Heterogeneous Agents at NB

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On the Future of Macroeconomic Models (Blanchard 2018)

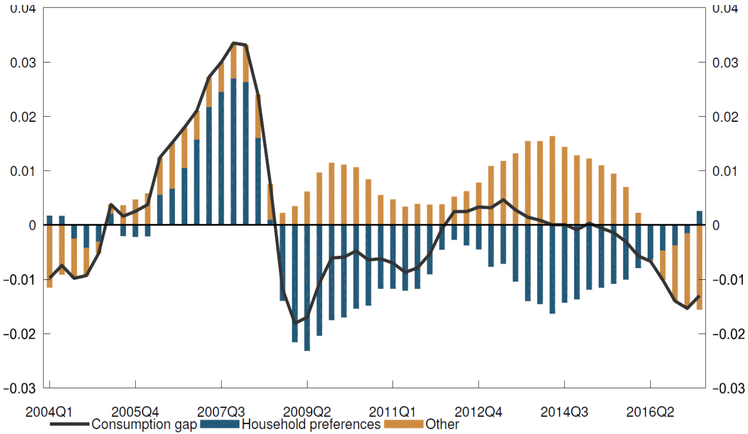
DSGE models should build on the large amount of work on consumer behaviour going on in the various fields of economics, from behavioural economics, to big data empirical work, to macro partial equilibrium estimation. This work is on-going and should indeed proceed on its own, without worrying about DSGE integration.

- We agree with Blanchard in most parts, but with a slight more attention on the (eventual) DSGE integration.

Problems with "Standard Households"

- Representative household
  - Shift in the financial markets
  - Household level policy analysis
  - Only saving motive intertemporal substitution
- Completely rational
- Restricts us in the questions we can ask
  - e.g., how does demographic change affect a result of a policy?

Consumption Decomposition

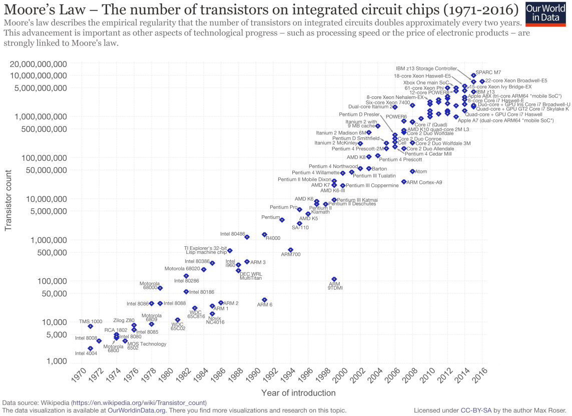


Sources: Statistics Norway and Norges Bank

Heterogeneity

- Heterogeneous household
  - Shift in the financial markets
  - Household level policy analysis
  - Different motives of savings
    - Precautionary/self-insurance
    - Lifecycle
    - Downpayment
- Question of rationality is no longer dichotomous
- Comes closer to the internal "mental model"

Heterogeneity: Why Now?



- and methodological improvements. Not impossible anymore!

Application of HANK in Literature

- (McKay-Nakamura-Steinsson 2016) Households with borrowing constraints do not weight future as strongly
  - reduced forward guidance puzzle (of monetary policy)
- (Kaplan-Moll-Violante 2017) Using liquid-illiquid asset structure matches the marginal propensity to consume (MPC) better
  - different transmission mechanism of monetary policy

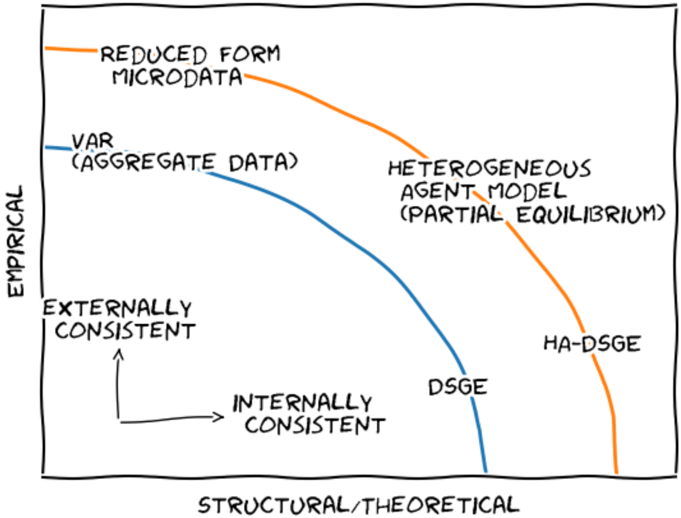
Heterogeneous Agents at Norges Bank

- Still work in progress
- Focus on using micro-data (for macroeconomic analysis)
  - Are we leaving some *motives* out with our model of households?
- Norway is at a very unique position as we have a lot of micro-data.

