How to study Macroeconomy: DSGE and ABM

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Today's Talk

- Disclaimer
  - I have worked with the dynamic stochastic general equilibrium (DSGE) model
  - I am studying what the agent based model (ABM) is

- Given that, I would like to talk about
  1. Introduce traditional (little) & Recent tools to study macroeconomy – DSGE & (f)VAR model $+ \alpha$
  2. What I hope that ABM could do (that is, what DSGE model cannot do) & could do more than traditionally thought

Main Conclusions

- Boring but easily to be missed: Each model has each own role
  - Even within the class of DSGE model, the large scale model is not always better than the smaller one. Note that it is not only about the cost-benefit problem
- Pros and Cons of DSGE model: Comes from the fixed point problem
  - Pros: Consistency, Resolve the Lucas' critique and give us really good lens to see the world
  - Cons: Rigidity. *Bad* for adding ingredients of the world
    – Bad means: Not only bad performance, but also bad for its goal

DSGE model

- Dynamic
  1. Simply: Solving today & tomorrow's problem
  2. For example, consume & save today, consume tomorrow
  3. Jargon: Forward looking & Rational expectations. For instance, what would you do with the government transfer if you expect that you have to pay it as taxes in the future?
- Stochastic
  1. Related to the dynamic: There would be shocks in the future
  2. Monetary policy shock, fiscal policy shock, productivity shock and etc
- General Equilibrium
  1. Market clearing: Demand $=$ Supply as prices changed
  2. It is about theory, not about belief. Most prevalent misunderstanding even within economists
  3. So what? Example: Consume more as you have the government transfer $\rightarrow$ Prices $\uparrow$ $\rightarrow$ Consume less later

Before we go to the model

About preoccupation for DSGE model

1. DSGE is not good as it solves linearly
   - In today's talk, there is only one model to be solved linearly
   - To be rigorous, even though each agent's problem has been solved non-linearly, distributional dynamics wrt macro shocks have been approximated linearly
   - Note: Linearization works well in the normal time

2. DSGE solves the representative agent model
   - At least today's talk, there is only one RANK model to say about the forecasting
   - More crucial one: Would it always good to have more heterogeneity (or more agents)? Even for forecasting, hard to agree

$\rightarrow$ What the ABM could do is/should be MORE! The main thing is, even with quite rich heterogeneous agent DSGE model due to the improvement computational techniques & sources, still there are things that DSGE model hard to study.

Simple Example: Aiyagari (1994)

Given r, the agent with asset a and labor productivity x solves the following problem optimally:

$$v(a,x) = \max_{\{c,a'\}} \left\{ u(c) + \beta \int v(a',x')dF(x'|x) \right\} \tag{1}$$

subject to

$$c + a' = (1+r)a + wx$$

1st order Markov process: $\rightarrow \log x' = \rho_x \log x + \sigma\varepsilon, \varepsilon \sim \mathbb{N}(0,1)$

Production function: $Y = F(K,L)$
where $K = \int ad\mu(a,x)$

Market clearing conditions
- $r + \delta = F_K(K,L)$ & $Y = C + I$

Stationary equilibrium: Today's μ and tomorrow's μ are the same $\rightarrow K' = K$

So What?

- Can derive essential economic fundamentals

- Precautionary savings: If you would expect you could have bad shock & cannot borrow freely $\rightarrow$ Save letter than consume all

- Low wealth agent have higher marginal propensity to consume (MPC) & have higher future consumption growth

- What this model cannot do: Business-cycle dynamics
  - In the stationary equilibrium: $r_t = r$ for all t as the model does not consider the aggregate shock
  - Once we have aggregate shock, theoretically, we have to solve $v(a, x; \Theta, \mu)$ $\rightarrow$ Requires large dimensions

- What we need/want to do
  - Aggregate shock, like monetary/fiscal policy/TFP shocks
  - Frictions $\rightarrow$ New-Keynesian model
  - Then, we have solve the bellman equation really quickly

