Welfare Consequences of Sustainable Finance

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Motivating Stylized Facts

- Sustainable finance mandates (Net-Zero Financial Alliance, NGFS)
  - Portfolio restrictions around 20% AUM (SIF)
- Incentivize firms to decarbonize (carbon removal) via cost-of-capital channel
  - Sovereign bonds issued with climate penalties in exchange for greenium (Financial Times)
  - Literature estimates of greenium (WACC) $\approx$ 100 bps (stdev 200 bps) (Hong and Shore (2023))
  - Annual investments in low carbon alternatives (decarbonization stock) around 0.10% of capital stock (Bloomberg)

Our Paper

- Two capital-stock model that can address these stylized facts
- Use model to ...
  1. Clarify economics of greeniums
  2. Can sustainable finance be a viable carbon policy tool (approx. planner's solution)?
  3. How to optimally set mandates?
- Sanity check of model using Renewable Power Standards for utilities in US 1991-2020*

Model: Climate States

- $\mathcal{S}_t = \mathcal{G},\, \mathcal{B}$
- Economy starts in the $\mathcal{G}$ state and transitions to the $\mathcal{B}$ state
  - Time-varying endogenous transition rate $\zeta_t > 0$
- Weather disasters are more frequent in the $\mathcal{B}$ state than the $\mathcal{G}$ state: $\lambda_t^{\mathcal{G}} < \lambda_t^{\mathcal{B}}$
  - Both $\lambda_t^{\mathcal{G}}$ and $\lambda_t^{\mathcal{B}}$ are endogenous

Firm Production and Capital Accumulation

- Output in both $\mathcal{S}$: $Y_t = AK_t$
- Capital stock K in state $\mathcal{S}_t$ follows

$$dK_t = \Phi(I_{t-}, K_{t-})dt + \sigma K_{t-} d\mathcal{B}_t - (1 - Z)K_{t-} d\mathcal{J}_t$$

- If a jump occurs, i.e., $d\mathcal{J}_t = 1$, capital changes from K_{t-} to $K_t = ZK_{t-}$ where $Z \in (0, 1)$ is the stochastic fraction of capital that survives the jump shock
- Homogeneity: $\Phi(I, K) = \phi(i)K$ where $i = I/K$
- State-dependent weather disaster arrival rate: $\lambda_{t-}^{\mathcal{S}_t}$

Two Capital Stocks

- Emissions: $\mathbf{E}_t = \mathbf{e}\mathbf{K}_t$
- Removals: $\mathbf{R}_t = \tau \mathbf{N}_t$
- Aggregate mitigation spending: $\mathbf{X}_t$
- Evolution of aggregate decarbonization stock $\mathbf{N}_t$:

$$d\mathbf{N}_t = \omega(\mathbf{X}_{t-}/\mathbf{N}_{\mathbf{t}-})\mathbf{N}_{\mathbf{t}-}dt + \sigma \mathbf{N}_{t-} d\mathcal{B}_t - (1 - Z)\mathbf{N}_{t-} d\mathcal{J}_t$$

Tipping Point and Disaster Arrival Rates

- Tipping point arrival, $\zeta(\,\cdot\,)$, and arrival rates, $\lambda^{\mathcal{S}_t}(\,\cdot\,)$, are functions of
$$\mathbf{n}_{t-} = \frac{\mathbf{N}_{t-}}{\mathbf{K}_{t-}}$$
- Transition dynamics for $\mathbf{n}_t$:
$$\frac{d\mathbf{n}_t}{\mathbf{n}_{t-}} = [\omega(\mathbf{x}_{t-}/\mathbf{n}_{t-}) - \phi(\mathbf{i}_{t-})]dt$$

Market Economy with Welfare-Maximizing Mandate

- Given α of total wealth restricted, the planner announces a qualification spending threshold $\{M_t; t \geq 0\}$ at $t = 0$ and commits to the announcement with the goal of maximizing the representative agent's utility

- The representative agent and firms take the mandate as given and optimize in market places

- To qualify as a sustainable (S) firm at t, it has to spend at least M_t at t on mitigation:

$$X_t \geq M_t$$

Qualifying for Sustainable Investment Mandate

- Homogeneity: $M_t = m(\mathbf{n_t}; \mathcal{S}_t)K_t$, where $m(\mathbf{n_t}; \mathcal{S}_t)$ is the firm's scaled minimal level of mitigation
- Mandate α creates inelastic demand for sustainable (S) firms
- The remaining $(1 - \alpha)$ of total wealth invested in U-portfolio