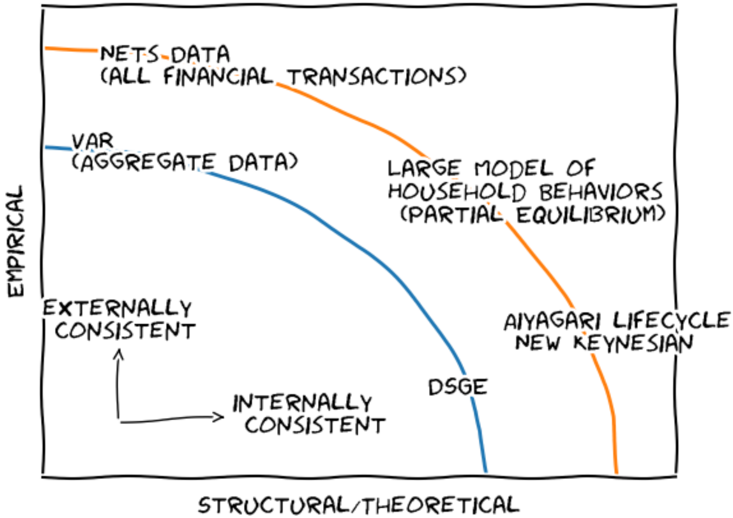
Micro Data in Norway

- Heterogeneous agent models need good quality micro data to
  - test hypothesis to choose the “best” model
- We have register data for Norwegian households from 1993-, covering a wide range of variables
  - Income, government taxes and transfers
  - Balance sheet variables
  - Demographics
  - Labor market transitions
  - Housing transactions
- (Currently being processed): Consumption
  - Collected data on near all electronic payments (Nets)
  - Will be merged with the other data sources

MODEL POSSIBILITY FRONTIER



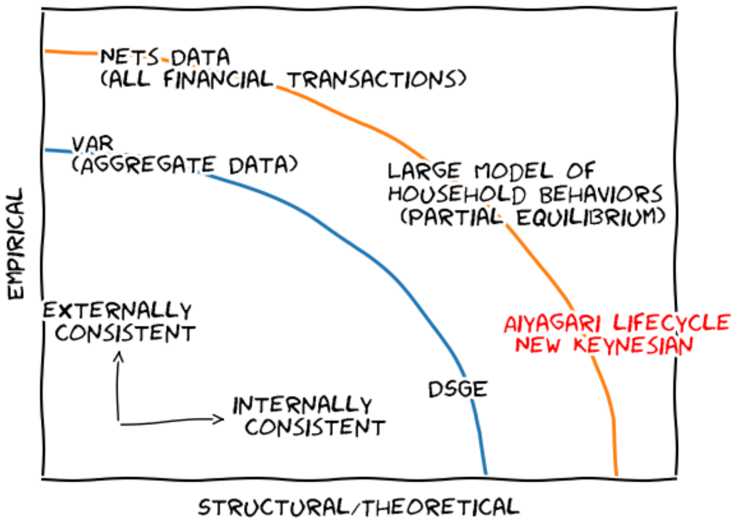
MODEL POSSIBILITY FRONTIER



Heterogeneity at Norges Bank

- Still work in progress
- Build things out one step at a time to see how they interact with each other.
  - General equilibrium models are built with small extensions from the established models (in literature)
  - Partial equilibrium models are built from data.

MODEL POSSIBILITY FRONTIER



Lifecycle Model

- To our surprise, there isn't really a "quantitative" general equilibrium model with life cycle
  - Most people use the Gertler model (two agents: workers, retirees), e.g., (Ho 2019)
- Q: how much of of life cycle patterns do you capture with a simple life cycle model?

What we do?

Build a parsimonious life-cycle heterogeneous agent New-Keynesian model that matches ....

