Macroeconomics II, Lecture XIII:
Incomplete Markets in General Equilibrium

Erik Öberg

Recap

- Recap:
    1. With incomplete markets, ex-ante homogeneous households will be **ex-post heterogeneous** in terms of $\{c, a, y\} \Rightarrow$ no aggregation into representative agent

    2. With incomplete markets, consumption dynamics influenced by a **precautionary savings** motive

- Today: we will study the interplay between incomplete markets and the aggregate economy
    - That is, we will set up a general-equilibrium model

Why general equilibrium? A reminder.

- PE enables us to explore how households consumption-saving decisions respond to income, risk, price changes, credit availability etc...

- But, since prices and income processes are endogenous objects, PE does not permit exploring how economy-wide objects respond to fiscal policy, technical change, labor market shocks etc.

- Economy-wide objects: the distribution of income and wealth, aggregate savings, aggregate demand, the equity premium etc.

- First-generation GE models focused on steady state: Bewley (1986), Imrohoroğlu (JPE 1989), Huggett (JEDC 1993) and Aiyagari (QJE 1994)

- Second generation added aggregate shocks: Krusell-Smith (JPE 1998)

- Currently, research using business-cycle models with heterogeneous agents grows exponentially

Agenda

1. The static Aiyagari model
   1. Model setup and definition of stationary recursive equilibrium
   2. The Aiyagari diagram

2. Applications
   1. Can the model explain US wealth inequality?
   2. Efficiency and Fiscal policy

The Aiyagari model

Overview

- The Aiyagari model = Neoclassical growth model with continuum of households that face uninsurable idiosyncratic income risk

- Three ingredients
  1. Households that solves an income-fluctuations problem
     ★ Determines supply of labor and assets, demand for consumption

  2. Competitive firms that maxmize production using a production function
     ★ Determines demand for labor and assets, supply of consumption

  3. Market clearing conditions
     ★ Goods demand = Goods supply
     ★ Labor demand = Labor supply
     ★ Asset demand = Asset supply

Household prefences

- A unit mass of households, indexed by i, who solve an income-fluctuations problem

- Preferences: households seek to maximize the objective

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_{it})$$

- $U(C)$ satisifies the usual regularity conditions

- Labor supply is exogenous, no disutility from labor

Household income

- Household income: $\epsilon_{it} W_t$

- Household effective labor supply ϵ varies stochastically

- ϵ has finite support $\epsilon \in \mathcal{E} = \{\epsilon_0, \epsilon_1, ..., \epsilon_N\}$ and follows a **Markov process** with transititions governed by

$$\pi(\epsilon', \epsilon) = Pr(\epsilon_{t+1} = \epsilon' | \epsilon_t = \epsilon)$$

- The transition probabilities are the same for all households

- This formulation of the income process allows for an arbitrary level of persistence (in contrast to transitory-permanent income process consider in last lecture)
  - See Tauchen (EL 1986) and Tauchen-Hussey (Ecmtra 1991) for how to map any continuous AR process into a discrete-space Markov process

Markov processes I

- Let $\mathcal{E} = \{0, 1\}$ (unemployed and employed)

- Collect transition probabilities in matrix T:

$$T = \left(\begin{array}{cc} \pi(0,0) & \pi(0,1) \\ \pi(1,0) & \pi(1,1) \end{array} \right)$$

- Suppose t is a quarter. What is the interpretation of $\pi(1,0)$? $\pi(0,1)$?

- Let $\pi_{it}(\epsilon)$ be the probability distribution over an individual household i's state in period t

  ▶ If we know the household i is unemployed in period t, then $\pi_{it}(\epsilon) = \left(\begin{array}{c} 1 \\ 0 \end{array} \right)$

- $\pi_{it+s}(\epsilon)$ is given by

$$\pi_{it+s}(\epsilon) = T^s \pi_{it}(\epsilon)$$

  ▶ If we know the household is unemployed in period t, then

$$\pi_{it+1}(\epsilon) = T \left(\begin{array}{c} 1 \\ 0 \end{array} \right) = \left(\begin{array}{c} \pi(0,0) \\ \pi(1,0) \end{array} \right)$$

