Virtual Seminar on Climate Economics

Federal Reserve Bank of San Francisco

Organizing Committee:
Glenn Rudebusch (Federal Reserve Bank of San Francisco)
Michael Bauer (University of Hamburg)
Stephie Fried (Federal Reserve Bank of San Francisco)
Òscar Jordà (Federal Reserve Bank of San Francisco)
Toan Phan (Federal Reserve Bank of Richmond)

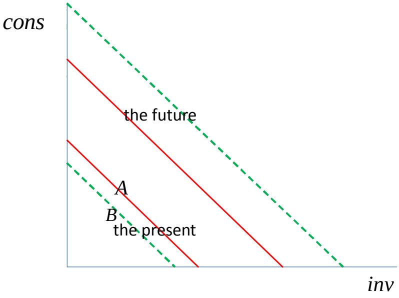
Asset Prices and Incentives for Climate Policy (Empower the Young!)

Larry Karp   Alessandro Peri   Armon Rezai

Federal Reserve April 2021

The comic book version of Integrated Assessment Models

- Abatement today reduces current world income, increases future world income
- Currently living young might benefit from today's abatement later in their life.
- Meaningful climate policy requires intergenerational altruism (or intergenerational transfers, requiring commitment or trigger strategies).



Definition

- The "composite commodity model" uses a linear production possibility frontier (PPF)
- Output can be converted to either the consumption good or the investment good at a constant rate, normalized to 1.

Our innovations

- We replace the composite commodity model with a strictly concave PPF (a consumption good and an investment good) – so that the price of investment (and thus the price of undepreciated capital) is endogenous.
- We replace the Infinitely Lived Representative Agent model with a Diamond OLG model – so that there is both a buyer and a seller of undepreciated capital.
- These changes enable us to introduce asset prices into an otherwise standard Integrated Assessment Model (IAM).
    - By our timing convention, the "asset price" equals the price of undepreciated assets at the *end* of a period, which equals the price of a unit of the investment good. (Old and new capital are equally productive.)

Basic ideas behind our paper:

- Asset prices depend on their expected future returns and on current demand.
- Protecting the future climate increases future returns to capital, thereby potentially increasing the current price of capital.
- Current abatement, by lowering current world income, might depress demand for savings, potentially lowering the current price of capital.
- People who sell or buy capital (the old and the young in our model) care about the current asset price even if they do not care about future generations.
- Asset markets can change the incentive to undertake climate policy even for *selfish* agents.

Research questions:

- (Qualitative/analytic) How – if at all – does the existence of an endogenous asset price alter selfish agents' incentive to reduce GHG emissions?
  - When – if ever – are the interests (with regard to abatement policy) of the old and the young (those who sell and those who buy capital) aligned?
- (Quantitative) Even if asset markets *potentially* alter incentives to undertake climate policy, is this effect likely to be significant?

The concave PPF versus composite commodity

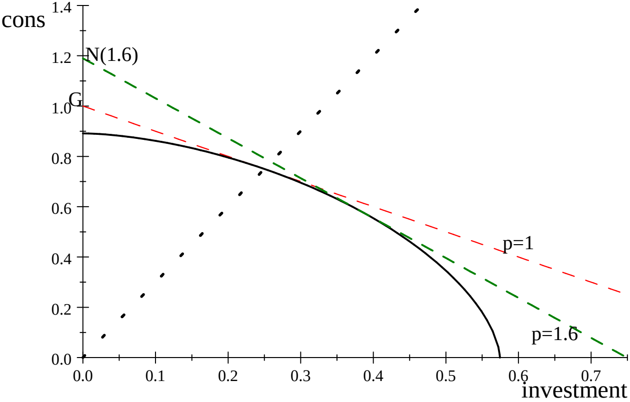


Figure: The first unit of abatement has a *first order* effect on the equilibrium asset price and only a *second order* effect on the PPF.

The concave PPF versus composite commodity – again

- With the concave PPF, climate policy and changes in climate stocks can alter both the price and the level of investment.
- With the composite commodity framework, any adjustment occurs via changes in the level of investment – the price of investment is fixed at 1 (a normalization).
- Our particular concave PPF is a tractable alternative to multi-sector models (e.g. Ricardo-Viner or Heckscher-Ohlin-Samuelson).