Risk Preferences and Complete Markets

- Epstein-Zin non-expected utility
- Dynamically complete markets
- Representative investor allocate between risk-free, sustainable ($S-$) and unsustainable ($U-$) portfolios
- All markets clear

Solution: Firm Value Maximization

- Let $Q_t^j = q^j(\mathbf{n}_t; \mathcal{S}_t)K_t^j$ denote the the market value of a type-j firm at t, where $j = \{S, U\}$
- A type-j firm maximizes its market value:

$$\max_{I^j, X^j} \mathbb{E}\left(\int_0^\infty e^{-\int_0^t r^j(\mathbf{n_v}; \mathcal{S}_v)dv} CF^j(\mathbf{n_t}; \mathcal{S}_t)dt\right),$$

  where

$$CF^S(\mathbf{n_t}; \mathcal{S}_t) = AK_t^S - I_t^S(\mathbf{n_t}; \mathcal{S}_t) - X_t^S(\mathbf{n_t}; \mathcal{S}_t)$$

  and

$$CF^U(\mathbf{n_t}; \mathcal{S}_t) = AK_t^U - I_t^U(\mathbf{n_t}; \mathcal{S}_t)$$

- Optimal mitigation:

$$x_t^U = 0 \quad \text{and} \quad x_t^S = m(\mathbf{n}_t; \mathcal{S})$$

Equilibrium Greenium

- In equilibrium, all firms have the same Tobin's average q and the same investment-capital ratio:

$$q^S(\mathbf{n};\mathcal{S}) = q^U(\mathbf{n};\mathcal{S}) = \mathbf{q}(\mathbf{n};\mathcal{S})$$

  and

$$i^S(\mathbf{n};\mathcal{S}) = i^U(\mathbf{n};\mathcal{S}) = \mathbf{i}(\mathbf{n};\mathcal{S}) .$$

- Greenium is

$$r^U(\mathbf{n};\mathcal{S}) - r^S(\mathbf{n};\mathcal{S}) = \frac{m(\mathbf{n};\mathcal{S})}{\mathbf{q}(\mathbf{n};\mathcal{S})} .$$

- Mitigation at the firm level $m(\mathbf{n})$ is related to the aggregate mitigation $\mathbf{x}(\mathbf{n})$:

$$m(\mathbf{n}) = \frac{\mathbf{x}(\mathbf{n})}{\alpha}$$

Interpretations

- Heterogenous investor interpretation: α investors only own sustainable, $(1-\alpha)$ own unsustainable stocks.
  - Survival of sustainable investors in long run.
  - Sustainable investors consume less but same fraction of wealth in economy over time.
- Renewable portfolio standards ($\alpha = 1$): RPS mandate utilities gradually produce a fraction of their output using renewables

Why Welfare-maximizing Mandate does not attain First Best?

- The investment FOCs are different
  - Planner's FOC: uses both $\mathbf{i}$ and $\mathbf{x}$ to achieve optimal path of $\mathbf{n}$
  - Welfare-maximizing Mandate: limited to only $\mathbf{x}$
  - Key difference: Too much investment in mandate economy

Two Instruments Restore First Best

1. welfare-maximizing mandate: $m_t = \mathbf{x}(\mathbf{n}_t; \mathcal{S}_t)/\alpha$
2. investment deviation tax:
   - if corporate investment i^j deviates from the aggregate investment $\mathbf{i}(\mathbf{n}; \mathcal{S})$, then for each unit of capital stock, tax the firm at the rate of to discourage socially inefficient overinvestment.

Taxation to address carbon and adaptation externalities when there is learning and costly capital adjustment (see Hong, Wang and Yang (2023) "Mitigating Disaster Risks in the Age of Climate Change" forthcoming *Econometrica*.)