Markov processes II

- Let $\Pi_t(\epsilon)$ be the distribution of all households across states ϵ in period t. $\Pi_{t+s}(\epsilon)$ is similarly given by

$$\Pi_{t+s}(\epsilon) = T^s \Pi_t(\epsilon)$$

- Stationary distribution $\Pi^*(\epsilon)$ satisfies

$$\Pi^*(\epsilon) = T\Pi^*(\epsilon)$$

- If T is regular (all entries of T^n for some $n > 0$ is positive), $\Pi^*(\epsilon)$ is given by

$$\Pi^*(\epsilon) = \lim_{s \to \infty} T^s \Pi_t(\epsilon)$$

for any starting distribution Π_0.

- Implication: there is a unique steady state value of aggregate labor supply, given by

$$L = \sum_{\epsilon \in \mathcal{E}} \epsilon \Pi^*(\epsilon)$$

Household constraints

- Households face budget constraint:

$$C_{it} + A_{it+1} \leq \epsilon_{it} W_t + R_t A_{it}$$

- and credit constraint

$$A_{it+1} \geq -\bar{A}$$

- Notes:
  - The savings instrument in this economy is capital, just as in lecture I-II
  - To make the determination of the real interest rate transparent, we assume here that depreciation happens at the firm
  - R_t is the real gross rate of return on savings in period t

Firms

- The representative firm rents labor and capital to produce consumption goods Y using a Cobb-Douglas production function:

$$Y_t = ZF(K_t, L_t) = ZK_t^\alpha L_t^{1-\alpha}$$

- Firm's problem

$$
\begin{aligned}
&\max_{K_t, L_t} ZF(K_t, L_t) + (1-\delta)K_t - W_t L_t - R_t K_t \\
= \quad &\max_{K_t, L_t} ZF(K_t, L_t) - W_t L_t - (R_t - (1-\delta))K_t \\
= \quad &\max_{K_t, L_t} ZF(K_t, L_t) - W_t L_t - (r_t + \delta)K_t
\end{aligned}
$$

where $r_t = R_t - 1$

- In the optimum:

$$
\begin{aligned}
r_t + \delta &= F_K(K, L) = \alpha \left(\frac{K_t}{L_t} \right)^{\alpha-1} \\
W_t &= F_L(K, L) = (1-\alpha) \left(\frac{K_t}{L_t} \right)^{\alpha}
\end{aligned}
$$

Market clearing

- The goods market clears when

$$\int_{i=0}^{1} C_{it} di + K_{t+1} - (1-\delta)K_t = Y_t$$

- The asset market clears when

$$K_t = \int_i A_{it} di$$

- The labor market clears when

$$L_t = \sum_{\epsilon \in \mathcal{E}} \epsilon \Pi_t(\epsilon)$$

Rational expectations with heterogenous households

- Note: R_{t+1} and W_{t+1}, depends on aggregate savings A_{it+1}, which, via household decision functions, in turn depends on the joint distribution of A_{it}, ϵ_{it}

- Denote the PDF of this distribution with $\gamma(A_{it}, \epsilon_{it})$

- To form rational expectations of R_{t+1}, W_{t+1}, households need to know $\gamma(A_{it}, \epsilon_{it})$

- $\Rightarrow$ γ **is, in general, a state variable in the household problem**
  - γ is a function, an infinite-dimensional object
  - Appears bothersome, recall "curse of dimensionality"

- In a stationary equilibrium, however, γ is constant and $R_t = R$ and $W_t = W$ for all t

- $\Rightarrow$ γ **is not a state variable assuming that we start and remain in steady state forever**

Stationary recursive household problem

- Defining, computing and illustrating the equilibrium is easier with a recursive setup

- In a stationary environment, the recursive household problem is

$$V(A, \epsilon) = \max_{C, A'} \quad u(C) + \beta \sum_{\epsilon' \in \mathcal{E}} \pi(\epsilon', \epsilon) V(A', \epsilon')$$

$$\text{s.t.} \quad C + A' = W\epsilon + (1+r)A$$
$$A' \geq -\bar{A}$$

- r, W constant $\Rightarrow$ solution functions $V(A, \epsilon), C(A, \epsilon), A'(A, \epsilon)$ are time-invariant

