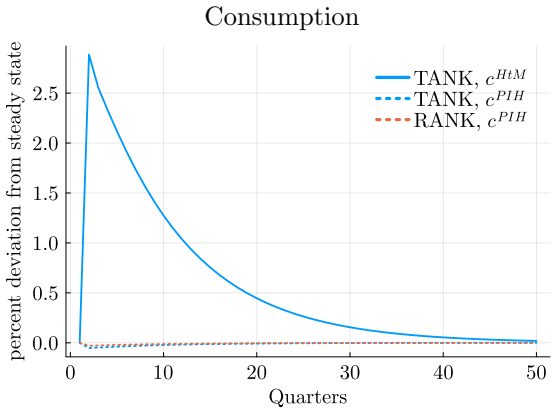
IRFs to OJS efficiency shock: Real Rate Response





IRFs to OJS efficiency shock: Real Rate Response





Results

Mutual Fund

- Owns intermediate and labor service firms, and all government bonds.
- Issues shares at price P^s and holds government bonds to earn a gross return of $1+i$.
- No-arbitrage implies returns on stock and bonds are equalized:

$$\frac{P^s_{t+1} + D_{t+1}}{P^s_t} = 1 + i_t.$$

- Cannot retain any funds. All balances are distributed to share owners as dividends:

$$D_t = B_{t-1} - \frac{B_t}{1+i_t} + P_t\Gamma^I_t + P_t\Gamma^S_t,$$

where Γ^I and Γ^S are per-period real profits of intermediate and service firms:

$$\Gamma^I_t = \left(1 - \frac{p^l_t}{z_t} - \frac{\eta}{2\vartheta}\log(1+\pi_t-\pi^*)^2\right) Y_t$$

$$\Gamma^S_t = \int \left(p^l_t F(h,x) - w(h,x,\alpha)\right) d\lambda^E_t(s,h,x,\alpha,\beta).$$

Monetary and Fiscal Authority

The central bank controls the short-term nominal interest rate following a Taylor rule:

$$i_t = i^* + \Phi_\pi \left(\pi_t - \pi^*\right) + \Phi_u \left(u_t - u^*\right).$$

The fiscal authority:

- Consumption tax τ_c, income tax (τ_t, Υ), UI, pensions ϕ^R, and exogenous spending G_t.

- Finances deficits by issuing nominal debt B_t.

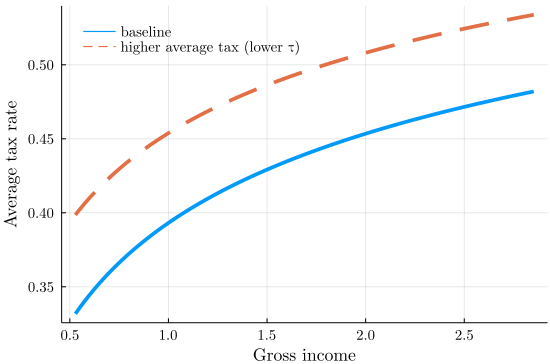
Government Budget Constraint

$$
\begin{aligned}
B_{t-1} + G_t + P_t \int UI(h) d\lambda_t^U(s,h,\beta) + P_t \int \phi^R d\lambda_t^R(s,\beta) = \frac{B_t}{1+i_t} + P_t \tau_c \int c(e,s,h,x,\alpha,\beta) d\lambda_t(e,s,h,x,\alpha,\beta) \\
+ P_t \int \left(UI(h) - \tau_t UI(h)^{1-\Upsilon} \right) d\lambda_t^U(s,h,\beta) \\
+ P_t \int \left(w(h,x,\alpha) - \tau_t w(h,x,\alpha)^{1-\Upsilon} \right) d\lambda_t^E(s,h,x,\alpha,\beta) \\
+ P_t \int \left(\phi^R - \tau_t (\phi^R)^{1-\Upsilon} \right) d\lambda_t^R(s,\beta),
\end{aligned}
$$

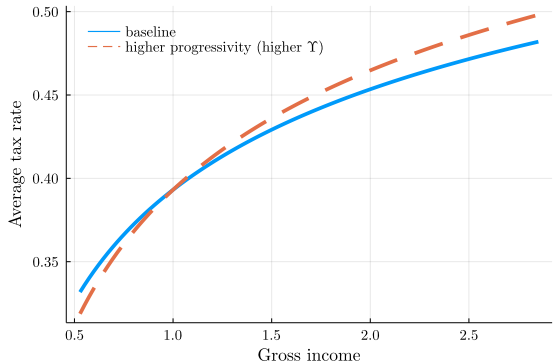
- Consumption tax τ_c and progressive income tax (τ_t, Υ).
- Unemployment benefit $UI(h)$, retirement pension ϕ^R, government expenditures G_t.
- Nominal debt B_t.
- $\lambda_t^X(.)$ worker distribution over relevant states.
- Nominal price level P_t.