Specifying Functional Forms

- Controlled drift functions for **K** and **N** accumulation:

$$\phi(i) = i - \frac{\eta_K i^2}{2} - \delta_{\mathbf{K}} \quad \omega(\mathbf{x}/\mathbf{n}) = (x/\mathbf{n}) - \frac{\eta_{\mathbf{N}}(\mathbf{x}/\mathbf{n})^2}{2} - \delta_{\mathbf{N}}$$

- A power-law function for distribution of Z: $\Xi(Z) = Z^\beta$ implies an expected fractional capital/output loss, ℓ, of

$$\ell = \mathbb{E}(1 - Z) = \frac{1}{\beta + 1}$$

- **n** decreases the tipping point arrival rate from $\zeta_0 > 0$ to

$$\zeta(\mathbf{n}) = \zeta_0(1 - \mathbf{n}^{\zeta_1}),$$

where $0 < \zeta_1 < 1$.
- **n** also decreases disaster arrival rate, λ_t:

$$\lambda(\mathbf{n}; \mathcal{S}) = \lambda_0^{\mathcal{S}}(1 - \mathbf{n}^{\lambda_1}),$$

where $\lambda_0^{\mathcal{S}} > 0$, and $0 < \lambda_1 < 1$.

Calibration

- Macro-finance moments
  - Standard risk aversion and discounting parameters + *EIS* > 1 (e.g., Bansal and Yaron (2004) long-run risk)
  - Capital productivity A and adjustment costs η_K from the q theory literature
- Climate-mitigation pathways
  - $\lambda_0^{\mathcal{S}}$ and conditional damage $\ell = 1/(\beta + 1)$ based on estimates of how extreme temperature (above 1.5^o) reduce GDP growth (1950-2003): Dell, Jones, and Olken (2012)
  - Pin down decarbonization capital accumulation parameter $\eta_{\mathbf{N}}$ by targeting a transition pathway (several decades) and determine the mitigation parameter, ζ_1 and λ_1, using estimates from Gates (2020)

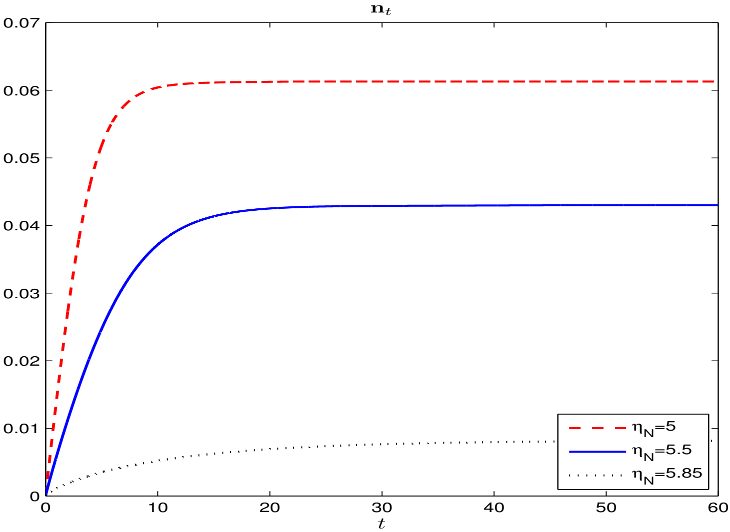
Parameter Values

Parameters	Symbol	Value
elasticity of intertemporal substitution	ψ	1.5
time rate of preference	ρ	4.2%
coefficient of relative risk aversion	γ	8
productivity for K	A	26%
adjustment cost parameter for K	η_K	5
adjustment cost parameter for $\mathbf{N}$	$\eta_{\mathbf{N}}$	5
diffusion volatility for $\mathbf{N}$ and K	σ	9%
depreciation rates for $\mathbf{N}$ and K	$\delta_K = \delta_{\mathbf{N}}$	6%
jump arrival baseline parameter from state $\mathcal{G}$ to $\mathcal{B}$	ζ_0	0.02
jump arrival sensitivity parameter from state $\mathcal{G}$ to $\mathcal{B}$	ζ_1	0.1
power-law exponent	β	39
jump arrival baseline parameter with $\mathbf{n} = 0$ in state $\mathcal{G}$	$\lambda_0^{\mathcal{G}}$	0.05
jump arrival baseline parameter with $\mathbf{n} = 0$ in state $\mathcal{B}$	$\lambda_0^{\mathcal{B}}$	2
mitigation technology parameter	λ_1	0.3