Stationary distribution

- A stationary equilibrium features a constant distribution $\gamma(A, \epsilon)$ with support $\mathcal{A} \times \mathcal{E}$

- Define the transition function $Q((A', \epsilon'), (A, \epsilon))$, Q is given by

$$Q((A', \epsilon'), (A, \epsilon)) = I_{A'=A'(A,\epsilon)}\pi(\epsilon', \epsilon)$$

- Importantly, Q is generated by the household policy functions

- γ' is then given by

$$\gamma'(A', \epsilon') = \int_{\mathcal{A} \times \mathcal{E}} Q((A', \epsilon'), (A, \epsilon))d\gamma$$

where $d\gamma = \gamma(A, \epsilon)dAd\epsilon$

- A stationary distribution γ^* maps itself onto itself:

$$\gamma^* = \int_{\mathcal{A} \times \mathcal{E}} Q((A', \epsilon'), (A, \epsilon))d\gamma^*$$

Stationary Recursive Competitive Equilibrium

- A SRCE is a value function $V(A, \epsilon)$, policy functions $C(A, \epsilon), A'(A, \epsilon)$, a distribution $\gamma(A, \epsilon)$, aggregate capital and labor demand K, L, and prices W, R, s.t.

    1. Given W, R: the value function $V(A, \epsilon)$ and policy functions $C(A, \epsilon), A'(A, \epsilon)$ solves the household Bellman equation

    2. Given W, R: K, L solves the firm problem

    3. The market for capital and labor clear:

    $$K = \int_{\mathcal{A} \times \mathcal{E}} A d\gamma$$

    $$L = \int_{\mathcal{A} \times \mathcal{E}} \epsilon d\gamma = \sum_{\epsilon \in E} \epsilon \Pi^*(\epsilon)$$

    4. $\gamma(\cdot)$ satisfies

    $$\gamma(A', \epsilon) = \int_{\mathcal{A} \times \mathcal{E}} Q((A', \epsilon'), (A, \epsilon)) d\gamma$$

    where Q is defined in the previous slide

Does an SCRE exist?

- Firm and household problem are well-defined: solutions exist and policy functions are continuous in R and W

- Labor supply is constant: Solving for W that clears the labor market is done by invoking firm optimality given a market clearing level of capital

- The question boils down to: does there exist an R s.t. the asset market clears?

- Restated: does asset demand and asset supply curves cross at least once?

Does an SCRE exist?

- To show existence, we will draw the **Aiyagari diagram** in r, K-space (Do on whiteboard)
  - $r = R - 1$

- Capital demand $K(r)$ is given by firm F.O.C.: $\alpha \left(\frac{K(r)}{L} \right)^{\alpha - 1} = r + \delta$
  1. decreasing
  2. $r \to -\delta : K(r) \to \infty$
  3. $r \to \infty : K(r) \to 0$

- Capital supply $A(r)$ is given by household savings: $A(r) = \int_{\mathcal{A} \times \mathcal{E}} A'(A, \epsilon; r) d\gamma$
  1. The stationary state replicates itself forever: $A(r) = $ long-run mean level of assets
  2. At the lower end, we have that $\lim_{r \to -1} A(r) = -\bar{A}$
  3. What about the upper end?

-

Asset convergence: No income risk

- Without any income risk, $\epsilon = 0$, it is straightforward to show that if
  1. $\beta(1 + r) > 1$, consumption and savings grow indefinetly
  2. $\beta(1 + r) = 1$, consumption is constant, savings is bounded
  3. $\beta(1 + r) < 1$, consumption and savings decrease until borrowing constraint binds, in the limt $C = \bar{Y}$

- Why? If credit constraint does not bind, then the household problem is characterized by

$$U_c(C) = \beta(1 + r)U_c(C')$$

- Implication: with complete markets (or no income risk), steady state interest rate $R = \frac{1}{\beta}$