Preview of Qualitative results: I

- We hold future climate policy fixed and examine the effect of the *first* unit of abatement in the current period.
- How does welfare respond to an abatement-induced change in the asset price?
    - Old agent benefits if and only this abatement increases the asset price.

- This result provides the basis for understanding the effect, on endogenous climate policy, of generations' relative political power.

Preview of Qualitative results: I

- We hold future climate policy fixed and examine the effect of the *first* unit of abatement in the current period.
- How does welfare respond to an abatement-induced change in the asset price?
  - Old agent benefits if and only this abatement increases the asset price.
  - Young agent benefits from an abatement-induced increase in the asset price iff EIS > 1.
- This result provides the basis for understanding the effect, on endogenous climate policy, of generations' relative political power.

Preview of Qualitative results: I

- We hold future climate policy fixed and examine the effect of the *first* unit of abatement in the current period.
- How does welfare respond to an abatement-induced change in the asset price?
  - Old agent benefits if and only this abatement increases the asset price.
  - Young agent benefits from an abatement-induced increase in the asset price iff EIS > 1.
  - $\Rightarrow$ Currently living agents' incentives are aligned if and only if EIS$>$1. (Conventional IAM calibration uses EIS$<$1.)
- This result provides the basis for understanding the effect, on endogenous climate policy, of generations' relative political power.

Preview of Qualitative results: II

- How does the *first* unit of abatement affect asset prices?
  - 2-period setting, as $EIS \rightarrow \infty$ (linear preferences) abatement increases asset price, benefiting both of the currently living agents and the agent born in the next period.

- For $EIS = 1$ (logarithmic utility),

Preview of Qualitative results: II

- How does the *first* unit of abatement affect asset prices?
  - 2-period setting, as $EIS \to \infty$ (linear preferences) abatement increases asset price, benefiting both of the currently living agents and the agent born in the next period.
  - 2-period setting, as $EIS \to 0$ (Leontieff preferences) abatement reduces the asset price, benefiting the young agent, harming the old agent and (typically) benefitting the agent born in the next period
- For $EIS = 1$ (logarithmic utility),

Preview of Qualitative results: II

- How does the *first* unit of abatement affect asset prices?
  - 2-period setting, as $EIS \to \infty$ (linear preferences) abatement increases asset price, benefiting both of the currently living agents and the agent born in the next period.
  - 2-period setting, as $EIS \to 0$ (Leontieff preferences) abatement reduces the asset price, benefiting the young agent, harming the old agent and (typically) benefitting the agent born in the next period
- For $EIS = 1$ (logarithmic utility),
  - First unit of abatement has zero first-order effect on everything.

Preview of Qualitative results: II

- How does the *first* unit of abatement affect asset prices?
  - 2-period setting, as $EIS \to \infty$ (linear preferences) abatement increases asset price, benefiting both of the currently living agents and the agent born in the next period.
  - 2-period setting, as $EIS \to 0$ (Leontieff preferences) abatement reduces the asset price, benefiting the young agent, harming the old agent and (typically) benefitting the agent born in the next period
- For $EIS = 1$ (logarithmic utility),
  - First unit of abatement has zero first-order effect on everything.
  - *Non-neglible* abatement lowers the asset price and harms both the young and old agents; agent born in the next period inherits a cleaner environment but lower capital stock.

Reasons you might be skeptical

- If capital depreciates by almost 100% in a period, the old agent has little capital to sell at the end of the period.
  - Here, the old agent cares about the current return on capital, but does not care much about the end of period asset price.
- Capital dynamics are "fast", climate dynamics are "slow".
- If the PPF is quite flat, there is little scope for price change; any shift between the consumption and the investment good is achieved by a very small change in the asset price.
- We need a quantitative model to determine endogenous policy and to assess both the direction and the magnitude of changes induced by the endogeneity of the asset price.