1. Monetary policy responses across age.
2. Earnings, consumption, and wealth across age.

... and use this model to analyze how demographic transitions affect aggregate monetary policy transmission.

Our Findings

1. Simple model matches the consumption responses to monetary policy in Wong (2018)
   - the life cycle pattern in wealth determines how the monetary policy affects households

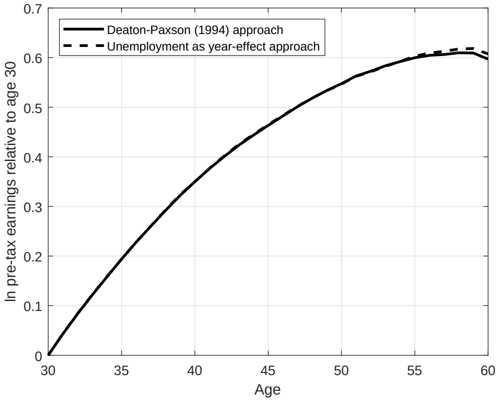
2. Demographic transitions... (in progress)

Annual consumption elasticities to monetary policy shocks by age (US)

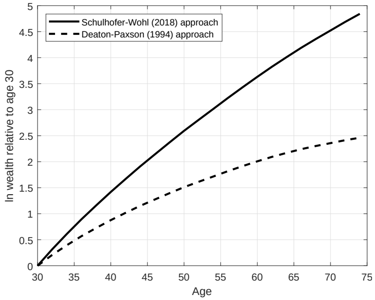
	Young 25-34		**Middle** 35-64		**Old** 65 +
CEX data					
Total	4.59 [2.01, 7.17]		0.79 [-1.44, 3.02]		-1.15 [-4.8, 2.5]
Non-durables	2.24 [0.67, 3.82]		0.47 [-0.7, 1.65]		0.12 [-1.83, 2.07]
			Age groups		
	25-34	35-44	45-54	55-64	65+
Nielsen data					
Non-durables (food)	0.79 [0.28, 1.31]	0.50 [0.21, 0.78]	0.60 [0.36, 0.83]	0.38 [0.14, 0.63]	0.03 [-0.23, 0.28]

Notes: This table is a reprint of Table 2 in Wong (2018). It presents annual consumption elasticities by age in response to a 1 standard deviation expansionary monetary policy shock using CEX or Nielsen home-scanner data. The brackets depict 80 percent confidence intervals.

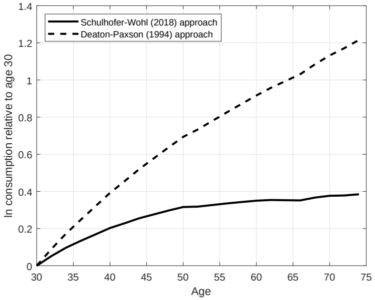
Earnings across age (NOR)



Wealth and consumption across age (NOR)



(a) Wealth



(b) Consumption

Model

Four blocks:

1. Households: life-cycle + income risk.
2. New-Keynesian production side
3. Government
4. Central bank with Taylor rule

Households

- Life-cycle, income risk, bequest motive

$$\max_{\{c_t, l_t\}_{t=0}^{T}} \quad \mathbb{E}_0 \left\{ \int_0^T e^{-\rho t} u(c_t, l_t) dt + e^{-\rho T} \mathbb{B}(x_T) \right\}$$

subject to

$$\begin{aligned} dx_t &= \left(r_t x_t + (1-\tau) w_t z_t q_a l_t + \Gamma_{at} - c_t\right) dt \\ dz_t &= \mu(z_t) dt + \sigma(z_t) dW_t \\ da &= dt \\ x_t &\geq \underline{x} \\ T &\sim \text{stochastic} \end{aligned}$$

c = consumption, l = hours, x = wealth, τ = labor tax,
z = productivity, q = age component of income, Γ = Transfers