One way to improve computation: Continuous Time

Ben-Moll's website: Click Here

$$\rho v(a,x) = \max_c \left\{ u(c) + v_a(a,x)da + v_x(a,x)\mu(x) + \frac{\sigma^2(x)}{2} v_{xx} v(a,x) \right\} \tag{2}$$

subject to

$$da = wx + ra - c$$
$$dx = \mu(x)dt + \sigma^2(x)dW$$

Why it fast? The policy function $c*(a,x) = v_a(a,x)$ directly! Due to $\Delta \to 0$, we need to consider only today's problem

So what? Based on the next slide, we can now study Heterogeneous Agent New Keynesian (HANK) model!

Computational Performance

	Continuous Time (Finite Difference Method)	Discrete Time (Golden Section Method)
# of Grids	Speed(sec)	Speed(sec)
100	0.23	6.94
1000	0.35	67.60
10000	1.89	739.14

Table: Computational Time for Consumption-Saving Choice Problem (Two-State Productivity): Continuous Time vs. Discrete Time. My own computation

Note 1. Continuous time model is relatively more sensitive to the interest rate

Note 2. Discrete time model can be much faster once we use endogenous grid method (EGM). With the EGM, the gap becomes smaller

With HA model, what could you do?

- If the government levies higher taxes for rich households but lower taxes for poor households (like me), how the inequality & efficiency change?
- If the government increases the government spending, how much the GDP increase/decrease?
  - Further: Fiscal multiplier wrt 16/12 categories of gov't spending
  - Spoiler: Seems not quite beneficial. In the next few slides
- Distributional effects of monetary policy

HA exercise: Progressive Taxation

Value function with the progressive taxation:

$$v(a,x) = \max_{\{c,n,a'\}} \left\{ u(c,n) + \beta \int v(a',x') dF(x'|x) \right\} \tag{3}$$

subject to

$$(1+\tau_c)c + a' = \lambda((1-\tau_k)ra + wxn)^{1-\tau} + a$$

Simply speaking, as $\tau \uparrow \rightarrow$ rich households pay taxes more & poor households pay taxes less

Key Concepts in this Exercise

- If taxes are more progressive,
- Benefits
  - Inequality $\downarrow$
  - Poor households' additional consumption & utility from the fiscal policy large $\rightarrow$ Can improve social welfare
  - Social welfare: $\int u(c(a,x), n(a,x)) d\mu(a,x)$
- Costs
  - Efficiency $\downarrow$
  - Rich households save less $\rightarrow K \downarrow \rightarrow w \downarrow$ & $r \uparrow$
  - Work less $\rightarrow$ contribution to aggregate labor efficiency $\downarrow \rightarrow w \downarrow$ & $r \downarrow$

Transition: Optimal Progressive Income Tax

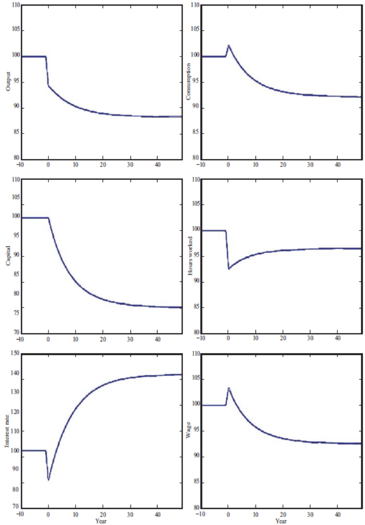


Figure: Transition to new steady state. $(\tau, \tau_k) = (0.14, 0.24) \rightarrow (\tau^*, \tau_k^*) = (0.24, 0.39)$. Reference: Chang, Kim and Chang (2015)