Preview of Quantitative results

- Equilibrium abatement tends to be larger for $EIS > 1$.
- For $EIS < 1$ (the conventional choice), abatement lowers asset price.
  - Equilibrium abatement is significant only if the young have significant influence in decision-making
- Even for parameters that produce negligible equilibrium abatement in the short run, the long run (cumulative) effects can be significant.
- Equilibrium abatement is still much lower than under the discounted utilitarian.

Preview of Quantitative results

- Equilibrium abatement tends to be larger for $EIS > 1$.
- For $EIS < 1$ (the conventional choice), abatement lowers asset price.
  - Equilibrium abatement is significant only if the young have significant influence in decision-making
  - The policy message: Empower the young.
- Even for parameters that produce negligible equilibrium abatement in the short run, the long run (cumulative) effects can be significant.
- Equilibrium abatement is still much lower than under the discounted utilitarian.

Three related papers

- Bovenberg and Heijdra (1998), Anderson et al. (2020), Kotlikoff et al. (2021).
  - Demonstrate and measure the ability of climate policy + intergenerational transfers via debt to make all generations better off.
- We have a different research question, use a different model, and different equilibrium concept

Three related papers

- Bovenberg and Heijdra (1998), Anderson et al. (2020), Kotlikoff et al. (2021).
    - Demonstrate and measure the ability of climate policy + intergenerational transfers via debt to make all generations better off.
    - Assume that the sequence of policy actions is chosen at the initial time (with commitment).
- We have a different research question, use a different model, and different equilibrium concept

Three related papers

- Bovenberg and Heijdra (1998), Anderson et al. (2020), Kotlikoff et al. (2021).
  - Demonstrate and measure the ability of climate policy + intergenerational transfers via debt to make all generations better off.
  - Assume that the sequence of policy actions is chosen at the initial time (with commitment).
- We have a different research question, use a different model, and different equilibrium concept
  - To what extent (if any) do endogenous asset prices create incentives for climate policy?

Three related papers

- Bovenberg and Heijdra (1998), Anderson et al. (2020), Kotlikoff et al. (2021).
    - Demonstrate and measure the ability of climate policy + intergenerational transfers via debt to make all generations better off.
    - Assume that the sequence of policy actions is chosen at the initial time (with commitment).
- We have a different research question, use a different model, and different equilibrium concept
    - To what extent (if any) do endogenous asset prices create incentives for climate policy?
    - We have a strictly concave PPF and endogenous asset prices; they use the composite commodity setting with a fixed asset price.

Three related papers

- Bovenberg and Heijdra (1998), Anderson et al. (2020), Kotlikoff et al. (2021).
  - Demonstrate and measure the ability of climate policy + intergenerational transfers via debt to make all generations better off.
  - Assume that the sequence of policy actions is chosen at the initial time (with commitment).
- We have a different research question, use a different model, and different equilibrium concept
  - To what extent (if any) do endogenous asset prices create incentives for climate policy?
  - We have a strictly concave PPF and endogenous asset prices; they use the composite commodity setting with a fixed asset price.
  - We assume that the current generation can choose the current policy, but not commit to future polices (Markov Perfect equilibrium).

Other related literature

- Empirical evidence that asset prices respond to changes in environmental conditions establishes the relevance of our research questions.
- Integrated Assessment Models (DICE) for a basis of comparison and for calibration.
- Use of Markov Perfect Equilibria to describe policy in second best settings when agents are forward looking.
- Numerical methods.

Interesting but orthogonal literature

- Questions about stranded assets.
- The role of uncertainty (e.g. the "climate β").
- International disagreements; contemporaneous free riding.
- Multiple assets and the choice of portfolios.

