Structural/DSGE modeling

A useful tool for policy analysis

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HH Team Knowledge Share

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Disclaimer: The views expressed in this presentation are my own and do not necessarily reflect those of the Bank of England nor its comittees.

What are DSGE models?

- The term DSGE model stands for ***D**ynamic **S**tochastic **G**eneral **E**quilibrium* models.
- It encompasses a **wide range of macroeconomic models** that span from the standard neoclassical growth model as well as New-Keynesian monetary models with numerous real and nominal frictions.
- What do they have in common?
  * Decision rules of economic agents are derived from assumptions about their preferences, technology, information, and the prevailing fiscal/monetary regime.
  * These decision rules are obtained by **solving intertemporal optimization problems**.
  * Most modern models do not admit a closed-from solution so we have to resort to **numerical methods** to approximate a solution to this problem.
- Hence, the solution of this models requires some algebra and great coding skills! Fun stuff :)

Why are they essential for policy analysis?

- Equally important is the **estimation/calibration** of these models as it is the way to validate these models against the data!

- DSGE model solution and estimation techniques are the two pillars that form the basis for **understanding the behavior of aggregate variables** such as GDP, employment, inflation, and interest rates.

- That's why many central banks and policy institutions (e.g. IMF, European Commission, HM Treasury) have been developing and using DSGE models.

- In a nutshell, once solved and estimated, there are three key uses of these models:

  1. Construct and interpret the **baseline forecasts** (e.g. how COMPASS is used in MA's forecast team).
  2. Generate **alternative scenarios** and perform **counterfactual analysis**.
  3. Inform staff and policy-makers about the **channels of transmission of certain policies**.

What type of models can be useful for MRD's Household Team?

- **What does the team usually care about?**
  * Borrower's resilience & aggregate demand externality $\Longrightarrow$ UK households level of *indebtedness*
    - DSRs, LTVs, LTIs
    - Distinction between secured and unsecured debts
    - Owner occupiers vs. buy to let investors
  * Ability to smooth out exogenous shocks: *saving buffers*
  * Other *vulnerable households* (e.g. renters)
- All these aspects call for **models that focus on**:
  * the housing/mortgage market
  * include borrowing constraints $\rightarrow$ housing as collateral
  * go beyond the representative agent paradigm $\rightarrow$ Two-Agent (TA) || Heterogenous-Agents (HA)
  * focus on consumption-saving and portfolio choice decisions

What models do we already have in stock?

- Model A: a sophisticated version of a Two-Agent New Keynesian (TANK) model
    * Two types of households: borrowers (mortgagors) and savers (outright owners)
    * Two firms: final good producer (competitive) & intermediate good producer (price setter)
    * Two types of frictions:
        - Long term nominal mortgage debt subject to loan-to-value OR payment-to-income constraint
        - Nominal rigidities: staggered price setting a la Calvo
    * Monetary authority sets the interest rate following a Taylor rule

- Model B: a sophisticated version of a Heterogenous Agent (HA) model
    * Households differ in their age, income and wealth (liquid and illiquid)
    * Consumption-saving choice (cont.) + endogenous housing tenure choices (discrete)
    * Housing and BTL/rental markets are in equilibirum

Different models $\Leftrightarrow$ different questions

- What are the **main differences** between these two models?