Asset convergence: With income risk

- With uninsurable income risk, household have a stronger savings motive

- Implication: assets and consumption grow without bound for lower levels of interest rate R

- For example, consider the case with $\beta R = 1$

- Optimality conditions

$$
\begin{aligned}
U_c(C) &= E\left[V_a(A', \epsilon')\right] + \mu \\
V_a(A', \epsilon') &= U_c(C')
\end{aligned}
$$

or

$$
V_a(A, \epsilon) \geq E\left[V_a(A', \epsilon')\right]
$$

Asset convergence: With income risk

- Recall: ϵ_N is the maximum of ϵ

- Suppose that the solution is bounded: the maximum of A' is A_{max}

- Evaluating optimality condition at point A_{max}, ϵ_N:

$$
\begin{aligned}
V_a(A_{max}, \epsilon_N) &\geq E\left[V_a(A'(A_{max}, \epsilon), \epsilon')\right] \\
&> E\left[V_a(A_{max}, \epsilon_N)\right] \text{ using that } V_{aa} < 0 \\
&= V_a(A'_{max}, \epsilon_N)
\end{aligned}
$$

which is a contradiction. Ergo A' does not have an upper bound $\Rightarrow$ asset holdings diverge to infinity

Does an SCRE exist?

- To show existence, we will draw the **Aiyagari diagram** in r, K-space (Do on whiteboard)
  - $r = R - 1$

- Capital demand $K(r)$ is given by firm F.O.C.: $\alpha \left(\frac{K(r)}{L} \right)^{\alpha - 1} = r + \delta$
  1. decreasing
  2. $r \to -\delta : K(r) \to \infty$
  3. $r \to \infty : K(r) \to 0$

- Capital supply $A(r)$ is given by household savings: $A(r) = \int_{\mathcal{A} \times \mathcal{E}} A'(A, \epsilon; r) d\gamma$
  1. The stationary state replicates itself forever: $A(r) =$ long-run mean level of assets
  2. At the lower end, we have that $\lim_{r \to -1} A(r) = -\bar{A}$
  3. What about the upper end?

-

Does an SCRE exist?

- To show existence, we will draw the **Aiyagari diagram** in r, K-space (Do on whiteboard)
  - $r = R - 1$

- Capital demand $K(r)$ is given by firm F.O.C.: $\alpha \left(\frac{K(r)}{L} \right)^{\alpha - 1} = r + \delta$
  1. decreasing
  2. $r \to -\delta : K(r) \to \infty$
  3. $r \to \infty : K(r) \to 0$

- Capital supply $A(r)$ is given by household savings: $A(r) = \int_{\mathcal{A} \times \mathcal{E}} A'(A, \epsilon; r) d\gamma$
  1. The stationary state replicates itself forever: $A(r) =$ long-run mean level of assets
  2. At the lower end, we have that $\lim_{r \to -1} A(r) = -\bar{A}$
  3. At the upper end, $\lim_{r \to \frac{1}{\beta} - 1} A(r) = \infty$

-

Does an SCRE exist?

- To show existence, we will draw the **Aiyagari diagram** in r, K-space (Do on whiteboard)
    - $r = R - 1$

- Capital demand $K(r)$ is given by firm F.O.C.: $\alpha \left(\frac{K(r)}{L} \right)^{\alpha - 1} = r + \delta$
    1. decreasing
    2. $r \to -\delta : K(r) \to \infty$
    3. $r \to \infty : K(r) \to 0$

- Capital supply $A(r)$ is given by household savings: $A(r) = \int_{\mathcal{A} \times \mathcal{E}} A'(A, \epsilon; r) d\gamma$
    1. The stationary state replicates itself forever: $A(r) =$ long-run mean level of assets
    2. At the lower end, we have that $\lim_{r \to -1} A(r) = -\bar{A}$
    3. At the upper end, $\lim_{r \to \frac{1}{\beta} - 1} A(r) = \infty$

- Therefore: Asset supply and asset demand cross at least once

Incomplete vs complete markets

- Consider the steady state of a representative-agent (complete-market) economy

- Euler equation implies:

$$u'(C_t) = \beta(1 + r)u'(C_{t+1})$$
$$\Rightarrow \quad r = \frac{1}{\beta} - 1$$