Income Taxes

High average tax rate (low τ)



High progressivity (high Υ)



$$\text{Net income} = \tau\omega^{1-\Upsilon} \Rightarrow \text{average tax rate} = 1 - \tau\omega^{-\Upsilon}$$

Timing: HANK

1. Aggregate shocks are realized.
2. Government sets taxes, and idiosyncratic life cycle and job separation shocks are realized.
3. Worker skills evolve.
4. Labor search: Service firms post vacancies, workers search, new matches are formed.
5. Production: Labor services, intermediate goods, and final goods are produced.
6. Monetary authority sets the nominal rate given unemployment rate and inflation.
7. Intermediate and service firms realize their profits, service firms pay wages, mutual fund pays out dividends, government collects taxes, issues new bonds, pays out UI and retirement benefits, and spends G.
8. Individuals decide consumption and savings.
9. Households pool income across their members and decide consumption.

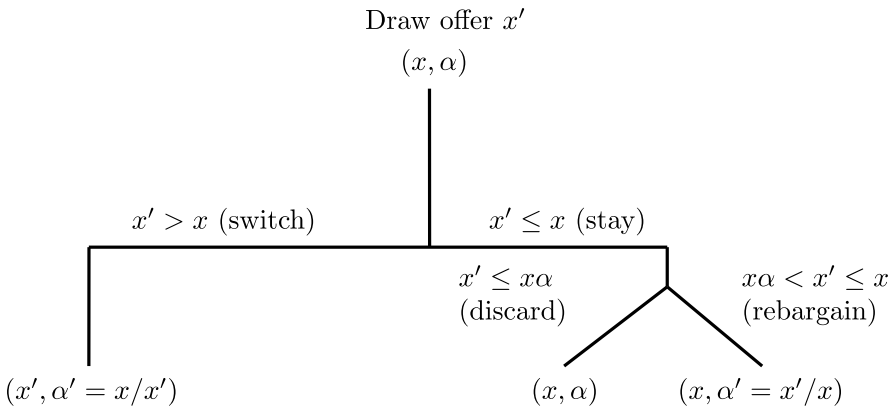
Individuals

- Discount factor: Permanent heterogeneity in discount factor β.
- Assets: Trade mutual fund shares s, at price P^s, which pays dividends D per share.
- Employment status: E, U, or R. Endogenous UE and EE, and exogenous EU transitions.
- Income: Wages (employed), UI (unemployed), pension (retired) and dividends from assets.
- General human capital h: Evolves stochastically depending on employment status.
- Match productivity x: Drawn from distribution upon contact and remains constant.
- Wages $w(h, x, \alpha)$ depend on skill h, match productivity x, and bargained piece rate α.

Employed

Wage Determination

- Wage is an endogenous piece rate α of output $F(h,x) = hx$: $w(h,x,\alpha) = \alpha\phi^E F(h,x)$.
  - $\phi^E \in (0,1)$: maximum share of output a worker can receive with full piece rate $\alpha = 1$.
  - α determined by Bertrand competition over flows.



Unemployed Worker

Value of unemployment:

$$V_t^U(s,h,\beta) = \max_{s' \geq 0,\ c} \ u(c) + \beta(1-\psi^R)\mathbb{E}_{h'|h}\left[\Omega_{t+1}^U(s',h',\beta)\right] + \beta\psi^R V_{t+1}^R(s',\beta)$$
$$\text{s.t.} \quad P_t c(1+\tau_c) + P_t^s s' = P_t \tau_t UI(h)^{1-\Upsilon} + (P_t^s + D_t)s$$

Value of job search:

$$\Omega_t^U(s,h,\beta) = f(\theta_t)\,\mathbb{E}_x V_t^E(s,h,x,\underline{x}/x,\beta) + (1-f(\theta_t))\,V_t^U(s,h,\beta)$$

- ψ^R: Probability of retirement
- $V_t^R(s)$: Value of retirement
- $UI(h)$: Unemployment benefits
- P_t: Price of final good
- P_t^s: Price of mutual fund shares
- D_t: Dividends

Employed

Retired Worker

Value of retirement:

$$V_t^R(s,\beta) = \max_{s' \geq 0,\ c} u(c) + \beta(1-\psi^D)V_{t+1}^R(s',\beta)$$
$$\text{s.t.} \quad P_t c(1+\tau_c) + P_t^s s' = P_t \tau_t (\phi^R)^{1-\Upsilon} + (P_t^s + D_t)s$$

Retired only face mortality risk.