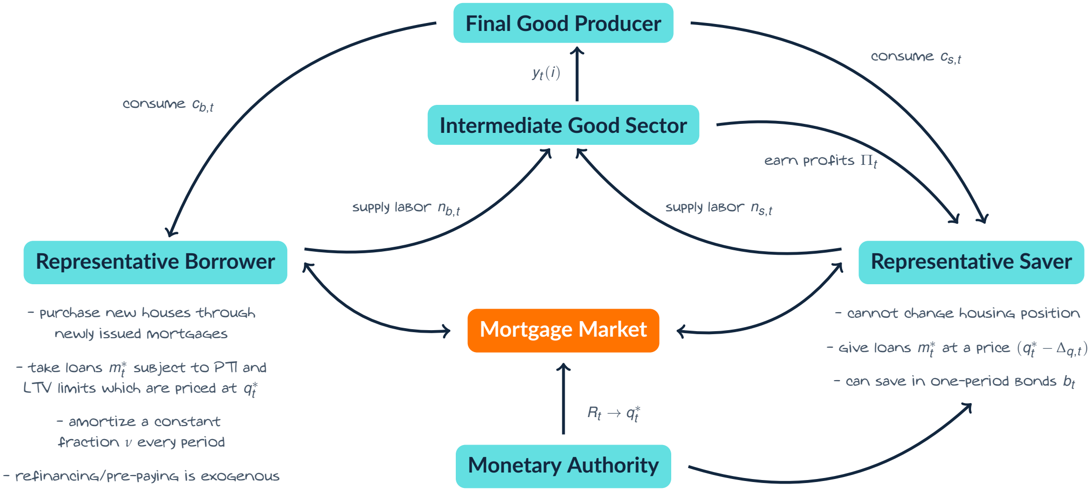
	Model A: Nominal	**Model B: Real**
Households		
Planning Horizon	∞	$J = 71$ years
Number of HHs	Two (borr. / saver)	$\approx 500,000 (= nA \times nY \times nh \times J)$
Housing Tenure	Outright or mortgagor	Renter, owner, landlord
Borrowing constraints	LTV & PTI (one of them always binds)	LTV & LTI (binds only for some)
Firms		
Housing good producer	No (endowment)	Yes
Final good producer	Yes (Input: int. goods)	Yes (Input: labor)
Intermediate good producer	Yes (Calvo pricing)	No
Aggregate uncertainty	Yes (TFP shocks)	No
Central Bank		
Taylor Rule	Yes (monetary & inflation target shocks)	No

- Given these model characteristics **what do you think we can use this models for**?

A TANK model of the mortgage market

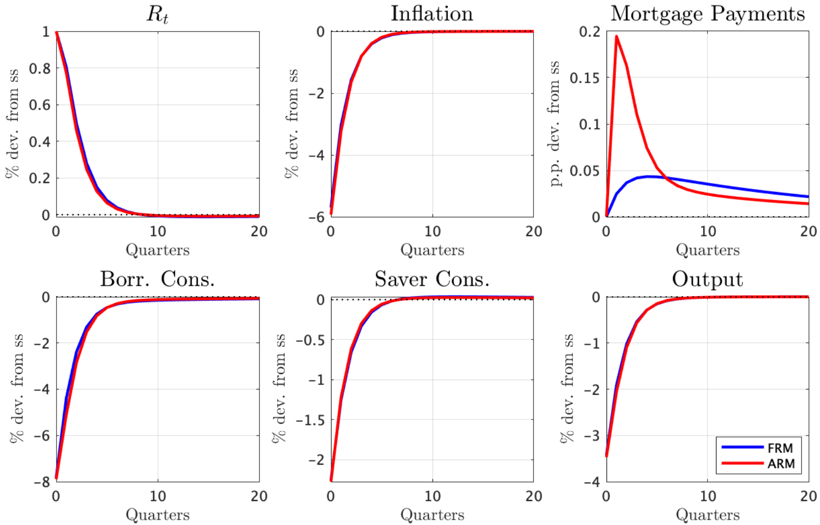
(Based on work with S. Millard & A. Varadi)

