

# Optimal Taxation with Incomplete Markets

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## Lucas and Stokey, 1983

*... the option to issue state-contingent debt is important: tax policies that are optimal under uncertainty have an essential 'insurance' aspect to them.*

# Commitment, representative agent, no capital

- ▶ **Incomplete markets**

- A single, possibly risky asset

- ▶ **Linear tax schedules**

- Proportional tax on labor earnings (maybe plus *nonnegative* transfers)

- ▶ **Aggregate shocks**

- To productivities, government expenditures

# Questions

1. Should a government accumulate or decumulate assets?
2. Why might different governments want to issue different amounts of debt?
3. Existing answers hinge on polar assumptions:
  - + Lucas Stokey (1984), complete markets: non history dependent debt quantities inherited from initial condition
  - + AMSS (2002), a risk-free bond only, quasi-linear preferences: govt. accumulates *assets* sufficient to finance activities using interest revenues
4. Unknown after AMSS (2002): what if interest rates fluctuate?

# Environment

- ▶ **Uncertainty:** Markov aggregate shocks  $s_t \in \mathcal{S}$ ;  $S \times S$  stochastic matrix  $\Pi$ ;  $g_t = g(s_t)$ ;  $\theta_t = \theta(s_t)$
- ▶ **Demography:** Infinitely lived representative agent plus a benevolent planner
- ▶ **Preferences** (representative household)

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(c(s^t), l(s^t))$$

- ▶ **Technology:** Aggregate output  $y_t = \theta_t l_t$

## Environment, II

- ▶ **Asset market:**

- ▶  $S \times S$  matrix  $\mathbb{P}$  with time  $t$  payoff being

$$p_t = \mathbb{P}(s_t | s_{t-1})$$

- ▶ **Linear Taxes:** Agent  $i$ 's tax bill

$$-T_t + \tau_t \theta_t l_t, \quad T_t \geq 0$$

- ▶ **Budget constraints**  $q_t$  is price of asset

- ▶ Household:  $c_t + b_t = (1 - \tau_t) \theta_t l_t + \frac{p_t}{q_{t-1}} b_{t-1} + T_t$
  - ▶ Government:  $g_t + B_t + T_t = \tau_t \theta_t l_t + \frac{p_t}{q_{t-1}} B_{t-1}$

- ▶ **Market Clearing**

- ▶ Goods:  $c_t + g_t = \theta_t l_t$
  - ▶ Assets:  $b_t + B_t = 0$

- ▶ **Initial conditions:** Assets  $b_{-1} = -B_{-1}$  and  $s_{-1}$

# Ramsey Problem

## Definition

**Allocation, price system, government policy**

## Definition

**Competitive equilibrium:** Given  $(b_{-1}, B_{-1}, s_{-1})$  and  $\{\tau_t, T_t\}_{t=0}^{\infty}$ , all allocations are individually rational, markets clear <sup>1</sup>

## Definition

**Optimal competitive equilibrium:** A welfare-maximizing competitive equilibrium for a given  $(b_{-1}, B_{-1}, s_{-1})$

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<sup>1</sup>Usually, we impose only “natural” debt limits.

# Ramsey problem

1. **Primal approach:** To eliminate tax rates and prices, use household's first order conditions:

$$U_{c,t}q_t = \beta \mathbb{E}_t p_{t+1} U_{c,t+1}$$

$$(1 - \tau_t)\theta_t U_{c,t} = -U_{l,t}$$

2. **Implementability constraints:** Derive by iterating the household's budget equation forward at every history  
 $\Rightarrow$  for  $t \geq 1$ , these impose *measurability restrictions* on Ramsey allocations
3. The  $t \geq 1$  **measurability constraints** contribute the only difference from Lucas-Stokey's Ramsey problem.



# Ramsey problem

4. **Transfers:** We temporarily restrict transfers  $T_t = 0 \forall t$ . This is convenient for our analytical results. We eventually show that this assumption is not restrictive.