- ψ^D: Probability of death
- ϕ^R: Retirement pensions
- P_t^s: Price of mutual fund shares
- D_t: Dividends

Service Firms

- Post vacancies v at cost κ to hire workers in a frictional labor market.
  - Labor market tightness $\theta = v/S$, where $S = \int d\mu^U(s,h,\beta) + \int \nu d\mu^E(s,h,x,\alpha,\beta)$.
  - CRS matching function $M(v,S)$ determines number of new worker-firm contacts.
  - Worker and firm contact rates, $f(\theta) = \frac{M(v,S)}{S}$ and $q(\theta) = \frac{M(v,S)}{v}$, pinned down by θ.
- Produce $F(h,x) = hx$ labor services using one unit of labor.
- Sell labor services to intermediate firms in a competitive market at nominal price P^l.

Service firm

Equilibrium

1. Nominal and real rates satisfy the Taylor rule and the Fisher equation.
2. Intermediate and labor services firm profits satisfy respective equations.
3. Share prices and dividends satisfy respective equations.
4. Bonds are such that GBC holds.
5. Individual consumption and savings decisions are optimal.
6. θ and p^l satisfy the free-entry condition and market-clearing condition for labor services.

$$Y_t/z_t = \int F(h,x)\, d\lambda_t^E(s,h,x,\alpha,\beta)$$

7. Inflation satisfies NKPC.
8. The shares market clears.

$$1 = \int g_t^{Us}(s,h,\beta) d\lambda_t^U(s,h,\beta) + \int g_t^{Es}(s,h,x,\alpha,\beta) d\lambda_t^E(s,h,x,\alpha,\beta) + \int g_t^{Rs}(s,\beta) d\lambda_t^R(s,\beta)$$

9. The worker distribution evolves according to the laws of motion.

Service firm

Externally Calibrated Parameters

Parameter	Explanation	Value	Reason
σ	Curvature in utility function	2	Standard
ψ^R	Retirement probability	0.00625	40 years of work stage
ψ^D	Death probability	0.0125	20 years of retirement stage
Δh	Skill appreciation/depreciation amount	0.275	Set
π^E	Skill appreciation probability	0.018	Wage growth for job stayers
ξ	Matching function elasticity	1.6	Set
ζ	Search efficiency of the unemployed	1	Normalization
η	Elasticity of substitution	6	20 percent markup
ϑ	Price adjustment cost parameter	0.021	Slope of Phillips curve, Gali and Gertler (1999)
x_G	Government spending/GDP ratio	0.19	Total net federal outlay/ GDP
x_B	Debt/GDP ratio	2.43	Total public debt/GDP
τ_c	Consumption tax rate	0.0302	Sales tax receipt/consumption exp.
Υ	Progressivity of income tax	0.151	Heathcote, Storesletten, Violante (2014)
ρ_τ	Responsiveness of income tax to debt level	0.10	Auclert, Rognlie, Straub (2020)
π^*	Steady-state inflation rate	0.00496	2% annual inflation rate
Φ_π	Responsiveness of interest rate to inflation	1.5	Taylor (1993) and Gali (2015)
Φ_u	Responsiveness of interest rate to unemployment	-0.25	Taylor (1993) and Gali (2015)

Solution of Model with Aggregate Shocks

Follow Auclert, Bardoczy, Rognlie, Straub (2021) to compute IRFs and model simulation.

1. Cast the model in sequence space for $t \in \{0, ..., T\}$ as a directed acylic graph (DAG).
   - + simple blocks
   - + heterogeneous-agent (HA) block
2. For each block, compute partial Jacobians of each output with respect to each input.
   - Automatic differentiation for simple blocks.
   - Numerical differentiation for HA block (fake-news algorithm).
3. Forward accumulate partials along topological sort of DAG to get total derivatives.
4. Use implicit function theorem to get the GE response of endogenous variables to shocks.
5. The GE Jacobian is sufficient to compute IRFs to aggregate shocks.
6. Simulate the model subject to aggregate shocks (IRF $\equiv$ MA).