Calibration

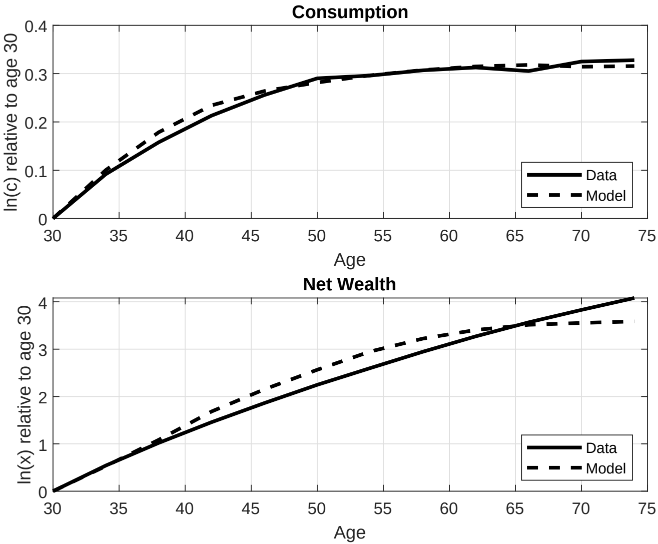
Fixed parameters

	Value	Description	Source
Preferences			
γ	2	risk aversion, inverse EIS	
ϕ_0	2.2	shifter on labor supply	time spent on labor during a day = 0.5
ϕ_1	1	Frisch elasticity	
r	0.02	real interest rate	
$\underline{x}$	0	borrowing constraint	
Income			
μ	0.91	annual autocorrelation	Heathcote et al. (2010)
σ	0.14	standard deviation	Heathcote et al. (2010)
Production			
α	0.33	production curvature	
ϵ	10	elasticity of substitution in $y_{j,t}$	Profit share of 11 %
θ	100	cost of price adjustment	Slope of Phillips curve, $\epsilon/\psi = 0.1$
Monetary policy			
ϕ_π	1.25	Taylor coefficient on inflation	Kaplan et al. (2018)
ϕ_y	0	Taylor coefficient on output	Kaplan et al. (2018)

Parameters used to match data

	Value	Description	
ρ	0.025	discount rate	match wealth/consumption ratio = 4.4
ψ_0	12.2	bequest shifter	
ψ_1	0.00	bequest luxuriness	
ψ_2	0.85	bequest curvature	
τ	0.59	linear tax on labor income	
χ_1	0.21	replacement rate of pensions	

Age patterns of consumption and wealth



Aggregate responses to a MP shock

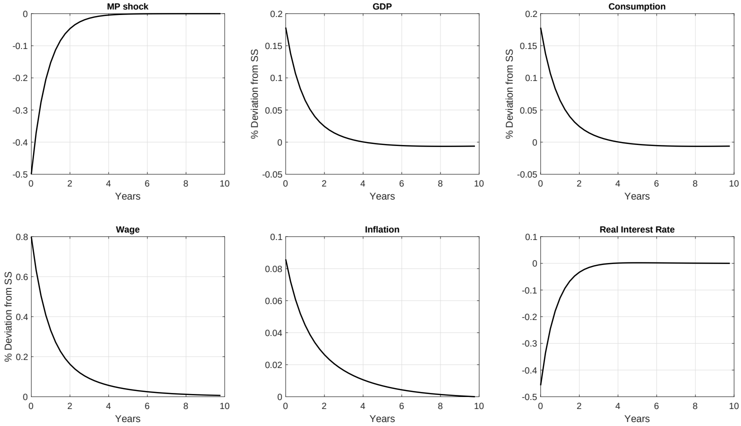


Figure: Aggregate responses to an expansionary 0.5 pp monetary policy shock.

Responses to a MP shock by age groups

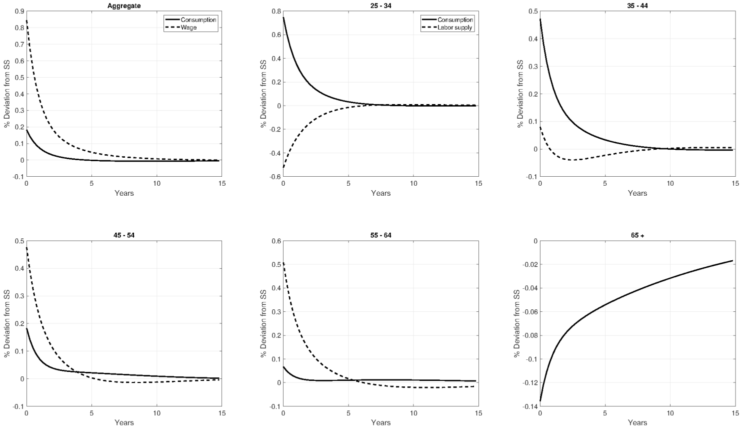


Figure: Consumption and labor supply responses to an expansionary 0.5 pp monetary policy shock by age groups.