# Ramsey problem (Lucas-Stokey)

$$\max_{\{c_t, l_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t)$$

subject to

(a) **Feasibility**

$$c_t + g_t = \theta_t l_t$$

(b) **Implementability constraint**

$$b_{-1} = \frac{1}{U_{c,0}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (U_{c,t} c_t + U_{l,t} l_t)$$

# Ramsey problem (BEGS)

$$\max_{\{c_t, l_t, b_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t)$$

(a) **Feasibility**

$$c_t + g_t = \theta_t l_t$$

(b) **Lucas-Stokey implementability constraint**

$$b_{-1} = \frac{1}{U_{c,0}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (U_{c,t} c_t + U_{l,t} l_t)$$

(c) **Measurability constraints**

$$\frac{b_{t-1} U_{c,t-1}}{\beta} = \frac{\mathbb{E}_{t-1} p_t U_{c,t}}{p_t U_{c,t}} \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j (U_{c,t+j} c_{t+j} + U_{l,t+j} l_{t+j}) \text{ for } t \geq 1$$

# Roadmap, analytic strategy

- ▶ Ramsey allocation – especially asymptotic properties – varies with **asset returns** that reflect
  - ▶ Prices  $\{q_t(s^t|B_{-1}, s_{-1})\}_t$
  - ▶ Payoffs  $\mathbb{P}$
- ▶ To focus on the exogenous  $\mathbb{P}$  part of returns, we first study quasi-linear preferences that pin down  $q_t = \beta \mathbb{E}_t \mathbb{P}(s_{t+1}|s_t)$
- ▶ Activate risk aversion and fluctuating  $q_t$  later

# Battlefield

*What is government debt in long-run?*

	risk-free bond	risky bond
Quasi-Linear		
Risk Aversion		

# Analysis with quasi-linear preferences

Quasilinear preferences  $U(c, l) = c - \frac{l^{1+\gamma}}{1+\gamma}$

To characterize **long-run** debt and taxes, we construct and then invert mapping  $\mathbb{P}^*(b)$

- ▶ Given **arbitrary** initial govt. assets  $b_{-1}$ , what is an **optimal** asset payoff matrix  $\mathbb{P}^* = \mathbb{P}^*(b_{-1})$ ?
- ▶ Under a Ramsey plan for an **arbitrary** payoff matrix  $\mathbb{P}$ , when would  $b_t \rightarrow b^*$ , where

$$\mathbb{P} = \mathbb{P}^*(b^*) \text{ or } b^* = \mathbb{P}^{*-1}(\mathbb{P})?$$

## Roadmap, the answers

- ▶ We first reverse engineer an optimal  $\mathbb{P}^*(b_{-1})$  from a Lucas-Stokey Ramsey allocation
- ▶ In a binary IID world, we identify a big set of  $\mathbb{P}$ 's that imply that  $b_t$  under a Ramsey plan converges to  $b^*$  that solves

$$\mathbb{P} = \mathbb{P}^*(b^*)$$

- ▶ For more general shock structures, we numerically verify an ergodic set of  $b_t$ 's hovering around  $\tilde{b}$ . The optimal  $\mathbb{P}^*$  associated with  $\tilde{b}$  seems close to  $\mathbb{P}$ :

$$\mathbb{P} \approx \mathbb{P}^*(\tilde{b})$$

## Optimal asset payoff matrix $\mathbb{P}^*$

1. Given  $b_{-1}$ , compute a Lucas-Stokey Ramsey allocation
2. Notice that the measurability constraints are invariant to scaling of  $p_t$  by a constant  $k_{t-1}$  that can depend on  $s^{t-1}$ .
3. From this class we choose a solution for  $p_t$  using the normalization that  $\mathbb{E}_{t-1} U_{c,t} p_t = 1$ .

$$p_t = \frac{\beta}{U_{c,t-1} b_{t-1} U_{c,t}} \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j (U_{c,t+j} c_{t+j} + U_{l,t+j} l_{t+j})$$