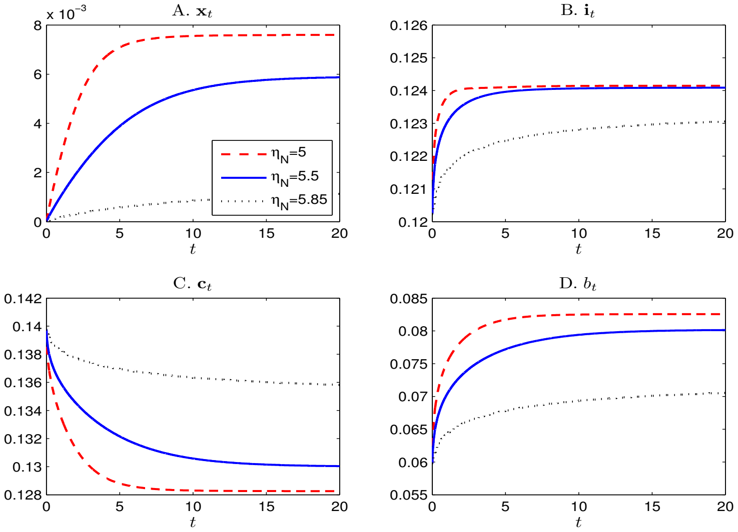
Comparing across the laissez faire, the mandated market, and the first-best economies in state $\mathcal{G}$

		laissez faire	mandate	first-best
scaled mitigation spending	$\mathbf{x}^{ss}$	0	0.76%	0.78%
scaled decarbonization stock	$\mathbf{n}^{ss}$	0	6.13%	6.48%
scaled aggregate investment	$\mathbf{i}^{ss}$	11.83%	12.41%	12.07%
Tobin's average q	$\mathbf{q}^{ss}$	2.45	2.64	2.52
scaled aggregate consumption	$\mathbf{c}^{ss}$	14.17%	12.82%	13.15%
expected GDP growth rate	$\mathbf{g}^{ss}$	2.04%	2.44%	2.30%
(real) risk-free rate	r^{ss}	1.10%	0.73%	0.91%
stock market risk premium	rp^{ss}	6.73%	6.58%	6.60%
aggregate welfare measure	b^{ss}	0.0542	0.0826	0.0830
time from $\mathbf{n} = 0$ to $0.99\mathbf{n}^{ss}$ in $\mathcal{G}$		0	10.9	10.0

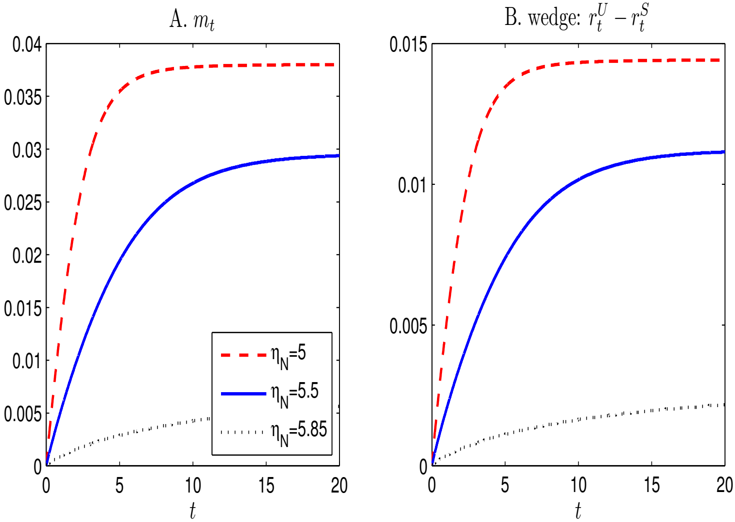
Decarbonization-to-productive capital stock