Compare with Wong (2018)

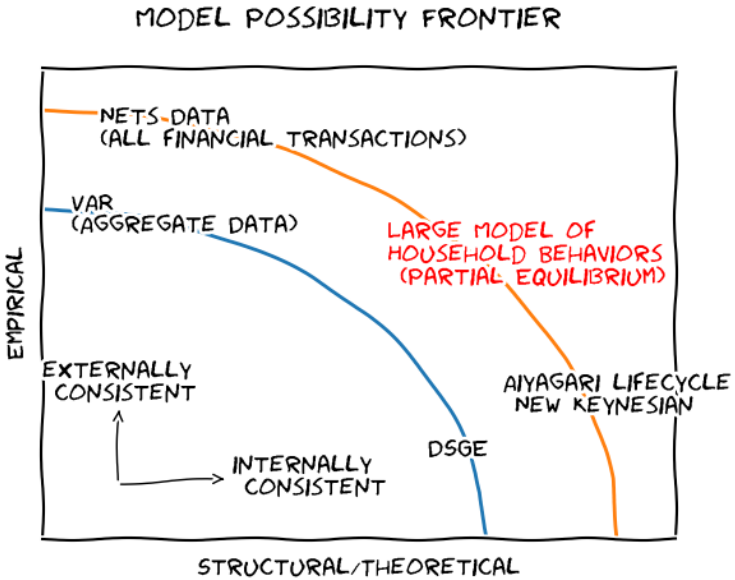
Table: Annual consumption elasticities to monetary policy shocks by age.

	Young 25-34	**Middle** 35-64	**Old** 65 +
Non-durables (CEX data)	2.24 [0.67, 3.82]	0.47 [-0.7, 1.65]	0.12 [-1.83, 2.07]
Model	2.29	0.71	-0.47

Notes: This table presents the annual consumption elasticities from a one standard deviation monetary policy shock from Wong(2018) and the annual consumption elasticities from a 0.5 pp expansionary monetary policy shock in the model. The brackets depict 80 percent confidence intervals.

Monetary Policy with Ageing: Conclusion

- Parsimonious, quantitative lifecycle model based on Norwegian data
- Working paper coming out soon.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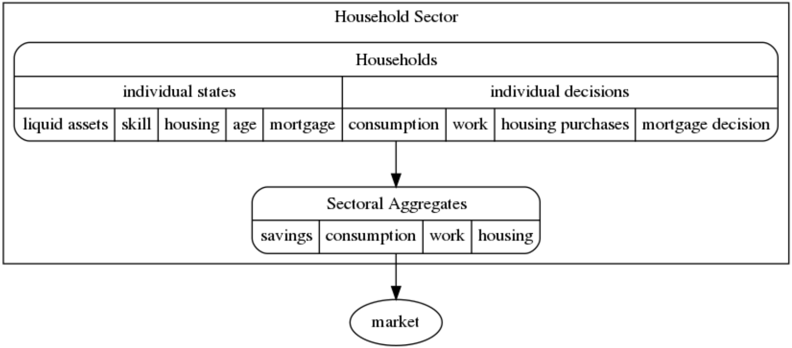
Big Model

- Target is an eventual general equilibrium integration
  - Start with partial equilibrium also to help us analyze microdata
  - Might be necessary to scale back some parts
  - but methodological improvements are also being made

Model of Households: Target



Household Model

$$\max_{\{c,\lambda(a,m,h),\text{prepayment}\}} \mathbb{E}\left[\int_{t=0}^{\tau} e^{-\rho t} u(c,h,\lambda(a,m,h))\,dt \right.$$
$$\left. + e^{-\rho\tau} \cdot B(a - m + p_h \cdot h) \right]$$

- τ: (stochastic) time of death
- ρ: discount factor
- $u(\cdot)$: utility function
- $B(\cdot)$: bequest motives

Household Model: Housing

- Housing by (discrete) ladders

$$h \in \{h_1, \ldots, h_n\}$$

- Search and matching framework once one decides to buy/sell their house
  - $\sim$ 3 matches per year
  - The matching rate can drop IF many households want to sell simultaneously.
    $\Rightarrow$ House becomes more illiquid precisely when you want to tap into the home equity.