The model: preferences

The young agent's maximization problem is

$$\max_{I_t,\ s_t,\ c_t^y,\ c_{t+1}^o} U(c_t^y) + \rho\ U(c_{t+1}^o) \text{ subject to}$$

$$\begin{aligned} c_t^y &\leq w_t - p_t \left[s_t (1-\delta) K_t + I_t \right] \\ c_{t+1}^o &\leq \left(r_{t+1} + p_{t+1} \left(1-\delta\right)\right) \left(s_t (1-\delta) K_t + I_t \right). \end{aligned} \tag{1}$$

Utility is CRRA:

$$U(c) = \frac{c^{1-\eta} - 1}{1-\eta} \text{ and } \eta \geq 0;\ \eta = \frac{1}{EIS} \tag{2}$$

The asset price equation

Agent's FOC implies the asset pricing equation:

$$p_t = \frac{r_{t+1} + p_{t+1}(1-\delta)}{\psi_t} \text{ with } \psi_t \equiv \frac{U'(c_t^y)}{\rho \; U'(c_{t+1}^o)} \tag{3}$$

The model: production

- $\mathbf{z} = (K_t, L, E_t, \mu_t)$ =(capital, labor, stock of atmospheric carbon, abatement rate). $G(\mathbf{z})$ = value of world output at $p = 1$; e.g. $G(\mathbf{z}) = D(E)\Lambda(\mu)(AL)^{\beta} K^{1-\beta}$
- We use a constant elasticity of transformation (CET) PPF with elasticity of transformation $\infty > \sigma \geq 0$ and shape parameter a:

$$c = \left(\left(1 + a^{-\sigma}\right)^{-\frac{1}{\sigma}} G(\mathbf{z})^{\frac{1+\sigma}{\sigma}} - a I^{\frac{1+\sigma}{\sigma}} \right)^{\frac{\sigma}{1+\sigma}}. \tag{4}$$

  - Produces composite commodity model in limit as $\sigma \to \infty$.
- This model produces closed form expressions for the wage, the return to capital, and investment, as functions of z and the price p. (Discuss alternatives if time permits.)
- We can use these to evaluate welfare and dynamics.

Stock dynamics

$$E_{t+1} = (1-\epsilon)E_t + (1-\mu_t)\,\zeta F\,(K_t, L)$$
$$\text{and}$$
$$K_{t+1} = (1-\delta)K_t + I_t, \text{ with } E_0 \text{ and } K_0 \text{ given.} \tag{5}$$

Our calibration sets $\epsilon = 0$: damages depend on cumulative CO_2 emissions.

The linear utility makes the role of asset prices transparent

- Let $\eta = 0$ (linear preferences) and $H = 1$ (the two-period problem)
- For $\sigma < \infty$ (*a strictly concave PPF*), the marginal unit of abatement increases the asset price, benefiting both the current young and old generations.
  - The higher asset price increases investment. The agent born in the next period inherits a cleaner environment and a larger stock of capital.
- In the limit as $\sigma \to \infty$ (*the composite commodity framework*). The asset price is fixed at $p_0 = 1 = \rho r_1 (K_1, L, E_1)$.

The linear utility makes the role of asset prices transparent

- Let $\eta = 0$ (linear preferences) and $H = 1$ (the two-period problem)
- For $\sigma < \infty$ (*a strictly concave PPF*), the marginal unit of abatement increases the asset price, benefiting both the current young and old generations.
  - The higher asset price increases investment. The agent born in the next period inherits a cleaner environment and a larger stock of capital.
- In the limit as $\sigma \rightarrow \infty$ (*the composite commodity framework*). The asset price is fixed at $p_0 = 1 = \rho r_1 (K_1, L, E_1)$.
  - Reduction in E_1 induces an offsetting reduction in K_1 to maintain the equality $1 = \rho r_1 (K_1, L, E_1)$.

The linear utility makes the role of asset prices transparent

- Let $\eta = 0$ (linear preferences) and $H = 1$ (the two-period problem)
- For $\sigma < \infty$ (*a strictly concave PPF*), the marginal unit of abatement increases the asset price, benefiting both the current young and old generations.
    - The higher asset price increases investment. The agent born in the next period inherits a cleaner environment and a larger stock of capital.
- In the limit as $\sigma \to \infty$ (*the composite commodity framework*). The asset price is fixed at $p_0 = 1 = \rho r_1 (K_1, L, E_1)$.
    - Reduction in E_1 induces an offsetting reduction in K_1 to maintain the equality $1 = \rho r_1 (K_1, L, E_1)$.
    - The marginal unit of abatement has zero first-order welfare effect on all agents' welfare.