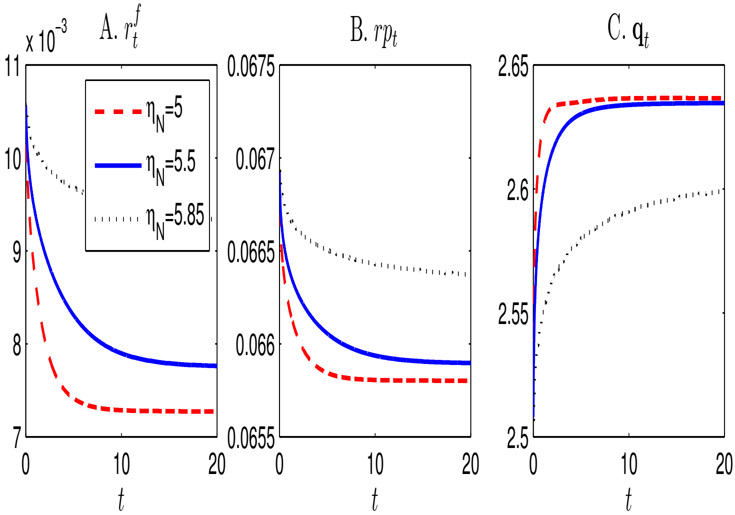
Mitigation **x**, investment **i**, consumption **c**, and welfare *b* under mandates



Given $\alpha = 20\%$, mandated spending for qualifying firms and cost-of-capital wedge

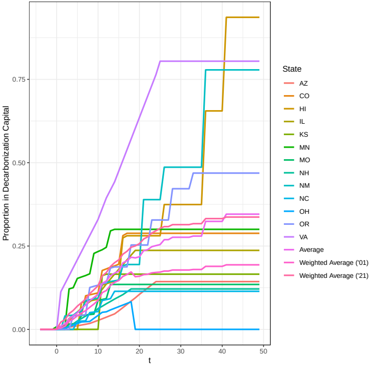


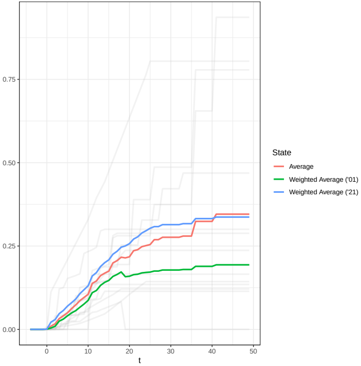
Asset pricing results



Application to RPS for US States 1991-2020

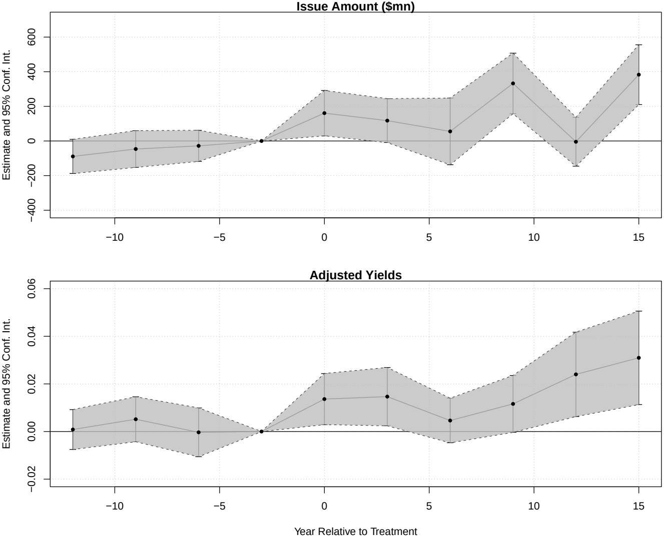
Hong, Kubik and Shore (2023) "Capital-Market Effects of Carbon Regulation"



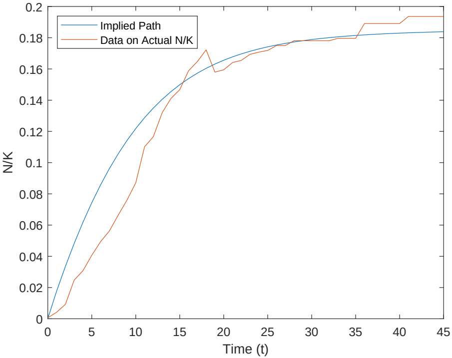


RPS Target Investor-Owned But Exempted Municipal Producers

Issue Level —Event Study with Three-Year Bins



Fit of Model Path of N/K versus Actual



Model can explain around half of cost-of-capital effect, i.e. higher dividend yield for targeted firms versus laissez faire counterfactual (firms that get to free ride)

Conclusions

- Sustainable finance mandates a viable policy option depending on greenium — WTP of restricted portfolios
- Realistically, a tool alongside other types of carbon regulation