Empirical Findings of 16 Categories of Gov't Spending

16대 분야별 정부지출 GDP 승수효과				
	일반정부		중앙정부	
	당기 승수	3년 누적 승수	당기 승수	3년 누적 승수
1. 일반공공행정	1.56	2.02	-0.1	-0.76
2. 국방	2.95	0.52	-0.02	-0.81
3. 공공질서 및 안전	21.56	51.1	21.23	52.78
4. 경제업무	0.49	1.06	0.53	1.79
5. 환경보호	14.1	16.78	4.46	6.92
6. 주택 및 지역개발	-3.87	-58.53	0.55	0.87
7. 보건	-0.63	-4.44	13	5.85
8. 오락 문화 및 종교	6.58	21.3	-18.34	-28.94
9. 교육	13.5	15.83	3.37	5.09
10. 사회보호	-1.38	-1.91	0.77	-6.57
총지출	0.52	0.75	0.25	0.73

Not good news for ABM, too. Means, there is no ground for targetting

Rigidity for Extending DSGE

- DSGE CAN study multi-sector model IF each sector is identified by specific parameter
- Ex: Multi-sector industry → DSGE Can & Have done!
- Sectoral gov't spending → No way to model each sector, as many of them would not be good to have production/utility function
  - In general, DSGE is better for analyzing taxes than gov't spending
- Financial sector: THERE EXIST DSGE models that incorporate financial markets
  - First, I am not quite familiar with macro-finance
  - Second, given that, my guess is that ABMs would be better to model the financial market with heterogeneous banks

Recent Literature on HANK model

Naming is only my own...

1. 1st Generation HANK model: Kaplan, Moll and Violante – Continuous Time + Dimension reduction

2. 2nd Generation: Estimating
   - Auclert, Bardóczy, Rognlie and Straub (2021): Sequence - Space Jacaboian (SSJ)
     – https://github.com/shade-econ/sequence-jacobian
   - Bayer, Born and Luetticke (Forthcoming): HANK + Smets and Wouters. Could be the next generation of DSGE model for forecasting used by the central bank
     – https://github.com/BASEforHANK

3. 2.5 Generation: Deep learning
   - Above models: Solve each agent's problem non-linearly & linear approximating wrt aggregate shock
   - Deep learning → Help reducing curse of dimension & solving the model globally wrt aggregate shock

Smets and Wouters: Large Scale RANK model

- RANK: Representative Agent New Keynesian model
- Smets and Wouters
  1. Almost all frictions & shocks
  2. Bayesian estimation
  3. Shock decomposition: Which shock matters for which macro variable?
  4. Forecasting
- (Quite rigorous) Consensus on Performance of DSGE model
  - Not good for forecasting: VAR $>>>$ DSGE
  - Exception: SW model $\rightarrow$ Used in the central bank