The linear utility makes the role of asset prices transparent

- Let $\eta = 0$ (linear preferences) and $H = 1$ (the two-period problem)
- For $\sigma < \infty$ (*a strictly concave PPF*), the marginal unit of abatement increases the asset price, benefiting both the current young and old generations.
  - The higher asset price increases investment. The agent born in the next period inherits a cleaner environment and a larger stock of capital.
- In the limit as $\sigma \rightarrow \infty$ (*the composite commodity framework*). The asset price is fixed at $p_0 = 1 = \rho r_1 \left(K_1, L, E_1 \right)$.
  - Reduction in E_1 induces an offsetting reduction in K_1 to maintain the equality $1 = \rho r_1 \left(K_1, L, E_1 \right)$.
  - The marginal unit of abatement has zero first-order welfare effect on all agents' welfare.
  - A non-marginal abatement reduces the welfare of currently living generations and has zero effect on the welfare of the agent born in the next period.

Linear utility, continued

- Let $\eta = 0$ (linear preferences) and $H = \infty$
- Joint welfare for current old and young

$$\Omega_t^o + \Omega_t^y = \underbrace{r_t K_t + w_t L}_{\text{income}} + \underbrace{(1-\delta)\, p_t K_t}_{\text{wealth}},$$

- Objective of the discounted utilitarian

$$\Omega^{utilitarianr} \equiv \underbrace{r_t K_t + w_t L}_{\text{income}} + \underbrace{(1-\delta)\, p_t K_t}_{\text{wealth}} + \underbrace{\left(\sum_{j=0}^{H} \rho^{j+1} w_{t+j+1} \right) L}_{\text{discounted future wages}}$$

- In protecting the value of their asset, selfish agents benefit agents born in the future.

Equilibrium abatement (numerical)

- Successive pairs of generations play a dynamic game with their successors. The payoff-relevant state variable is (K, E, t). (t affects technology and population). Equilibrium is Markov Perfect.
- Currently living agents choose *abatement* to maximize a convex combination of their joint welfare:

$$M(K, E, t) = \max_{\mu_t} \xi \, \Omega_t^y + (1 - \xi) \, \Omega_t^o,$$

  taking as given future policy rules and current investment.
  - Investment emerges as a rational expectations competitive equilibrium.
- *Larger ξ implies the young have more influence in decision-making process.*

Equilibrium abatement (numerical)

- Successive pairs of generations play a dynamic game with their successors. The payoff-relevant state variable is (K, E, t). (t affects technology and population). Equilibrium is Markov Perfect.
- Currently living agents choose *abatement* to maximize a convex combination of their joint welfare:

$$M(K, E, t) = \max_{\mu_t} \xi \, \Omega_t^y + (1 - \xi) \, \Omega_t^o,$$

  taking as given future policy rules and current investment.
    - Investment emerges as a rational expectations competitive equilibrium.
    - Climate policy is not used as a means of influencing current investment.
- *Larger ξ implies the young have more influence in decision-making process.*

Equilibrium abatement, continued

- Except for logarithmic utility, the equilibrium abatement rule $M(K, E, t)$ depends on next period price (a function of $K', E', t+1$, and next period abatement, $M(K', E', t+1)$.
- We compare MPE against BAU (zero abatement) and against the (standard) discounted utilitarian facing the same technology.
  - We've considered a couple of alternative comparators.

Calibration

- We try to stick close to DICE
- We use a 35-year time step and a 6% annual depreciation rate; 12% of beginning-of-period capital left at the end of a period.
  - DICE uses 10% annual depreciation.
- To calibrate σ and a (the parameters of the CET function) we set the elasticity of supply of the investment good, evaluated at an investment share 0.24, equal to 1.