DAG

Estimation of Shocks

- Estimate AR(1) processes for discount factor β, productivity z, OJS efficiency ν.
- Target std. dev. of Y, u, EE, and π as well as their corr. w/ Y, and autocorr. of Y.

	Data			Model		
	Std. dev	Autocorr.	Corr. w/ Y	Std. dev	Autocorr.	Corr. w/ Y
Y	0.017	0.926	1	0.008	0.942	1
u	0.130	0.942	-0.626	0.136	0.889	-0.675
EE	0.046	0.700	0.202	0.047	0.567	0.204
θ	0.268	0.923	0.661	0.080	0.317	0.535
π	0.304	0.749	0.328	0.351	0.777	0.331

DAG

Estimated parameters

Shock	ρ	σ
z	0.834	0.0027
ν	0.975	0.0009
β	0.912	0.0015

Std. dev. of OJS efficiency shocks are small but these shocks are persistent.

DAG

Variance Decomposition

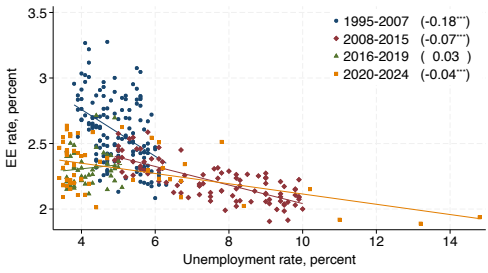
	Share of variance explained by		
	z	ν	β
Y	0.051	0.056	0.893
u	0.232	0.033	0.735
EE	0.162	0.463	0.375
θ	0.280	0.021	0.699
π	0.338	0.158	0.504

- 73.5 percent of unemployment fluctuations are due to discount factor shocks.
- OJS efficiency shocks account for
  - 46.3 percent of EE fluctuations
  - 15.8 percent of inflation fluctuations.

DAG

Missing $corr(u, EE)$ Post-Great Recession

Unemployment vs EE rate



Rolling correlation between unemployment and EE



Missing correlation is neither artifact of detrending nor picking a specific time window.

Back

Model Simulation of Post-Great Recession

Goal: Quantify magnitude of "missing inflation" due to weakening $corr(u, EE)$ in 2016–2019.

Consider two economies **starting from the same steady state**.

Economy 1: *Counterfactual economy* — EE moves with unemployment

- Shocks to discount factor to match decline in unemployment post-Great Recession

$$\beta_t = (1 - \rho_\beta)\beta^* + \rho_\beta \beta_{t-1} + \varepsilon_{\beta,t}.$$

Economy 2: *Post-Great Recession* — flat EE rate

- Shocks to discount factor to match decline in unemployment post-Great Recession

$$\beta_t = (1 - \rho_\beta)\beta^* + \rho_\beta \beta_{t-1} + \varepsilon_{\beta,t}.$$

- Shocks to OJS efficiency to match path of EE rate

$$\nu_t = (1 - \rho_\nu)\nu^* + \rho_\nu \nu_{t-1} + \varepsilon_{\nu,t}.$$

Great Recession experiment

Details on Model Simulation

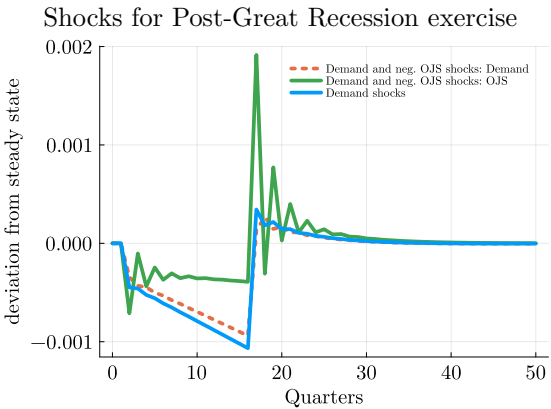
- Targets over transition horizon $t \in \{0, \ldots, T\}$:
  1. Path of unemployment rate during post-Great Recession:
     - 23% decline by $\overline{T} = 16$ quarters and revert back to steady state with