Model Description

Basic SW Forecasting

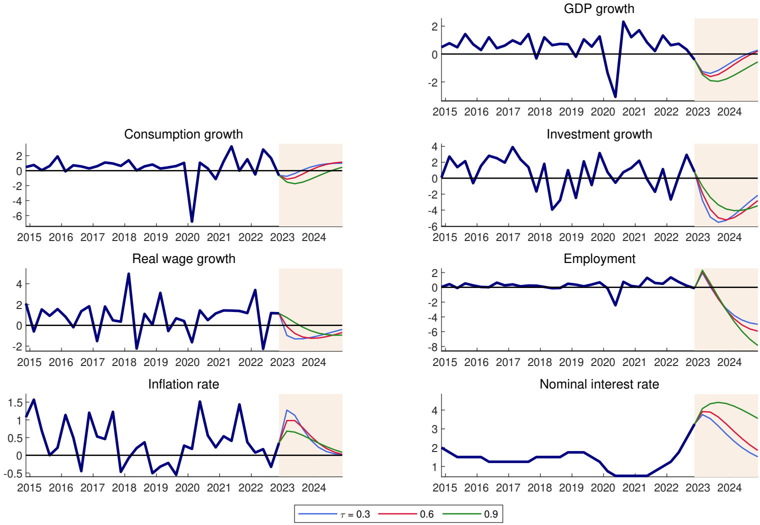


Figure: Unconditional Forecasting

About Shock

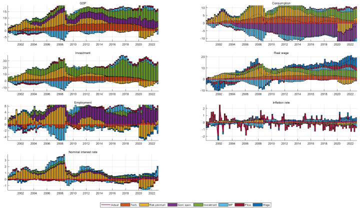


Figure: Shock Decomposition

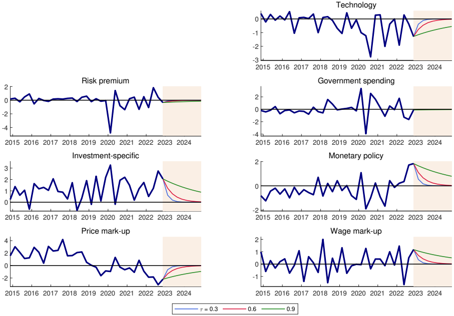
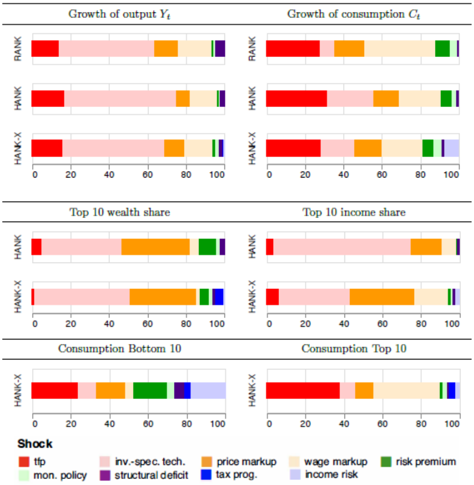


Figure: Forecasted Shock

HANK version of SW: BBL (Forthcoming)

Figure 1: Variance decompositions: Output growth, consumption growth, and inequality



Notes: Conditional variance decompositions at business cycle frequencies (6-32 quarter forecast horizon) for the estimated RANK, HANK, and HANK-X models.

Figure: Bayer, Born and Luetticke (Forthcoming)

Alternative way: VAR model

- VAR: Vector Auto-Regressive model

$$A_0 X_t = k_t + \sum_{p=1}^{P} A_p X_{t-p} + u_t \tag{4}$$

- Very efficiently represent the dynamic macro system
- Lineaized DSGE model $\rightarrow$ Could be matched with the VAR model
- Role
  - Complemtarities for DSGE model: Empirical evidence – Impulse Response Function
  - Forecasting: In practice, most popular one.

Functional VAR (fVAR) model: IRFs

Simply speaking, now X has cross-sectional information, which would be results of Sieve estimation or FPCA(what we use)