- Asset demand still given by the same firm F.O.C.: $\alpha \left(\frac{K(r)}{L}\right)^{\alpha-1} = r + \delta$

- Result: The addition of uninsurable income risk raises K and depresses r

Stationary state: computational algorithm

1. Set initial r_0 which satisfies $-\delta < r_0 < \frac{1}{\beta} - 1$

2. Solve for K and then W from firm F.O.C.

3. Solve household problem given $\{r_0, W\}$, e.g., by value function iteration
   - This gives you $A'(A, \epsilon; r_0)$

4. Solve for γ_T for some large T using the law of motion

$$\gamma_{t+1} = \int_{\mathcal{A} \times \mathcal{E}} Q((A', \epsilon'), (A, \epsilon)) d\gamma_t$$

   - Note: this involves picking initial distribution γ_0 and then simulating using the computed policy functions

5. Compute $A_{agg} = \int_{\mathcal{A} \times \mathcal{E}} A'(a, \epsilon; r) d\gamma_T$

6. If $A_{agg} > K$, set $r_1 < r_0$ and repeat. If $A_{agg} < K$, set $r_1 > r_0$ and repeat until A_{agg} is sufficiently close to K

A note: Aiyagari vs Huggett

- An incomplete-markets model without physical capital is sometimes referred to as a Huggett model, after Huggett (JEDC 1993)

- Example production function:

$$Y_t = F(L_t) = ZL_t^{1-\alpha}$$

- In the case of zero net asset suppy (e.g., no government debt, money, foreign borrowing etc), asset market clearing is simply

$$\int_{\mathcal{A} \times \mathcal{E}} A d\gamma = 0$$

  ▶ Zero net asset supply: households can borrow and save in partial equilibrium, but in net, aggregate savings are zero

- Aiyagari diagram the same, except that aggregate demand curve is vertical at zero
  ▶ See your problem set

Applications

The Aiyagari model put to work

- Now we have an incomplete markets stationary equilibrium, lets put it to work

- Questions:
  - Does the equilibrium wealth distribution match the data?
  - Can fiscal policy be welfare-improving? Redistributive taxation? Public debt management?

Wealth inequality

- Taken a realistic income process as given, can the model explain the observed wealth inequality?

- This is theory of wealth inequality entirely based on luck

- Some agents will experience lucky income draws and accumulate assets to insure against bad draws in the future

- Some agents will experience not so lucky income draws and deaccumulate assets/borrow to smooth consumption

- Some agents will experience very unlucky income draws and hit the borrowing constraint

US wealth inequality

Quantiles	0	1	5	10	20	40	60	80	90	95	99	100
Earnings	−1,547	0.0	0.0	0.0	0.0	25.7	50.4	87.5	126.1	180.2	497.0	161,523
Income	−506.0	4.2	8.9	12.3	20.1	36.3	58.8	98.7	142.0	207.2	680.7	187,202
Wealth	−474.0	−31.3	−4.6	0.0	7.3	64.7	197.7	496.9	908.4	1,890	8,327	1,411,730

Numbers measured in $\$*10^3$. From {Diaz-Giminez}-Glover-{Rios-Rull} (FED Minneapolis 2011). Data from SCF.

	Earnings	Income	Wealth
Coefficient of variation	3.60	4.32	6.02
Variance of the logs	1.29	0.99	4.53
Gini index	0.64	0.58	0.82
Top 1% / lowest 40%	183	88	1,526
Location of mean (%)	69	74	80
Mean / median	1.72	1.77	4.61

From {Diaz-Giminez}-Glover-{Rios-Rull} (FED Minneapolis 2011). Data from SCF.