4. By construction,  $p_t$  disarms the  $t \geq 1$  measurability constraints.
5. Using the fact that the Lucas-Stokey allocation is stationary, we can construct the optimal payoff matrix

$$\mathbb{P}^*(s_t, s_{t-1} | b_{-1}) = p_t$$



## Quasilinear preferences $U(c, l) = c - \frac{l^{1+\gamma}}{1+\gamma}$

Given initial assets  $b_{-1}$ , let  $\mu(b_{-1})$  be the Lagrange multiplier on the Lucas-Stokey implementability constraint

### 1. Multiplier $\rightarrow$ Tax rate:

$$\tau(\mu) = \frac{\gamma\mu}{(1+\gamma)\mu - 1}$$

### 2. Tax rate $\rightarrow$ net of interest surplus:

$$S(s, \tau) = \theta(s)^{\frac{\gamma}{1+\gamma}} (1 - \tau)^{\frac{1}{\gamma}} \tau - g(s)$$

### 3. Surplus $\rightarrow$ optimal payoff structure:

$$\mathbb{P}^*(s, s_- | b_{-1}) = (1 - \beta) \frac{S(s, \tau)}{\mathbb{E}_{s_-} S(s, \tau)} + \beta$$

# Initial holdings influence optimal asset payoff structure

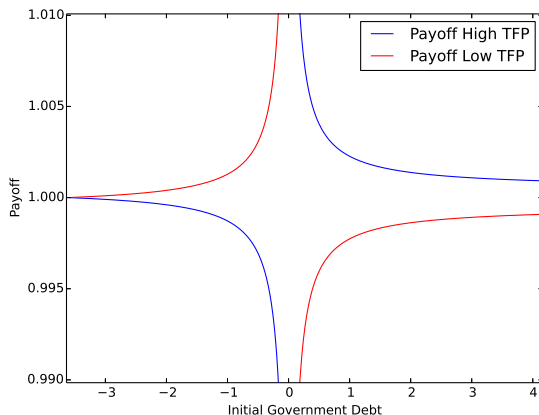
Denote state  $s$  as “adverse” if it has “high” govt. expenditures or “low ” TFP; formally,  $s$  is “adverse” if

$$g(s)\mathbb{E}_{s_-}\theta^{\frac{\gamma}{1+\gamma}} - \theta(s)^{\frac{\gamma}{1+\gamma}}\mathbb{E}_{s_-}g > 0$$

Properties of optimal payoff matrix  $\mathbb{P}$

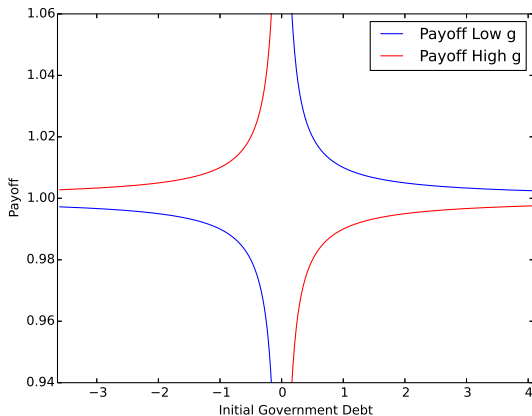
- ▶ With positive initial govt. assets: want an asset that pays *more* in “adverse” states
- ▶ With negative initial govt. assets: want an asset that pays *less* in “adverse” states

# Optimal Payoff Structure: TFP shocks



**Figure:** Optimal asset payoff structure as a function of initial government debt when TFP follows a 2 shock i.i.d process

# Optimal Payoff Structure: Expenditure shocks



**Figure:** Optimal asset payoff structure as a function of initial government debt when government expenditures follow 2 shock i.i.d process

# Inverting the $\mathbb{P}^*$ mapping

1. **Exogenous payoff structure:** Suppose  $\mathbb{P} \neq \mathbb{P}^*(b_{-1})$
2. **Steady States:** A steady state is a government debt  $b^*$  such that

$$b_t = b^* \text{ implies } b_{t+\tau} = b^* \quad \forall \tau > 0$$

3. **Characterization:** Given an asset payoff structure  $\mathbb{P}$ 
  - ▶ Does a steady state exist? Is it unique?
  - ▶ Value of  $b^*$ ?
  - ▶ For what *initial government debts*  $b_{-1}$  does  $b_t$  converge to  $b^*$ ?