Household Model: Mortgage Decision

- Determines how much mortgage to take out when buying/selling houses with LTV constraint

$$m_{\text{new}} \leq (\text{LTV Constraint}) \cdot h_{\text{new}}$$

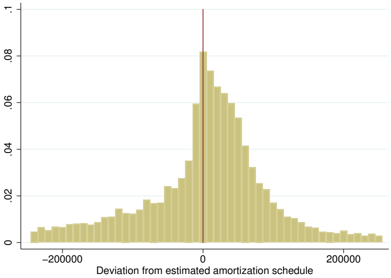
- LTV only applies when you buy/sell houses
  ($\Rightarrow$) no effect of LTV from future price changes

- Current setup does not have LTI, but it would be just one extra inequality.

$$m_{\text{new}} \leq (\text{LTI Constraint}) \cdot \text{income}$$

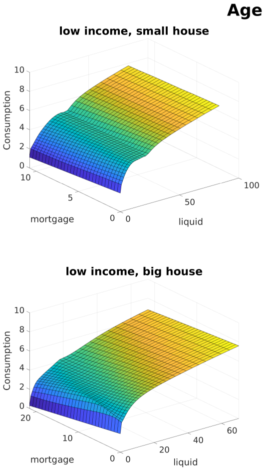
Household Model: Mortgage Amortization

- Long-term mortgage
- Households can prepay (cheaply)

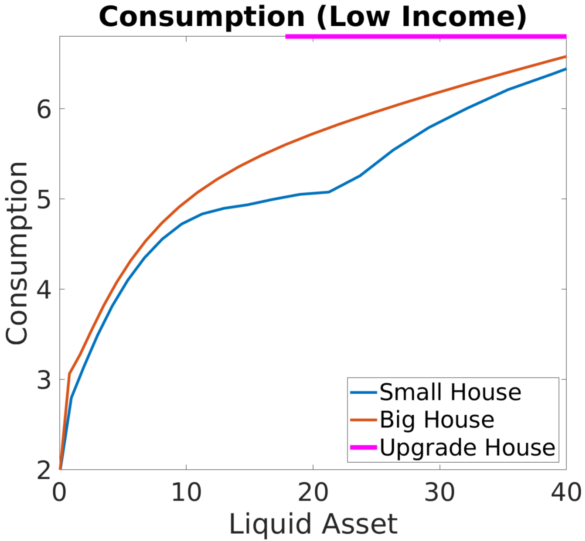


- Adjustment cost for new home-equity loan

Household Model: Consumption Decision



Household Model: Consumption Decision



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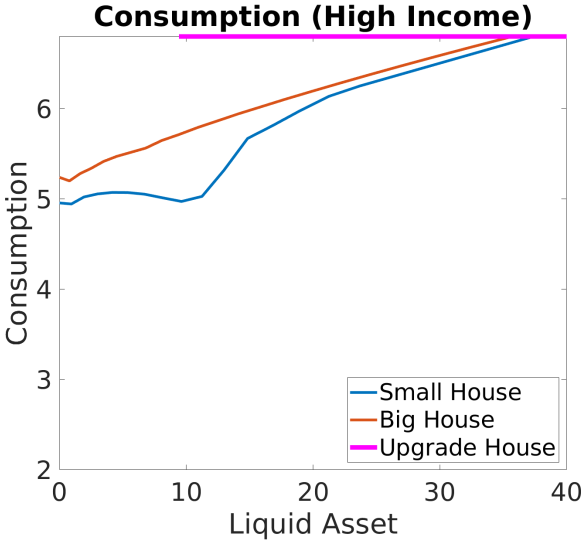
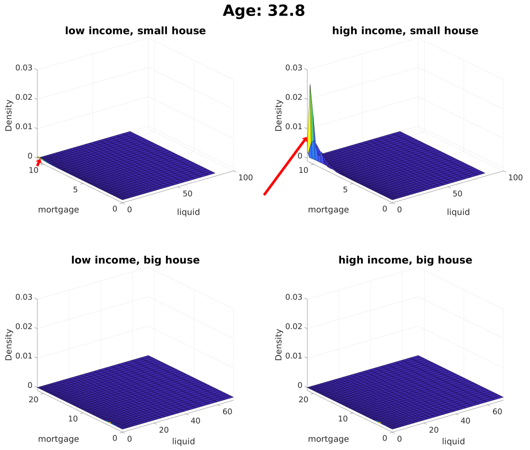
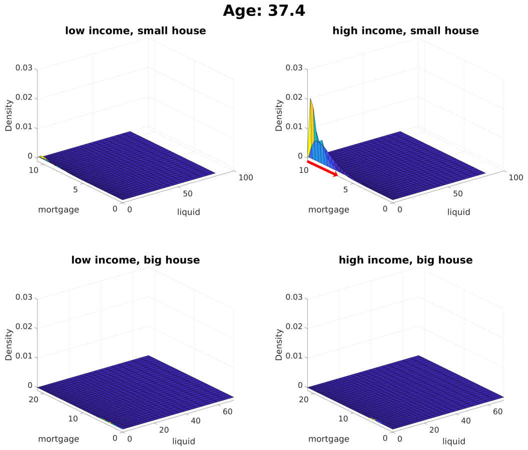