Model sketch

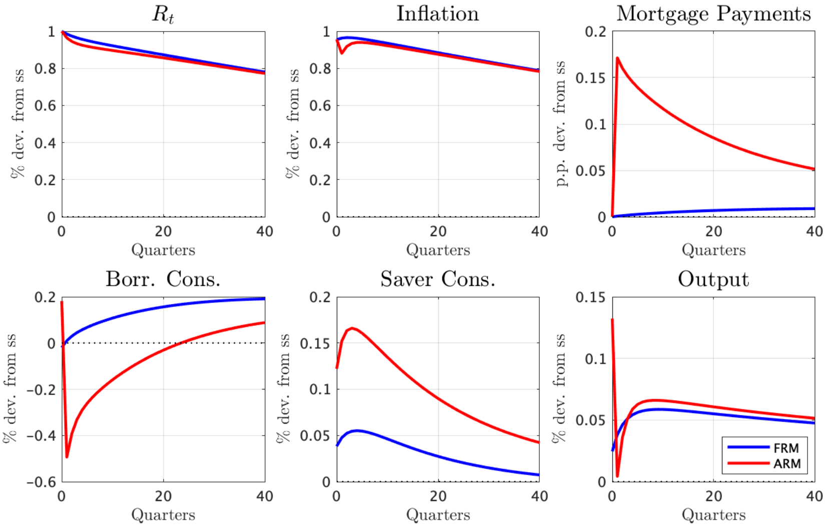


▷ Details

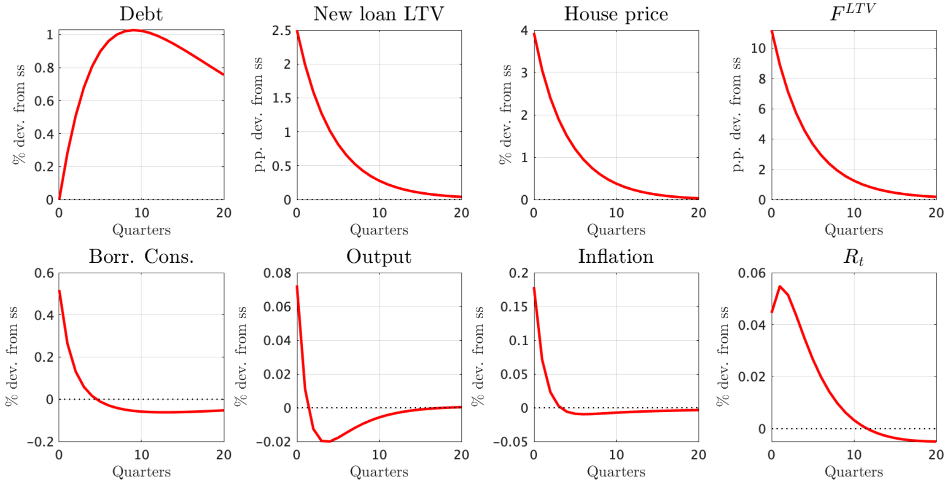
Transitory monetary policy shock



Persistent monetary policy shock



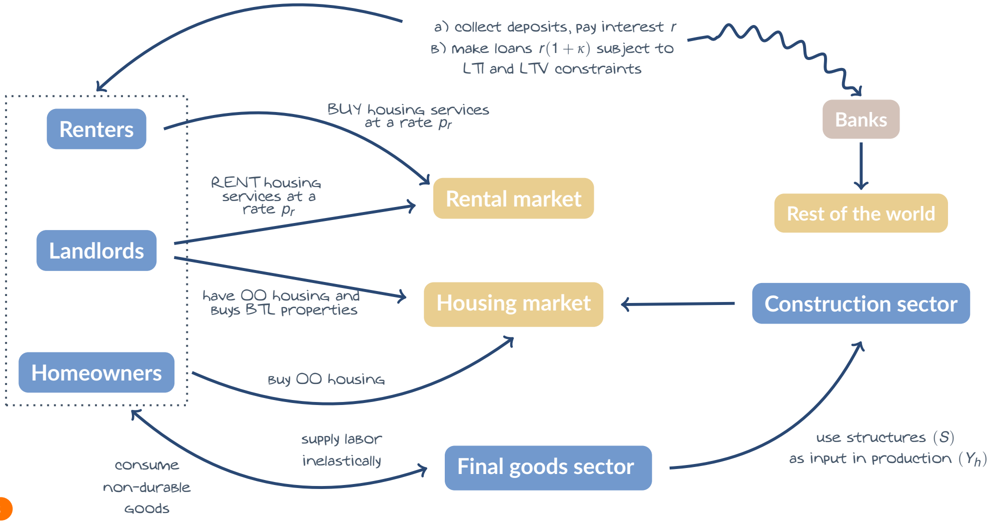
A credit shock that loosens the PTI limit



A HA model of the housing & rental markets

(Based on work with A. Hannon & G. Paz-Pardo)

Model sketch



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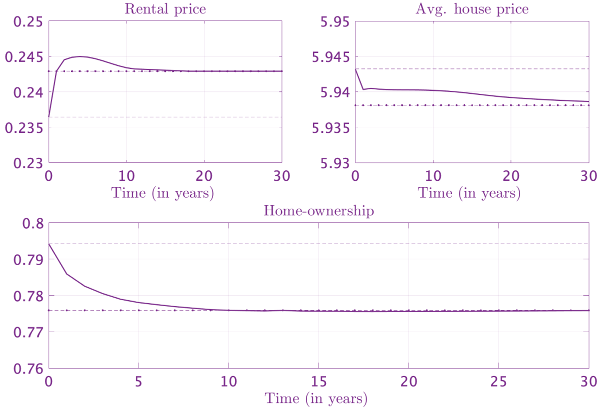
Unintended consequences of tightening credit