## Existence and $\mathbb{P}^{*-1}$

When shocks are i.i.d and take two values

1.  $\mathbb{P}(s_-, s)$  is independent of  $s_-$  (so  $\mathbb{P}$  can be a vector)
2. Under the normalization of  $q_t = \beta$  we have  $\mathbb{E}\mathbb{P}(s) = 1$ .  
Payoffs are then determined by a single scalar  $p$ .
  - ▶  $p$  is the payoff in the “good” state  $s$
  - ▶ A risk-free bond is a security for which  $p = 1$
3. A steady state is obtained by inverting the optimal payoff mapping  $p^*$

$$b^* \text{ satisfies } p = p^*(b^*) \text{ or } p^{*-1}(p) = b^*$$

One equation in one unknown  $b^*$

## Existence regions in $p$ space

The payoff  $p$  in good state  $\in (0, \infty)$ .

We can decompose a set of economies with different asset payoffs into 3 regions via thresholds  $\alpha_2 \geq \alpha_1 \geq 1$

- ▶ Low enough  $p(\leq \alpha_1)$ : government holds assets in steady state
- ▶ High enough  $p(\geq \alpha_2)$ : government issues debt in steady state
- ▶ Intermediate  $p(\alpha_1 > p > \alpha_2)$ : steady state does not exist

## Thresholds: $\alpha_1 < \alpha_2$

- ▶ With only government expenditure shocks

$$\alpha_1 = 1 \text{ and } \alpha_2 = (1 - \beta) \frac{\theta^{\frac{\gamma}{1+\gamma}} \left( \frac{1}{1+\gamma} \right)^{\frac{1}{\gamma}} \frac{\gamma}{1+\gamma} - g(s_1)}{\theta^{\frac{\gamma}{1+\gamma}} \left( \frac{1}{1+\gamma} \right)^{\frac{1}{\gamma}} \frac{\gamma}{1+\gamma} - \mathbb{E}g} + \beta > 1$$

- ▶ With only TFP shocks

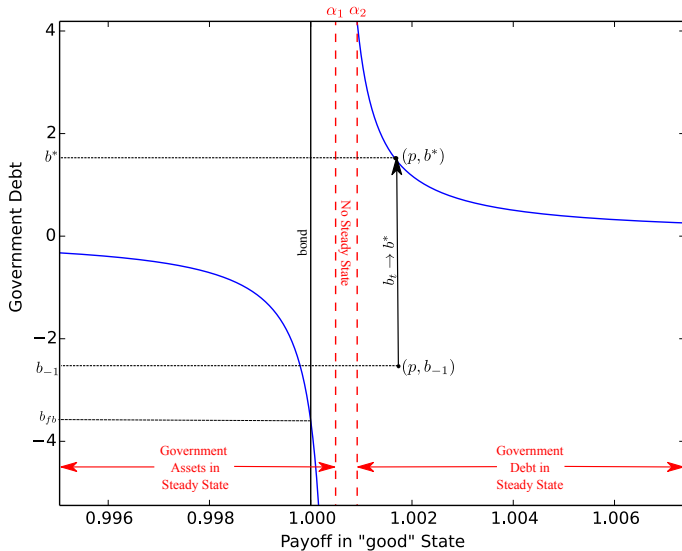
$$\alpha_1 = (1 - \beta) \frac{\theta(s_1)^{\frac{\gamma}{1+\gamma}}}{\mathbb{E}\theta^{\frac{\gamma}{1+\gamma}}} + \beta > 1$$

and

$$\alpha_2 = (1 - \beta) \frac{\theta(s_1)^{\frac{\gamma}{1+\gamma}} \left( \frac{1}{1+\gamma} \right)^{\frac{1}{\gamma}} \frac{\gamma}{1+\gamma} - g}{\mathbb{E}\theta^{\frac{\gamma}{1+\gamma}} \left( \frac{1}{1+\gamma} \right)^{\frac{1}{\gamma}} \frac{\gamma}{1+\gamma} - g} + \beta > \alpha_1$$