Household Model: Density



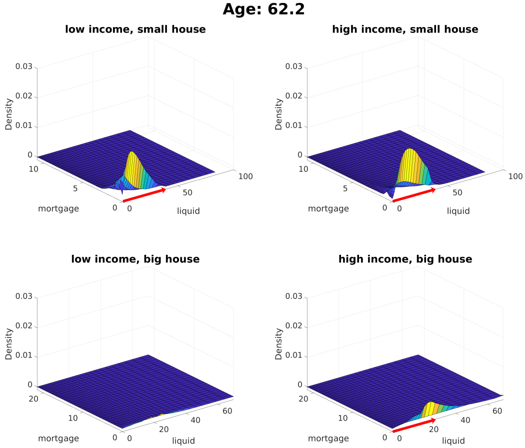
- Buy houses taking out LTV-limit of mortgage debt
- High income households purchase houses earlier in life cycle

Household Model: Density



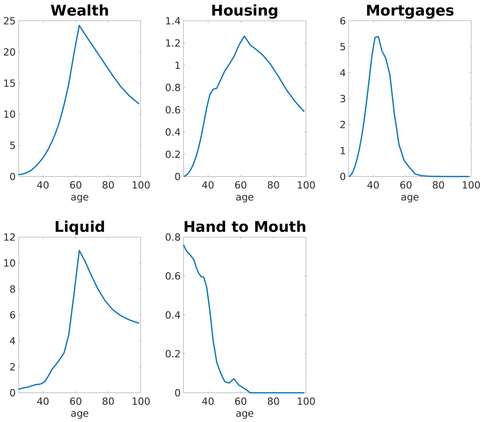
- People start paying off mortgages
- Hold liquid assets, but not too much

Household Model: Density



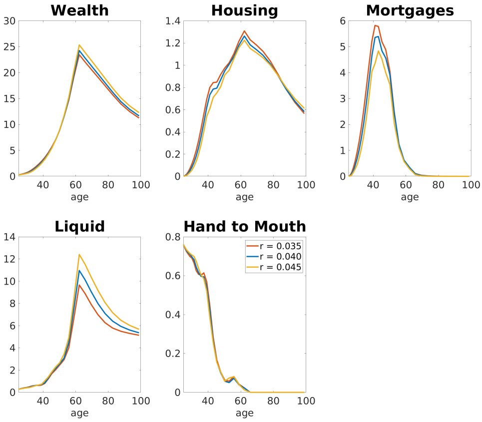
- Once mortgage is paid off, save in deposits

Household Model



- "Integrate" to get aggregate behaviors

Household Model: Interest



- Logical responses to changes in r (and LTV-constraints)

Big Household Model

- Still in testing phase, but everything behaves logically so far...
- Currently being calibrated
  - the first step of the housing ladder
  - reasonable moving pattern in households