- Main take-away: wealth distribution a lot more concentrated than income distribution

A (standard) parameterization

- $\underline{A} = 0$ or $\underline{A} =$ natural borrowing constraint

- Income process:
  1. Run Mincer regression

     $$\log y_{it} = \alpha + \beta X_{it} + \nu_{it}$$

     where X controls for changes in earnings that are predetermined
  2. Find a process $\mathcal{E} = \{\epsilon_0, ..., \epsilon_1\}$, $\pi(\epsilon, \epsilon')$ that matches autocorrelation and variance of ν_{it}

- $\sigma \in [1, 5]$, consistent with experimental evidence on risk aversion
  - $\sigma = 1 \Leftrightarrow$ log utility

- Calibrated parameters:
  - α to match labor share $\frac{WL}{Y}$
  - β to match risk-free interest rate r
 - δ to match outside estimates

Results

- Calibrated model typically has wealth Gini coefficient around 0.4
  - ▶ US wealth Gini coefficient is 0.8

- Suggests that precautionary savings can explain some, but not all, of US wealth inequality
  - ▶ would be very surprising if it could explain everything...

- Failure due to problems at both ends of wealth distribution:
  1. Very few households close to borrowing constraint
     - ★ The welfare loss of not being able ot smooth at all is large
  2. Very few households with savings several multiples of income at top of distribution
     - ★ Only rational if you face substantial risk loosing all your income for a long time

# What is the model missing?

- Suggestions
  - ▶ Adding means-tested social insurance eliminates saving motive among income-poor (Skinner-Hubbard-Zeldes, JPE 1995)

  - ▶ Adding bequest savings as a luxury good generates additional savings among the income-rich (De Nardi, ReStud 2004)

  - ▶ β-heterogeneity: given some r, households with low β deaccumulate, households with high β accumulate $\rightarrow$ more wealth heterogeneity within income groups (Krusell-Smith, MD 1997; JPE 1998)

  - ▶ $r-$heterogeneity:
    - ★ Similar logic to β-heterogeneity
    - ★ In the data, large fraction of top wealth is held by entreprenuers. Quadrini (RED 2000) and Cagetti-De Nardi (JPE 2006) model entreprenuers as households with access to high-return investments
    - ★ See also Krusell-Hubmer-Smith (NBERannual 2020); Paulie-Ridder-Westergren (2021)

  - ▶ Non-zero probability of very rich people to loose it all ({Diaz-Giminez}-Glover-{Rios-Rull}, JPE 2003)
    - ★ Authors argue that we miss this in standard calibrations due to top coding in survey income data

Return heterogeneity in Norway
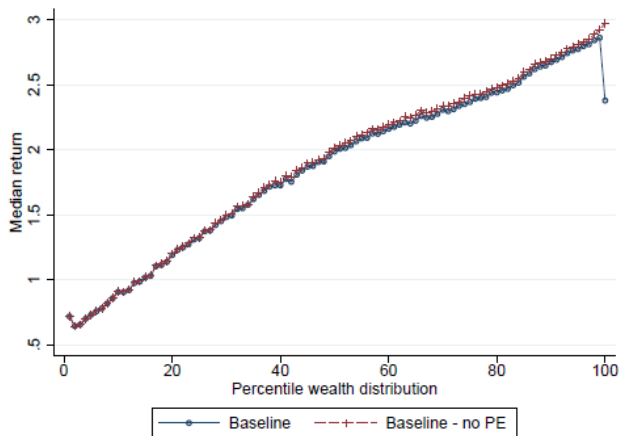
From Fagereng-Guiso-Malacrino-Pistaferri (Ecmtra 2020). Norwegian registry data.

Return heterogeneity in Norway
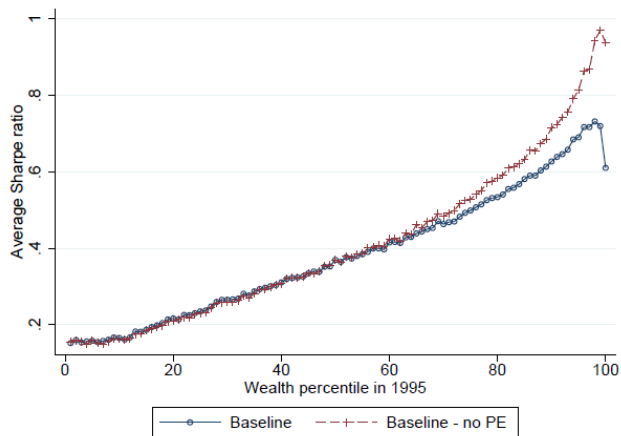
From Fagereng-Guiso-Malacrino-Pistaferri (Ecmtra 2020). Norwegian registry data.