# Existence regions in $p$ space



# Convergence

- ▶ Our analysis verifies existence of a steady state in a 2-state i.i.d. economy.
- ▶ To study long-run properties of a Ramsey allocation, we want to know whether steady state is stable
- ▶ **Risk-adjusted martingale:**  
The Lagrange multiplier  $\mu_t$  on the implementability constraint satisfies

$$\mu_t = \mathbb{E}_t p_{t+1} \mu_{t+1}$$

or

$$\mathbb{E}_t \mu_{t+1} = \mu_t - \text{Cov}_t(p_{t+1}, \mu_{t+1})$$

- ▶ **Stability criterion:** Away from a steady state, is the drift of  $\mu_t$  big enough?

# Characterizing convergence under quasi-linearity, iid, and $S = 2$

- ▶ Reminder:  $p$  is the payoff in the “good” state.
- ▶ We partition the “ $p$  space” into stable and unstable regions

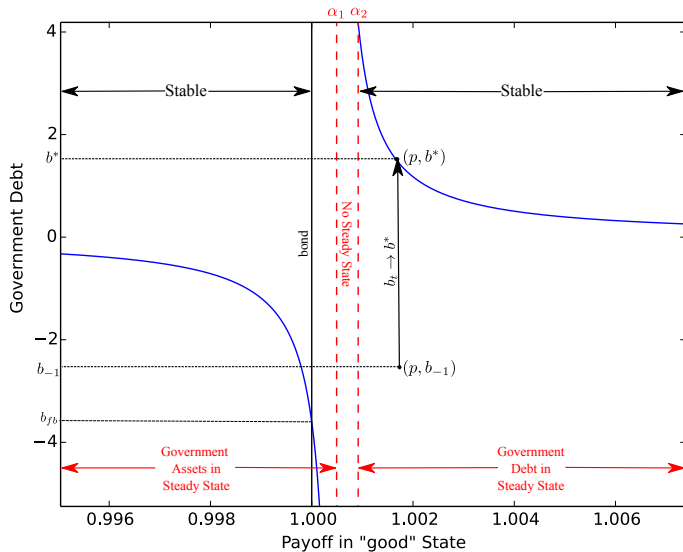
## Theorem

*Let  $b^*$  denote steady state govt. debt and  $b_{fb}$  be govt. debt that supports the first-best allocation with complete markets. Then*

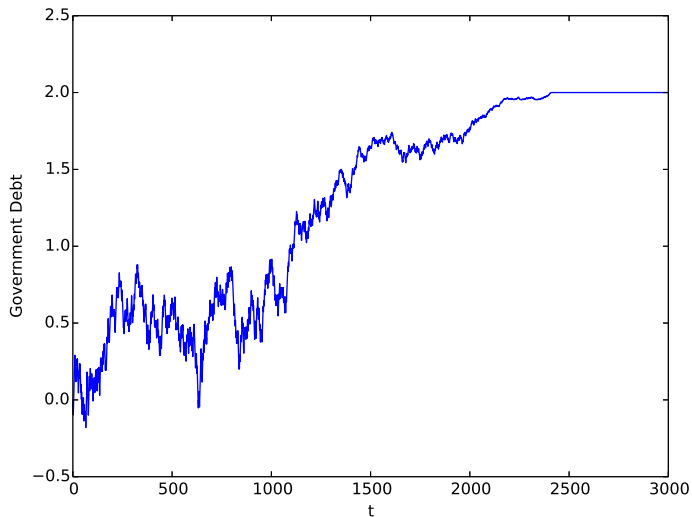
1. **Low  $p$ :** *If  $p \leq \min(\alpha_1, 1)$  then  $b_{fb} < b^* < 0$  and  $b_t \rightarrow b^*$  with probability 1.*
2. **High  $p$ :** *If  $p \geq \alpha_2$  then  $0 < b^*$  and  $b_t \rightarrow b^*$  with probability 1.*

For the intermediate region where  $b^*$  either does not exist or is unstable, there is a tendency to run up debt