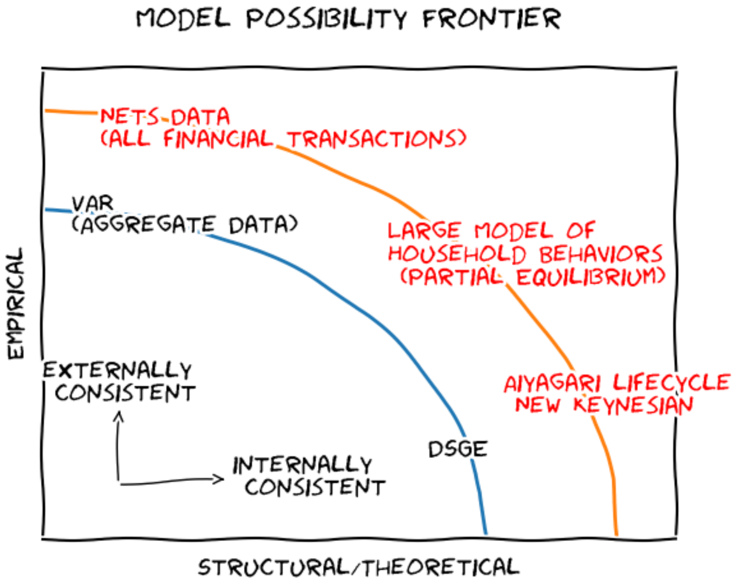
  with a target deadline of *mid-May*.

Other things in progress

- Automation being written
  - Based on large part on Achdou et al. (2017)

    $\Rightarrow$ inherit speed and robustness of continuous time approach

    but with automation...
  - Only need to write economic things for most parts, i.e., utility function, consumption decision (i.e., FOCs)
    - Aiyagari-Bewley-Huggett model is 14 lines.
  - Targeted to be open-sourced with an staff memo + internal course around August
- (Cloud) Parallelization being tested (C++ based).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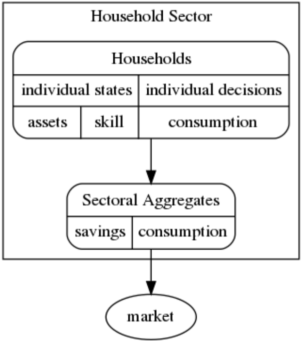
Appendix

Example: Aiyagari-Bewley-Huggett Model



Example: Aiyagari-Bewley-Huggett Model

```
function [output] = util(obj,input)
    output = (input).^(1-obj.gamma)/(1-obj.gamma);
end

function [output] = consumption_decision(obj,dx_dv)
    output = (dx_dv).^(-1/obj.gamma);
end

function [output] = consumption_decision0(obj,ind_0)
    income = obj.r.*obj.grid_HJB.x_i{1}(:) + (1-obj.tau).*obj.w.*obj.grid_HJB.x_i{2}(:) + obj.transfer;
    output = {income(ind_0)};
end

function [output] = savings(obj,x)
    income = obj.r.*obj.grid_HJB.x_i{1}(:) + (1-obj.tau).*obj.w.*obj.grid_HJB.x_i{2}(:) + obj.transfer;
    output = income(:) - x(:);
end
```

- Type out the equations (after defining parameters and such)

Example: Aiyagari-Bewley-Huggett Model

```
function obj = household_s_income_liquid_c_consumption()
    obj.maxiter_HJB = 100;
    obj.conv_crit = 1e-6;

    obj.n_dim = 2;
    obj.x_min = {-1, 0.5};
    obj.x_max = {30, 1.5};

    % Create Grid
    obj.grid_HJB = regular_grid;
    % obj.grid_HJB = sparse_grid;
    obj.grid_HJB.n_dim = 2;
    obj.grid_HJB.n_grid = {100; 30};
    obj.grid_HJB.x_min = {-1, 0.5};
    obj.grid_HJB.x_max = {30, 1.5};

    if isa(obj.grid_HJB, 'regular_grid')
        obj.grid_HJB.init_unif_grid();
        obj.grid_HJB.create_diff_mats();
    elseif isa(obj.grid_HJB, 'sparse_grid')
        obj.grid_HJB.init_grid(7);
    else
        error('Unknown form of grid');
    end
```

- Define grid for approximation

Example: Aiyagari-Bewley-Huggett Model

```
function output = one_iter_HJB(obj)
    % Consumption Decision
    [c,mu_c,A] = obj.build_upwind({@obj.savings}, 1, {@obj.consumption_decision}, @obj.consumption_decision0);

    obj.mu{1} = mu_c{1};
    obj.reaction = obj.util(c{1});
    obj.c = c{1};

    % Update transition matrix
    obj.A_HJB = A{1} + obj.A_HJB_base;

    % Take one-time step
    V_new = obj.step_HJB();
    output = max(abs(V_new(:) - obj.V(:)));
    obj.V = V_new;
end
```

- Follow standard syntax
- You are done!