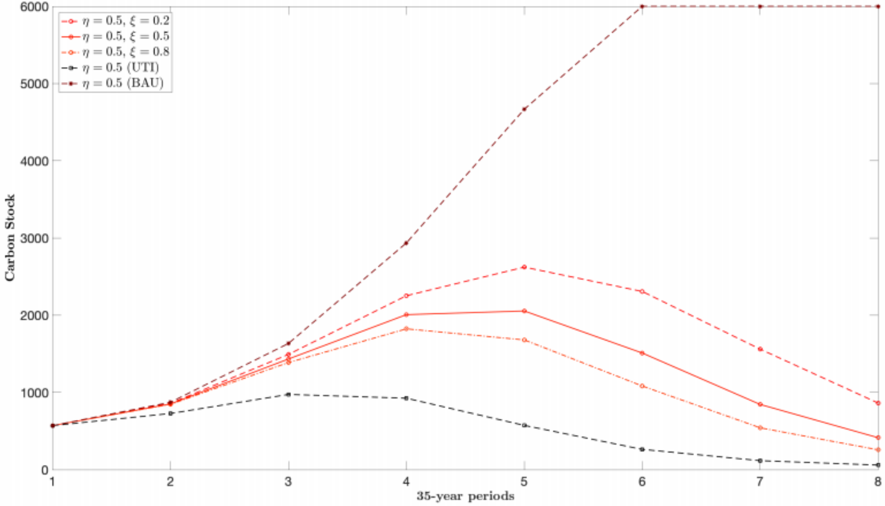
Calibration

- We try to stick close to DICE
- We use a 35-year time step and a 6% annual depreciation rate; 12% of beginning-of-period capital left at the end of a period.
  - DICE uses 10% annual depreciation.
  - Penn Table has mean of 4% annual depreciation.
- To calibrate σ and a (the parameters of the CET function) we set the elasticity of supply of the investment good, evaluated at an investment share 0.24, equal to 1.

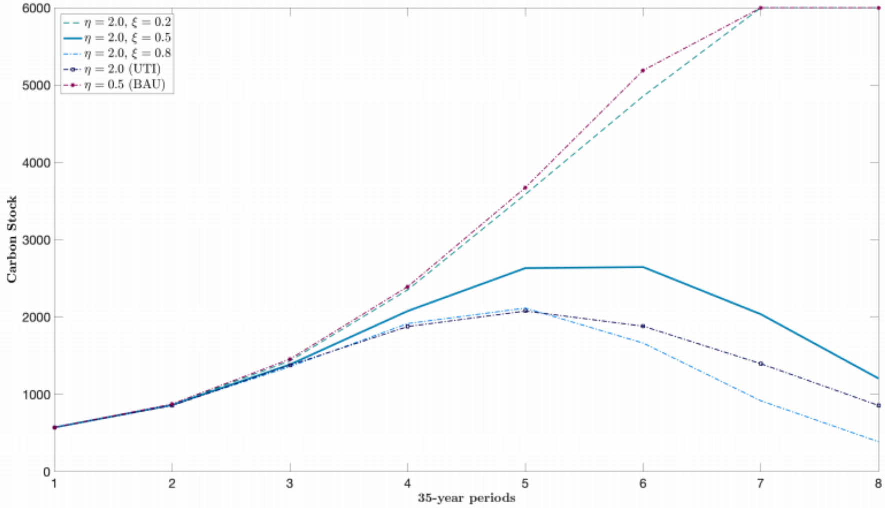
Results, summary

- Provided that the young has significant representation in the decision-making process (ξ is reasonably large), endogenous asset prices give selfish agents the incentive to engage in substantial abatement.
- Even if the initial MPE policy is small (relative to the utilitarian level), the cumulative effects of MPE policy may be substantial.