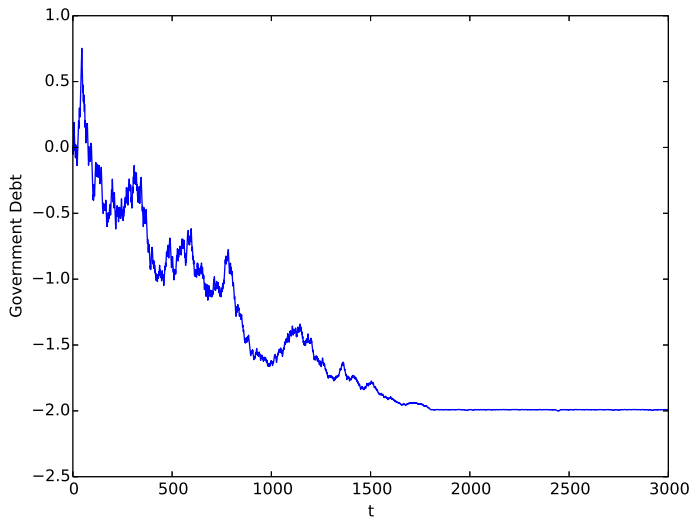
# Stability regions



## A sample path with $p > 1$



## A sample path with $p < 1$



# Intuition for Convergence

- ▶ The optimal policy with incomplete markets smooths the welfare costs of distorting labor taxes by manipulating debt positions
- ▶ With a risk free bond the marginal cost of raising funds  $\mu_t$  follow a martingale. In such economies, changes in debt levels help smooth tax distortions across time.
- ▶ If the payoff matrix of the asset differs across states, then level of government debt smooths tax distortions across states by generating state contingent revenues.
- ▶ The steady state  $b^*$  is a unique debt level that provides the exact “state contingency” to overcome the missing assets markets
- ▶ When issuing debt the government takes this benefit into account, distorting the martingale, and leading to either the accumulation or decumulation of debt.
- ▶ Although this is achieved by raising taxes, locally, the welfare costs of taxes is second order dominated by the gains from coming closer to  $b^*$  which are first order in terms of welfare.
- ▶ This explains the long run convergence to  $b^*$

# Outcomes with quasi-linear preferences

## Outcomes:

1. Often  $b_t \rightarrow b^*$  when the aggregate state follows a 2-state i.i.d. process
2. The level and sign of  $b^*$  depend on the **exogenous payoff structure**  $\mathbb{P}$
3. The limiting allocation corresponds to a complete market Ramsey allocation for initial govt. debt  $b^*$



# Turning on risk-aversion

## Modifications:

- ▶ Another source of return fluctuations – the risk-free interest rate
- ▶ Marginal utility adjusted debt encodes history dependence
- ▶ With binary i.i.d shock process,  $x_t = u_{c,t}b_t$  converges
- ▶ Long-run properties of  $x_t$  depend on equilibrium returns  $R_{t,t+1} = \frac{\mathbb{P}(s_t, s_{t+1})}{q_t(s^t)}$ . Now  $q_t$  varies in interesting ways

## Roadmap, II

Two subproblems

1.  $t = 0$  Bellman equation in value function  $W(b_{-1}, s_0)$
2.  $t \geq 1$  Bellman equation in value function  $V(x, s_-)$

Seek steady states  $x^*$  such that  $x_t \rightarrow x^*$

# A Recursive Formulation

1. Commitment implies that government actions at  $t \geq 1$  are constrained by the public's anticipations about them at  $s < t$
2. This contributes additional state variables like marginal utility of consumption
3. Scaling the budget constraint by marginal utility makes Ramsey problem recursive in  $x = U_c b$

$$\frac{x_{t-1} p_t U_{c,t}}{\beta \mathbb{E}_{t-1} p_t U_{c,t}} = U_{c,t} c_t + U_{l,t} l_t + x_t$$