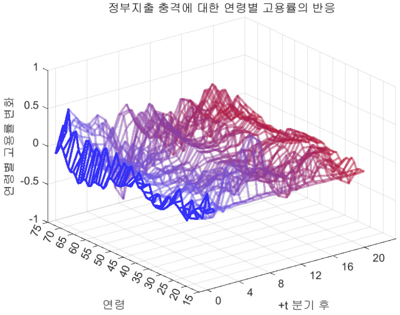


Figure: Distributional IRFs

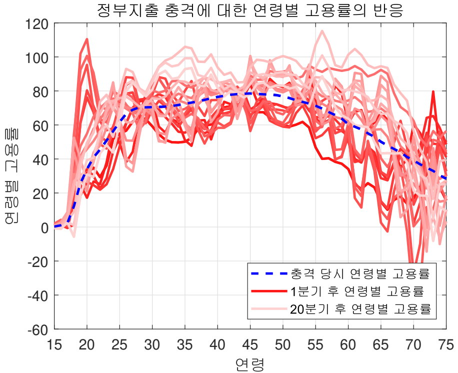


Figure: Deviation from SS

Functional VAR (fVAR) model: Forecasting

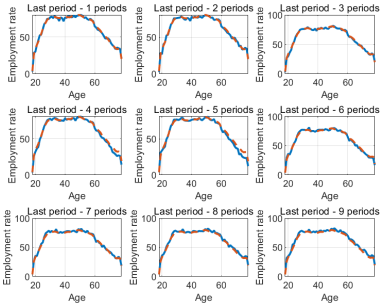


Figure: Distributional Performance

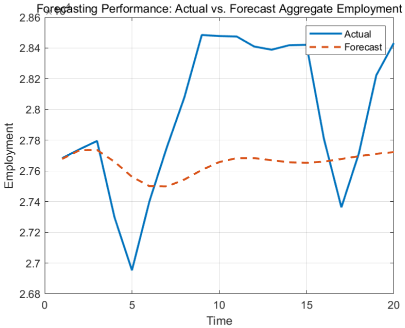


Figure: Aggregate Employment

Conclusion

- I introduce various ways to analyze macro-economy
- Why we need ABM or DSGE? $\rightarrow$ Wanna simulate
  - Why simulate? $\rightarrow$ To better understand how people have behave & will behave
- As we have seen, it seems quite hard to add something for DSGE models. This means both benefits & costs
- ABMs what our dear colleagues have shown, seem to have great potential
  - Poledna's Austrian ABM: Very impressive as it mimics the national accounting
  - Hard (and not necessary based on its goal) for DSGE
- AND we have one of the best researcher who understand how model works

Appendix

Environment

- Households (HH)
  - Income: Labor income (Wages) & Interest income (Savings)
  - Choice: Choose consumption, labor, savings and physical capital to maximize HH life-time utility
  - Individual optimality: Marginal Benefit=Marginal Cost
- (Intermediate Goods) Firms
  - Choice: Set prices (Monopolistic competitor), labor and capital
  - vs. Real Business Cycle (RBC) model: Stickiness on prices

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Firm's problem: Map

- vs. Classical RBC model
    - Frictions on goods prices or wages
    - What we need(not sufficient condition): Imperfect competition $\rightarrow$ Each firm could have power to set price
    - What we need more: Frictions on price setting: Random timing for price adjustment(Calvo - Yun), Adjustment cost(Rotermberg) or Menu cost(Mankiw)
- with Classical RBC
    - Equilibrium or Market clearing

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Profit Maximization: Price setting

Calvo − Yun fashion: Each firm h can reset price with probability ξ_p. Given $\Omega_{t,t+k} = \beta \frac{\Lambda_{t,t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}}$: Household's stochastic discount factor, the firm h solves the following problem optimally:

$$\max_{p_t^o, S_t, p_t^*} \mathbb{E}_t \sum_{k=0}^{\infty} \xi_p^k \Omega_{t,t+k} \left\{ \begin{array}{l} \left[p_t(h) Ind_{t,k}^p - MC_t^{nom}(h)\right] \left[\frac{1}{n}\left(\frac{p_t(h)}{P_{H,t+k}} Ind_{t,k}^p\right)^{-\theta} (A_{H,t+k})\right] + \\ \left[S_t p_t(h)^* - MC_{t+k}^{nom}(h)\right] \left[\frac{1}{n}\left(\frac{S_t p_t(h)^*}{S_{t+k} P_{H,t+k}^*} Ind_{t,k}^p\right)^{-\theta} \left(A_{H,t+k}^*\right)\right] \end{array} \right\} \tag{5}$$

Assumption: Law of one price $\rightarrow S_t p_t^*(h) = p_t^o(h)$

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Fiscal & Monetary Authority

Fiscal authority: Government spending is financed by the lump-sum tax

$$G_t + T_t = 0$$

Monetary authority: Taylor rule

$$\frac{R_t}{R_t} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\bar{\pi}}\right)^{\rho_\pi} \left(\frac{y_t}{\bar{y}}\right)^{\rho_Y}\right] \varepsilon_t^R$$