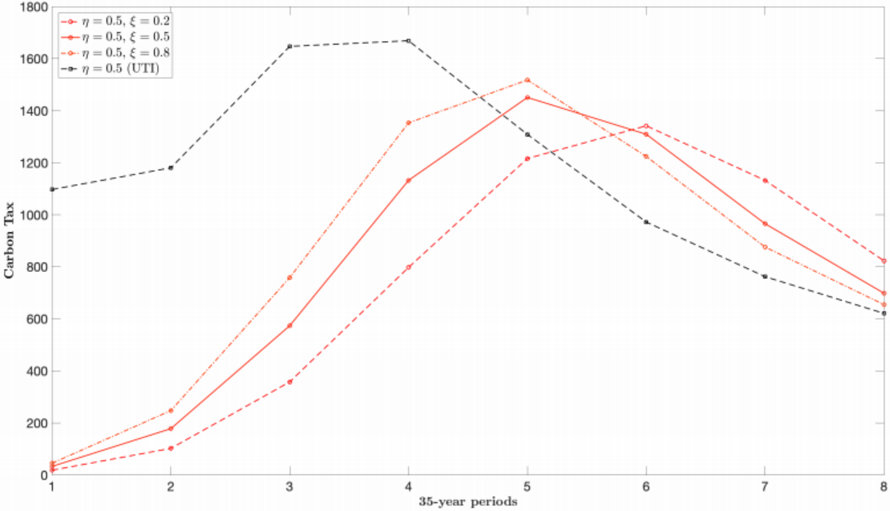
Results: Carbon stocks, high EIS



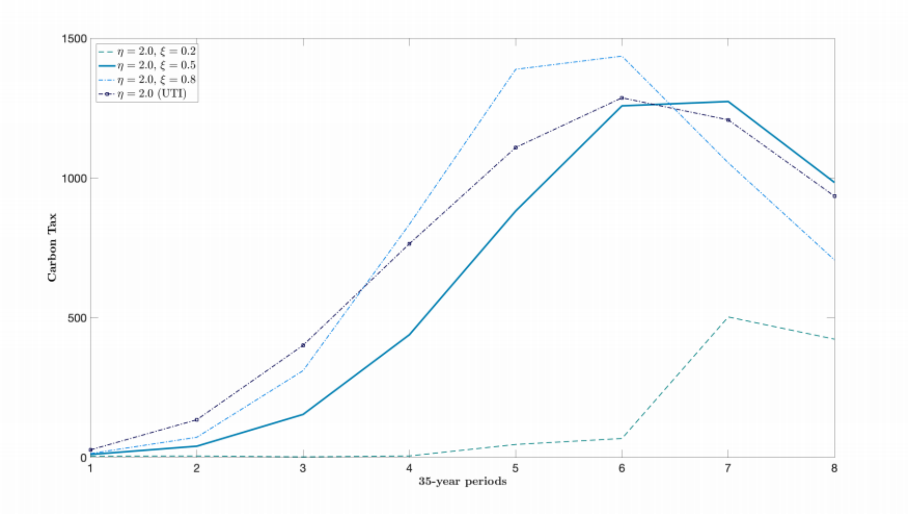
Results: Carbon stocks, low EIS



Results: policies, high EIS



Results: Carbon stocks, high EIS



Results: First period policies

	$\eta = 0.5$ $(EIS = 2)$			$\eta = 2$ $(EIS = 0.5)$		
UTI	$(\$1100, 48\%)$			$(\$27, 7\%)$		
MPE	$\xi = 0.2$	$\xi = 0.5$	$\xi = 0.8$	$\xi = 0.2$	$\xi = 0.5$	$\xi = 0.8$
	$(\$18, 5\%)$	$(\$33, 7\%)$	$(\$45, 9\%)$	$(\$5, 2\%)$	$(\$11, 4\%)$	$(\$14, 5\%)$

Table 4.2. First period carbon tax ($\$/tCO2$) and abatement (percent of BAU emissions) under the utilitarian and in the MPE.

Conclusions

- We have a tractable model that includes asset prices in an IAM, involving:
  - a strictly concave PPF and OLG.
- Using comparative statics we find that young and old agents' incentives are "aligned" iff EIS$>$1
- For a two-period model
- For $EIS = 1$ (logarithmic utility) – where the savings rate is constant – policies are "intertemporally decoupled".

Conclusions

- We have a tractable model that includes asset prices in an IAM, involving:
  - a strictly concave PPF and OLG.
- Using comparative statics we find that young and old agents' incentives are "aligned" iff EIS$>$1
- For a two-period model
  - With $EIS = \infty$ all agents benefit from a small level of abatment.
- For $EIS = 1$ (logarithmic utility) – where the savings rate is constant – policies are "intertemporally decoupled".