Efficiency and policy I

- Recap: the incomplete-markets equilibrium features a lower r and higher K (and higher Y) than the corresponding complete markets equilibrium in which $\beta(1+r) = 1$

- Unsurprisingly, this reflects that the market allocation is **inefficient**

- An unconstrained social planner would insure all households against idiosyncratic income risk $\Rightarrow$ Constant consumption for all households in the stationary state $\Rightarrow$ $\beta(1+r) = 1$
    - An unconstrained social planner effectively reintroduce the missing market for a complete set of Arrow securities

- Is the stationary equilibrium allocation **constrained efficient**?
    - Constrained efficiency: Would a social planner, who can use the same savings instruments as the households, choose different policy functions $A'(A, \epsilon), C(A, \epsilon)$ than households choose in the decentralized equilibrium?
    - Davila-Hong-Krusell-{Ríos-Rull} (Ecmtra 2012): The Aiyagari model is not constrained efficient, the planner wants to instruct well-off households to save more, so to raise the wage of the poor households
    - $\Rightarrow$ K(constrained efficient equilibrium) $>$ K(decentralized equilibrium) $>$ K(efficient equilibrium)

Efficiency and policy II

- Lack of efficiency opens many doors for welfare-improving policy

- Flodén-Linde (RED 2001) studies redistributive taxation
  - A flat labor tax τ to finance lump sum payments T ("basic income"), provides insurance and so raises welfare
  - At the same time, it depresses incentives to work (labor supply decision easily added to the model)
  - Floden and Linde adds labor supply decision to Aiyagari model and finds optimal level of labor taxes $\tau \approx 0.27$ for US calibration

- A progressive income tax schedule is a even more effective insurance device
  - Optimal progressivity studied by Bénabou (Ecmtra 2002); Conesa-Krueger (RED 2006); Krueger-Ludwig (AER 2013); Heathcote-Storesletten-Violante (QJE 2017)

- Aiyagari-McGrattan (JME 1998) studies government debt management
  - A higher level of debt B increases the set of liquid assets $\rightarrow$ enables more insurance
  - Higher B crowds out savings in the capital stock K $\rightarrow$ reduces output and consumption
  - Aiyagari and McGrattan find that these effects largely offset eachother, and the welfare effects from varying the overall debt level is small

What about dynamics?

- So far, our analysis has been static: no aggregate shocks

- Generally, analyzing dynamics requires computational techniques which we do not practice in this course (covered in first second-year course)

- Central problem: the entire wealth distribution is a state-variable, infinite-dimensional object

- Useful to know: two computational approaches:
  1. Approximate equilibrium (Krusell-Smith JPE, 1998): exploit that knowing just a few moments of the wealth distribution is sufficient to make very good forecast of prices

  2. Linearization (Boppart-Krusell-Mitman, JEDC 2018; Auclert-Bardoczy-Rognlie-Straub, Ecmtra 2021): transition dynamics (IRFs) to one-time unexpected shock is a sufficient statistic for solving a first-order approximation, just like in rep-agent RBC
     - Computing transition dynamics to one-time unexpected shock is bigger system of equations, byt conceptually the same as computing the steady state

Summary

- Ayiagari model = Neoclassical growth model with uninurable earnings risk

- Key prediction: equilibrium real interest rate lower, due to precautionary savings motive

- Due to incomplete markets, equilibrium is neither efficient nor constrained efficient

- Very general framework for exploring the joint distribution of earnings, consumption and wealth, and their interaction with macroeconomic dynamics
  - The literature using incomplete-market models for investigating macroeconomic dynamics has exploded
  - To conclude the course, I will briefly talk in next class about one area of rapidly evolving research: Heterogeneous-Agent New-Keynesian (HANK) models
    - In particular, we will look at a HANK model that also has a frictional labor market, integrating all elements from this course