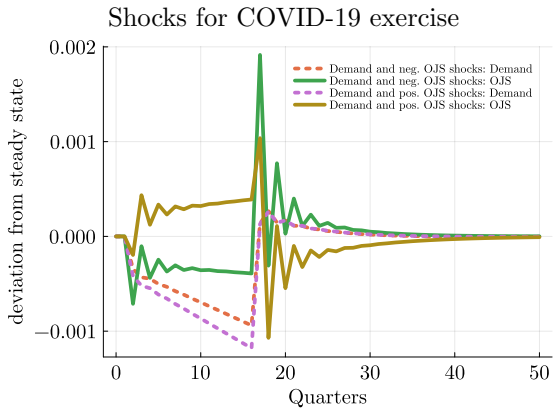
$$u_t = (1 - \rho_u)u^* + \rho_u u_{t-1}, \qquad \text{where } \rho_u = 0.85.$$

  2. Path of EE rate during post-Great Recession:
     - Remain at steady state level of EE rate despite declining unemployment rate.
- Two economies:
  1. Economy 1: positive demand shocks
     - Shocks modeled as innovations to discount factor β.
     - Assume at each $t = 0, \ldots, T$, shock $\varepsilon_\beta < 0$ hits economy.
  2. Economy 2: positive demand and negative OJS shocks
     - Shocks modeled as innovations to discount factor β and OJS efficiency ν.
     - Assume at each $t = 0, \ldots, T$, shocks $\varepsilon_\beta < 0$ and $\varepsilon_\nu < 0$ hit economy.

Great Recession experiment

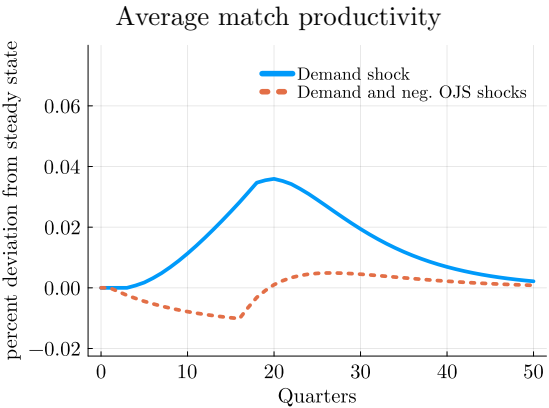
Estimated path of demand and OJS Efficiency Shocks

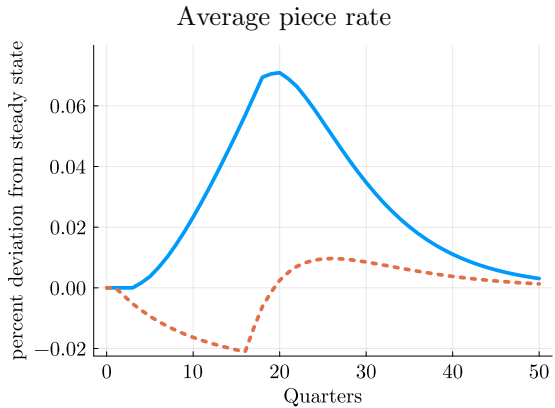




Great Recession experiment

Average Match Productivity and Piece Rate

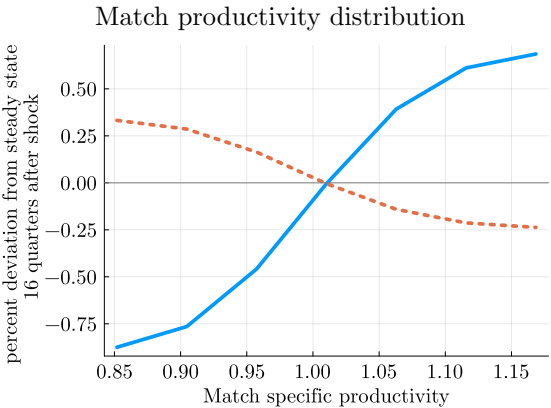


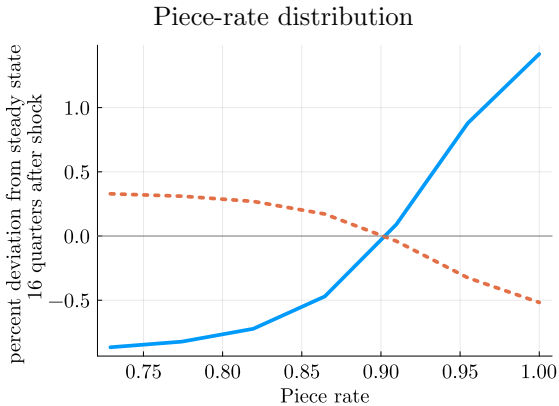


Negative OJS efficiency shocks limit the rise in average x and α.