- As a result of tighter LTV/LTI limits, fewer HHs can get their desired home
- They are forced to downsize, postpone or cancel their home buying decisions

  $\Longrightarrow$ lower house prices

  $\Longrightarrow$ lower homeownership
- Increased rental demand by these constrained HHs needs to be met by a higher supply of rental units by landlords

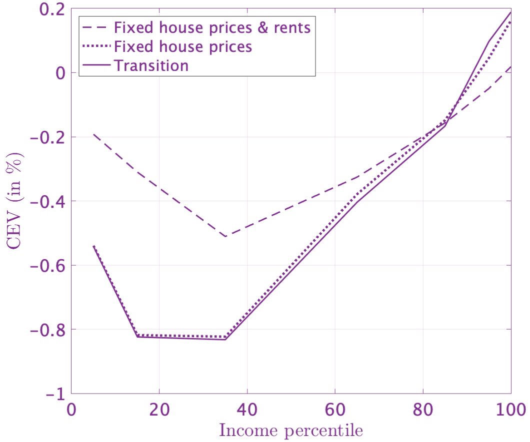
  $\Longrightarrow$ higher rental prices

Distributional implications (income distribution)

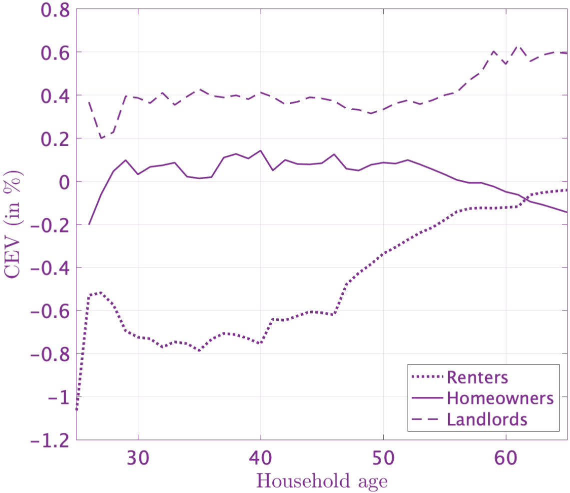
- **Tighter LTV & LTI** limits affects potential (constrained) homebuyers in the **middle** of the income distribution

- **Increase in rental prices** hurts those at the **bottom**: more likely to be renters, harder to save for downpayment

- Limited role for house prices



Distributional implications (age & housing tenure)



- **Renters are the biggest losers**: harder to access homeownership + they pay higher rental prices
- **Homeowners are indifferent**
- **Landlords benefit**: higher cash flows from their housing portfolio

Other Applications

An incomplete list of other potential applications

(i) Would these models have been useful to tackle previous policy questions?
(ii) How would you use these models going forward?

- **Examples using Model A**:
  * Simulate a housing boom scenario via changes in the preferences over housing consumption.
  * Aggregate impacts of different PTI / LTV calibrations via steady state comparisons (e.g. on consumption, house prices, GDP, inflation, etc.)
- **Examples using Model B**:
  * Simulation analysis allows me to compute average age at which the median household becomes a homeowner under alternative scenarios.
  * Aggregate (house price, rents, homeownerhip rate) and distributional implications associated to the end of the Stamp Duty Land Tax (SDLT) Covid holidays

Appendix

Model A's Details

Borrower's Problem

- Chooses *consumption* $c_{b,t}$, *labor* supply $n_{b,t}$, the size of newly purchased *houses* $h^*_{b,t}$, and the face value of newly issued *mortgages* m^*_t
- to maximize lifetime expected discounted utility using the aggregate utility function

$$u(c_{b,t}, h_{b,t-1}, n_{b,t}) = \log(c_{b,t}/\chi_b) + \xi \log(h_{b,t-1}/\chi_b) - \eta_b \frac{(n_{b,t}/\chi_b)^{1+\varphi}}{1+\varphi} \tag{1}$$