Conclusions

- We have a tractable model that includes asset prices in an IAM, involving:
  - a strictly concave PPF and OLG.
- Using comparative statics we find that young and old agents' incentives are "aligned" iff EIS>1
- For a two-period model
  - With $EIS = \infty$ all agents benefit from a small level of abatment.
  - With $EIS = 0$ a small level of abatement benefits current young, harms current old.
- For $EIS = 1$ (logarithmic utility) – where the savings rate is constant – policies are "intertemporally decoupled".

Conclusions

- We have a tractable model that includes asset prices in an IAM, involving:
  - a strictly concave PPF and OLG.
- Using comparative statics we find that young and old agents' incentives are "aligned" iff EIS$>$1
- For a two-period model
  - With $EIS = \infty$ all agents benefit from a small level of abatment.
  - With $EIS = 0$ a small level of abatement benefits current young, harms current old.
- For $EIS = 1$ (logarithmic utility) – where the savings rate is constant – policies are "intertemporally decoupled".
  - A small level of abatement has zero first order effect on all agents.

Conclusions

- We have a tractable model that includes asset prices in an IAM, involving:
  - a strictly concave PPF and OLG.
- Using comparative statics we find that young and old agents' incentives are "aligned" iff EIS>1
- For a two-period model
  - With $EIS = \infty$ all agents benefit from a small level of abatment.
  - With $EIS = 0$ a small level of abatement benefits current young, harms current old.
- For $EIS = 1$ (logarithmic utility) – where the savings rate is constant – policies are "intertemporally decoupled".
  - A small level of abatement has zero first order effect on all agents.
  - A non-negligible level of abatment harms both currently living agents.

Conclusions, continued

- We use (mostly) DICE to calibrate a model. We solve a dynamic game among a sucession of selfish agents who are unable to use intergenerational transfers. They cannot commit their successors to following particular policies, but they have rational expectations about sucessors' policies.
- We find that:
  - Provided the young agent has substantial representation in the decision-making process, the endogeneity of asset prices lead to significant abatement over time. Market-induced incentives are important, and in the climate context they have been overlooked.

Conclusions, continued

- We use (mostly) DICE to calibrate a model. We solve a dynamic game among a sucession of selfish agents who are unable to use intergenerational transfers. They cannot commit their successors to following particular policies, but they have rational expectations about sucessors' policies.
- We find that:
  - Provided the young agent has substantial representation in the decision-making process, the endogeneity of asset prices lead to significant abatement over time. Market-induced incentives are important, and in the climate context they have been overlooked.
  - However, these market-induced incentives are not a substitute for intergenerational altruism – or for intergenerational transfers using debt.

If there is any time left over

- The following slides provide intuition for theoretical results

Welfare effect of the first unit of abatement

- Assume $\Lambda'(0) = 0$. Marginal cost of first unit of abatement is zero $\Rightarrow$ first unit of abatement has only a *second order* effect on $G(\mathbf{z}) = D(E)\Lambda(\mu)(AL)^{\beta} K^{1-\beta}$ but it has a *first order* effect on next period stock and next period damages, and thus (in general) has a first order effect on p_t.
- The first unit of abatement increases old agent's welfare iff abatement increases p_t.
- The young agent benefits from a higher p_t iff $EIS > 1$.
  - For $EIS < 1$ (the conventional case) the old and young generations' have opposing interests.

What happens if abatement increases the asset price?

- Pre-abatement wage is w_t and consumption point is at A. Increase in $p_t \Rightarrow w_t$ rises, I_t rises and c_t falls – a movement along the PPF. c_t^o rises, so c_t^y falls. Consumption moves toward B (higher welfare) or toward C (lower welfare).
- If consumption moves toward B then ψ_t must have risen. Income effect promotes higher current consumption for young, and substitution effect promotes lower current consumption. Substitution effect $>$ Income effect $\Rightarrow EIS > 1$.