Bellman equation for  $t \geq 1$  (*ex ante*)

$$V(x, s_-) = \max_{c(s), l(s), x'(s)} \sum_s \Pi(s, s_-) \left( U(c(s), l(s)) + \beta V(x'(s), s) \right)$$

subject to  $x'(s) \in [\underline{x}, \bar{x}]$

$$\frac{x \mathbb{P}(s) U_c(s)}{\beta \mathbb{E}_{s_-} \mathbb{P} U_c} = U_c(s) c(s) + U_l(s) l(s) + x'(s)$$

$$c(s) + g(s) = \theta(s) l(s)$$

## Time 0 Bellman equation (*ex post*)

Given an initial debt  $b_{-1}$ , state  $s_0$ , and continuation value function  $V(x, s_-)$

$$W(b_{-1}, s_0) = \max_{c_0, l_0, x_0} U(c, l) + \beta V(x_0, s_0)$$

subject to time zero implementability constraint

$$U_c(c_0, l_0)c + U_l(c_0, l_0)l_0 + x_0 = U_c(c_0, l_0)b_{-1}$$

and resource constraint

$$c_0 + g(s_0) = \theta(s_0)l_0$$

and

$$x_0 \in [\underline{x}, \bar{x}]$$

# Progress report

1. Existence proved only under a special case of a risk-free bond  
 $\mathbb{P}(s|s_-) = 1 \ \forall (s, s_-)$   
This focuses attention on *endogenous* component of returns coming from  $q_t(s^t)$
2.  $x^*$  is an initial condition for which the optimal asset payoff in a LS economy is a risk-free bond

## Revisiting steady states with risk aversion

Let  $x'(s; x, s_-)$  be an optimal law of motion for the state variable for the  $t \geq 1$  recursive problem.

### Definition

A steady state  $x^*$  satisfies  $x^* = x'(s; x^*, s_-)$  for all  $s, s_-$

*Thus, a steady state is a node at which continuation allocation and tax rate have no further history dependence.*

# Existence

1. For a class of economies with separable iso-elastic preferences
$$U(c, l) = \frac{c^{1-\sigma}}{1-\sigma} - \frac{l^{1+\gamma}}{1+\gamma}$$
2. Shocks that take two values and are i.i.d with  $s_b$  being the “adverse” state (either low TFP or high expenditure)

Let  $x_{fb}$  be a value of the state  $x$  from which a government can implement first=best with complete markets

## Proposition

*Let  $q_{fb}(s)$  be the shadow price of government debt in state  $s$  using the first best allocation. If*

$$\frac{1 - q_{fb}(s_b)}{1 - q_{fb}(s_g)} > \frac{g(s_b)}{g(s_g)} > 1$$

*Then there exists a steady state with  $x_{fb} > x^* > 0$*



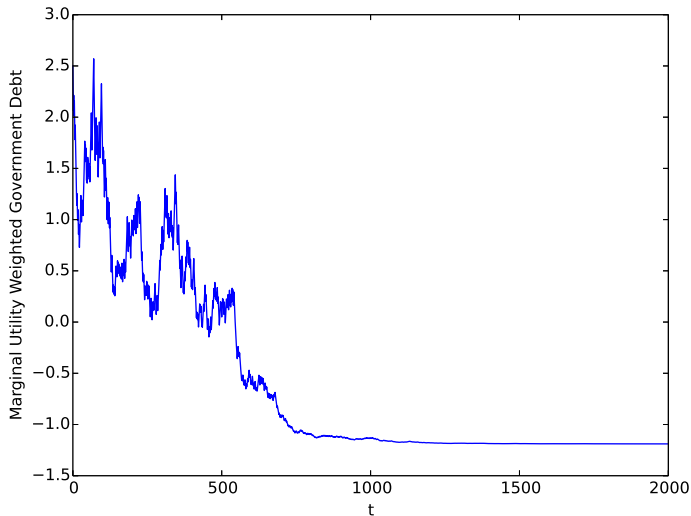
# Stability

1. Here interest rates are aligned with marginal utility of consumption; they are low in “good” states (high TFP or low expenditure)
2. The government holds claims against the private sector in the steady state. Similar to the quasilinear case with low  $p$
3. The incomplete markets Ramsey allocation converges to a Lucas-Stokey Ramsey allocation for all initial conditions