- subject to the **budget constraint**

$$\begin{aligned} c_{b,t} \leq & (1-\tau_y) w_t n_{b,t} - \pi_t^{-1} \left((1-\tau_y) x_{b,t-1} + \nu m_{t-1}\right) + \rho \left(m^*_t - (1-\nu)\pi_t^{-1} m_{t-1}\right) \\ & - \delta p^h_t h_{b,t-1} - \rho p^h_t \left(h^*_{b,t} - h_{b,t-1}\right) + T_{b,t} \end{aligned} \tag{2}$$

- the **debt constraint**

$$m^*_t \leq \bar{m}_t = \underbrace{\left(\theta^{PTI} w_t n_{t,i} e_{t,i}\right) / q^*_t}_{=\bar{m}^{PTI}_t} \int^{\bar{e}_t} e_i d\Gamma_e(e_i) + \underbrace{\theta^{LTV} p^h_t h^*_{i,t}}_{=\bar{m}^{LTV}_t} \left(1 - \Gamma_e(\bar{e}_t)\right) \tag{3}$$

- and **laws of motion** for total start-of-period debt balances m_{t-1}, total promised payments on existing debt $x_{t-1} \equiv q_{t-1} m_{t-1}$ and total start-of-period borrower housing $h_{b,t-1}$

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LOM: Housing, Mortgage Debt & Promised Payments

- Independently from the interest fixation period T, *housing* and *mortgage debt* evolve

$$h_{b,t} = \rho h^*_{b,t} + (1-\rho) h_{b,t-1} \tag{4}$$

$$m_t = \rho m^*_t + (1-\rho)(1-\nu)\pi_t^{-1} m_{t-1} \tag{5}$$

- FRM, ARM and HRM economies **only differ** in the evolution of *promised payments*

$$x^{ARM}_{b,t} = q^*_t m_t \tag{6}$$

$$x^{FRM}_{b,t} = \rho q^*_t m^*_t + (1-\rho)(1-\nu)\pi_t^{-1} x_{b,t-1} \tag{7}$$

$$\begin{aligned} x^{HRM}_{b,t} = & \sum_{\tau=0}^{T-1} \left[\rho \left((1-\rho)\,(1-\nu) \right)^{\tau} \left(\prod_{i=0}^{\tau-1} \pi^{-1}_{t-i} \right) q^*_{t-\tau} m^*_{t-\tau} \right] \\ & + \left((1-\rho)\,(1-\nu) \right)^{T} \left(\prod_{i=0}^{T-1} \pi^{-1}_{t-i} \right) q^*_{t-T} m_{t-T} \end{aligned} \tag{8}$$

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Saver's Problem

- Chooses *consumption* $c_{s,t}$, *labor* supply $n_{s,t}$, one period bonds b_t, and the face value of newly issued *mortgages* m_t^*
- to maximize lifetime expected discounted utility using the aggregate utility function

$$u(c_{s,t}, n_{s,t}) = \log(c_{s,t}/\chi_s) + \xi \log(\tilde{H}_{s,t-1}/\chi_s) - \eta_s \frac{(n_{s,t}/\chi_s)^{1+\varphi}}{1+\varphi} \tag{9}$$

- subject to the **budget constraint**

$$\begin{aligned} c_{s,t} \leq (1-\tau_y)\, w_t n_{s,t} + \pi_t^{-1} x_{s,t-1} - \rho \left(m_t^* - (1-\nu)\pi_t^{-1} m_{t-1} \right) \\ - \delta p_t^h \tilde{H}_s - \left(R_t^{-1} b_t - \pi_t^{-1} b_{t-1} \right) + \Pi_t + T_{s,t} \end{aligned} \tag{10}$$

- and **laws of motion** for total start-of-period debt balances m_{t-1}, and total promised payments on existing debts, which again differ across the three economies
- In addition, there is a proportional tax on all future mortgage payments $\Delta_{q,t}$ that follows a stochastic process (term premium shock = innovation of this process)

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The rest of the economy – NK block