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Equilibrium

Goods market clearing

$$Y_t(h) = A_t K_t^{\alpha} \left[Z_t L_t \right]^{1-\alpha} - \Phi Z_t =$$

$$\left[\begin{array}{c} \left[\gamma_c \left(\frac{P_{H,t}}{P_t} \right)^{-\epsilon} C_t + \gamma_x \left(\frac{P_{H,t}}{P_t^X} \right)^{-\epsilon} X_t + G_t \right] + \\ \frac{1-n}{n} \left[\gamma_c^* \left(\frac{P_{H,t}^*}{P_t^*} \right)^{-\epsilon} C_t^* + \gamma_x^* \left(\frac{P_{H,t}^*}{P_t^{X,*}} \right) \right] \end{array} \right]$$

Bonds markets clearing (Zero net supply):

$$\int_0^n B_{H,t}\left(j, s_{t+1}\right) dj = 0$$

$$\int_0^n B_{F,t}\left(j, s_{t+1}\right) dj + \int_n^1 B_{F,t}^*\left(j, s_{t+1}\right) dj = 0$$

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Equilibrium: Continued

Labour markets clearing

$$L_t = \int_0^n L_t(h)dh = \int_0^n \int_0^n l_t(h,j)dhdj$$
$$L_t^* = \int_0^n L_t^*(f)df = \int_0^n \int_0^n l_t^*(f,j^*)dfdj^*$$

Capital markets clearing

$$K_t = \int_0^n K_t(h)dh$$
$$K_t^* = \int_0^n K_t^*(f)df$$

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Labour Market

- Sticky wages
  - Seller's market power to set wages $\rightarrow$ Intermediate labour union
  - Friction on setting prices: Calvo fashion in this paper

- Labour union:
  Households supply homogeneous labour to an intermediate labour union, which differentiates the labour services from labour varieties of type l and set wages in a Calvo fashion, selling the labour varieties of type l to labour packers

$$\max_{W_t^{nom}(l)} \mathbb{E}_t \sum_{t=0}^{\infty} (\beta\xi_w)^k \frac{\Lambda_{t+k}}{\Lambda_t} \frac{P_t}{P_{t+k}} \left\{ W_{t+k}^{nom,ind} - W_{t+k}^{hh,nom} \right\} L_{t+k}(l)$$

where $1-\xi_w$: the union can reset the wage in the current period

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Labour Market (continued)

subject to

$$L_{t+k}(l) = \frac{1}{n}\left(\frac{W^{nom,ind}_{t+k}(l)}{W^{nom}_{t+k}}\right) L_{t+k}$$

$$W^{nom,ind}_{t+k}(l) = W^{nom}_{t}(l) Ind^{w}_{t,k}$$

$$W^{hh,nom}_{t+k} = \frac{P_{t+k}\left[\frac{(C_{t+k}-hC_{t+k-1})^{1-\sigma_c}}{1-\sigma_c}\right]\exp\left(\frac{-(1-\sigma_c)}{1+\sigma_l}L_{t+k}(l)^{1+\sigma_l}\right)(\sigma_c-1)L_{t+k}(l)^{\sigma_l}}{-\Lambda_{t+k}}$$

where $Ind^{w}_{t,k}$ denotes the rule for wage indexation, which is given by

$$Ind^{w}_{t,k} = \left\{\begin{matrix} 1 \text{ for } k=0 \\ \left(\Pi^{k}_{l=1}\gamma\pi^{\iota_w}_{t+l-1}\pi^{1-\iota_w}\right)\end{matrix}\right\}$$

where ι_w: a parameter governing the degree of this wage indexation

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Sticky Wages (ξ_w)

- Microfoundations
  - Staggered contract: Annual wage contract
  - Newly hired vs. Existing workers
  - Stayer vs. Switcher

- Estimates/Calibration
  - This paper: 0.766 (mean)
  - Smets and Wouters: 0.70 (mean)/0.73 (mode)
  - Other paper: 3−4 quarters on average

- Korean calibration/estimates
  - Claim: Limited due to the lack of business cycle frequency wage data
  - Park and Shin (2014): Give qualitative evidence but needs improvements on quantitative aspects

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