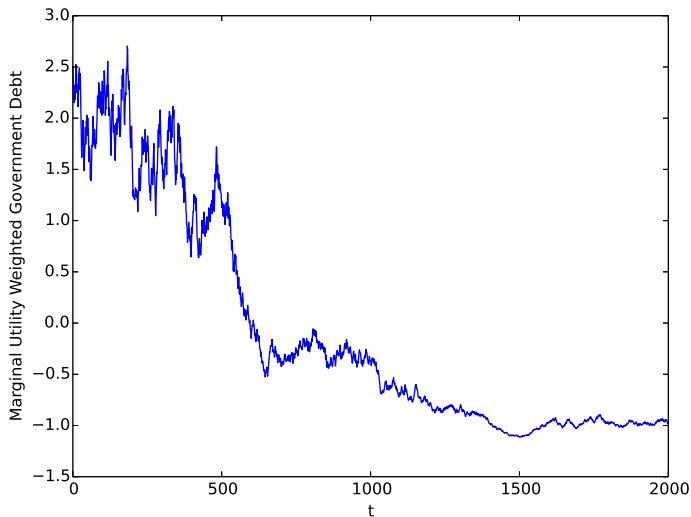
## Proposition

*Let  $\{c_t(s^t), l_t(s^t), x_t(s^{t-1})\}$  solve the incomplete markets Ramsey problem with  $x_0 > x^*$ . Then  $x_t(s^{t-1}) \rightarrow x^*$  as  $t \rightarrow \infty$  with probability 1 for all initial conditions*

## A sample path for 2 state i.i.d. process with risk aversion



## A sample path for economy with $S > 2$ states



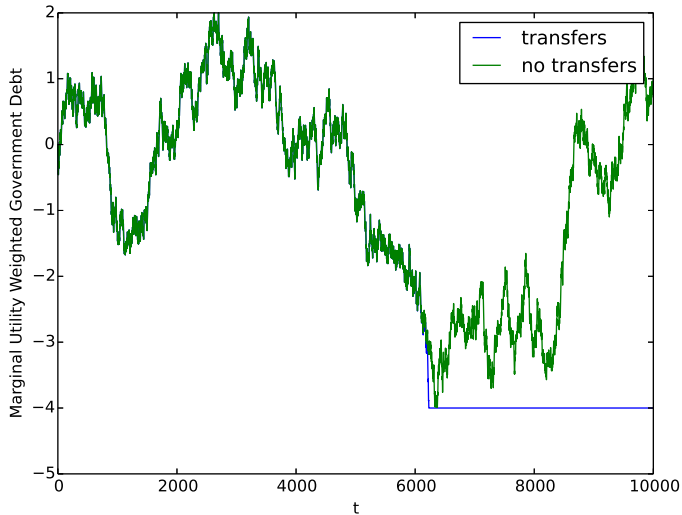
# Transfers

- ▶ Access to nonnegative transfers makes first-best level of assets trivially a “steady state”
- ▶ All results hold *on one side* of steady state

## Theorem

*With nonnegative lump sum transfers, in cases where a steady state exists and is stable, if the initial debt of the government exceeds its steady state level, the economy converges with probability 1 to the steady state.*

# Quasilinear preferences and risk-free bond with and without nonnegative transfers



# Battlefield

*What is government debt in long-run?*

With shocks that are IID and take two values

	risk-free bond	risky bond
Quasi-Linear	(AMSS) With $T_t \geq 0$ , govt. accumulates enough assets for first best.	Partition payoff space so that govt. either a) issues or b) runs up debt eventually
Risk Aversion	Conditions under which limiting govt. assets < first best	<i>Conjecture:</i> Similar to quasi-linear out- comes

In future work we plan to study more general shocks processes

# Comparison to literature

1. Angelotos (2002), Buera and Nicolini (2004)
  - ▶ Begins with a complete market Ramsey allocation
  - ▶ Asks if this can be attained using only *some* collection of non-contingent debt of different maturities?
2. This paper
  - ▶ Begins with an incomplete markets Ramsey allocation
  - ▶ Asks whether the long-run allocation coincides with *some* complete market allocation?
3. BEGS1 studies a related problem with heterogeneous agents