- **Production**
  - A competitive *final good producer*: $\max_{y_t(i)} P_t \left[\int_0^1 y_t(i)^{\frac{\lambda-1}{\lambda}} di\right]^{\frac{\lambda}{\lambda-1}} - \int_0^1 P_t(i) y_t(i) di$
  - A continuum of *intermediate good producers* that choose price $P_t(i)$ and operates a linear technology $y_t(i) = a_t n_t(i)$ to meet the final's good producer demand.
  - Intermediate good producers are subject to *price stickiness* – Calvo pricing with indexation.
- **Monetary authority**: it follows a *Taylor rule* of the form

$$\begin{aligned} \log R_t = & \log \bar{\pi}_t + \phi_r \left(\log R_{t-1} - \log \bar{\pi}_{t-1}\right) \\ & + (1-\phi_r)\left[\left(\log R_{ss} - \log \pi_{ss}\right) + \psi_\pi \left(\log \pi_t - \log \bar{\pi}_t\right)\right] + \log \eta_t \end{aligned} \tag{11}$$

where $\log \eta_t$ is a temporary monetary policy shock and $\bar{\pi}_t$ is a time-varying inflation target that follows an AR(1) in logs (innovation = infl. target shock)

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Model B's Details

Production

- **Final Good Producer**
  * Linear technology: $Y_c = A_c N$, where A_c is a parameter and N is labor
  * Profit maximization: wage $= A_c$
- **Housing Good Producer**
  * Cobb-Douglas technology: $Y_h = A_h \bar{L}^{\alpha_L} S^{1-\alpha_L}$ where $\{A_h, \alpha_L\}$ are parameters, $\bar{L}$ land permits and S structures
  * Profit maximization: $Y_h = A_h^{1/\alpha_L} \left((1-\alpha_L) \, p_h \right)^{(1-\alpha_L)/\alpha_L} \bar{L}$ (housing investment function)
  * *Housing stock* is composed by *houses of different qualities*: $H = \sum_i^N \tilde{h}_i H_i^{sh}$ where $\tilde{h}_i$ denotes quality and H_i^{sh} is its share in the aggregate stock
    - Final transaction price depends on type: $p(\tilde{h}_i)$
    - Conversion between types is costly for the firm
    - Households will need to buy and sell to adjust their stock

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Household's problem

$$V(a,\underbrace{\{h,\tilde{h}\}}_{=s},y,j) = \max_{c,a',s'}\left\{\frac{(c\,f(\tilde{h}))^{1-\gamma}}{1-\gamma} + \sigma_\varepsilon \varepsilon(s) + \beta \mathbb{E} V(a',s',y',j+1)\right\} \tag{12}$$

s.t.

$$\begin{aligned} c + a' + p(\tilde{h}')h' + \mathbb{1}_{sell}\tau^h p(\tilde{h})h + \mathbb{1}_{buy}\tau^h p(\tilde{h}')h' + \delta^h p(\tilde{h})h \leq \\ y + (1 + r(1 + \mathbb{1}_{a'<0}\kappa))\,a + p(\tilde{h})h + p_r(h-1) \end{aligned} \tag{13}$$

$$a' \geq \begin{cases} \max\{-\lambda_{LTV}\, p(\tilde{h}')\, h', -\lambda_{LTI}\, y\} & \text{if } h' > h \\ a(1 + r(1+\kappa) - m(j)) & \text{if } h > 0 \text{ and } a < 0 \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

$$\varepsilon(s) \sim F, \text{ extreme value type I dtb} \tag{15}$$

$$m(j) = \frac{r(1+\kappa)(1+r(1+\kappa))^{J-j}}{(1+r(1+\kappa))^{J-j}-1} \tag{16}$$

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Market clearing & equilibrium

- r is fixed $\rightarrow$ small open economy
- **Housing market**
  - houses bought = houses produced + houses sold - depreciation
- **Rental market**
  - Competitive: renters meet landlords
  - p_r is determined using household's equilibrium distribution, $\mathcal{D}(a, s, y, j)$

$$\underbrace{\sum_{j=1}^{J} \int \int \mathcal{D}(a, s_1, y, j) da\, dy}_{\text{renters}} = \underbrace{\sum_{j=1}^{J} \int \int \mathcal{D}(a, s_4, y, j) da\, dy}_{\text{landlords w/ 1 btl property}} + 2 \underbrace{\sum_{j=1}^{J} \int \int \mathcal{D}(a, s_5, y, j) da\, dy}_{\text{landlords w/ 2 btl properties}}$$

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