Results

Distribution of Match Productivity and Piece Rate





Negative OJS efficiency shocks lead to leftward shifts in distributions of x and α.

Results

Details for Inflation Decomposition

1. Start from total Jacobians of a block of interest, e.g., H6 (free-entry condition).

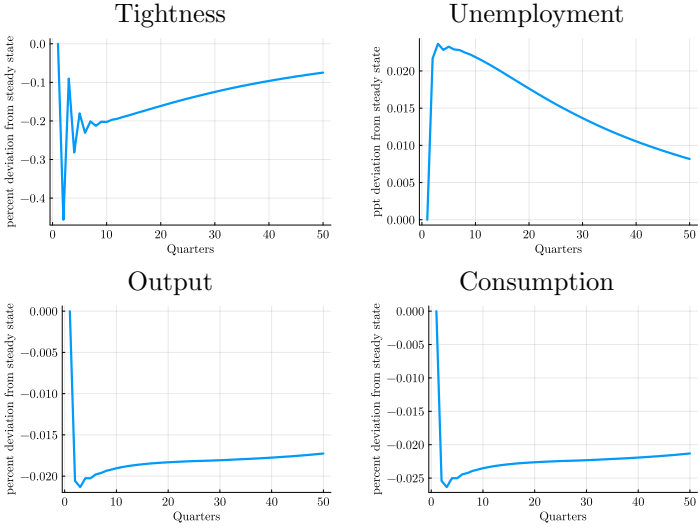
2. Apply IFT to H6 to get the derivative of p^l w.r.t. endogenous and exogenous variables.

3. Multiply the total derivative of p^l with GE IRFs of variables w.r.t ν.

4. This gives the response of p^l components ν, θ, π, u w.r.t ν (direct and indirect).

5. Can further decompose these components, e.g., θ using other related blocks, e.g., H2.

IRFs to OJS efficiency ν Shocks

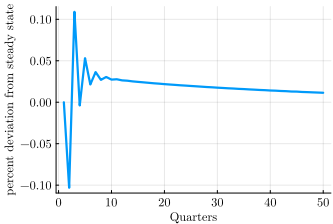


Impulse responses to a unit increase in ν.

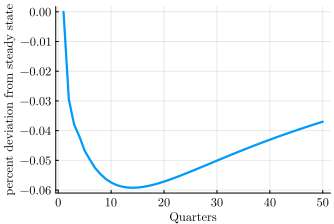
Decomposition

IRFs to OJS efficiency ν Shocks

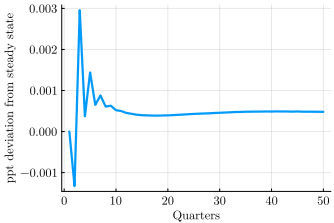
Price of labor services



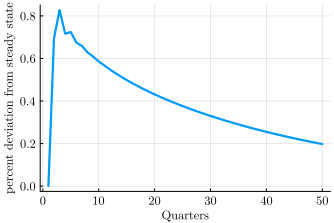
Total real profits



Real interest rate



EE rate



Impulse responses to a unit increase in ν.

Decomposition

Internally Calibrated Parameters: Low MPC Model

Parameter	Explanation	Value	Target	Data	Model
κ	Vacancy creation cost	0.701	Unemployment rate	0.051	0.048
δ	Job separation probability	0.111	EU rate	0.038	0.033
ν	Search efficiency of employed	0.110	EE rate	0.020	0.022
π^U	Skill depreciation probability	0.134	Earnings drop upon job loss	-0.35	-0.34
σ_x	Standard deviation of productivity	0.071	Wage growth of job switchers	0.09	0.10
ϕ^E	Maximum share of output as wages	0.795	Labor share	0.67	0.70
ϕ^U	UI replacement rate	0.383	UI replacement rate	0.40	0.45
ϕ^R	Retirement benefit amount	0.406	Retirement income/labor income	0.34	0.40

- Eliminate discount factor heterogeneity, i.e., $\bar{\beta}$ and $\Delta\beta$, and set a common β.
- Recalibrate other parameters to match same moments except those targeted by $\bar{\beta}$ and $\Delta\beta$.
- This model generates average quarterly MPC value of 2 percent instead of 20 percent.

Results