Stranding ahoy?

Heterogenous transition beliefs and capital investment

Louison Cahen-Fourot[1], Emanuele Campiglio[2], Louis Daumas[3], Michael Miess[4], Andrew Yardley[5]

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[1]Roskilde University
[2]University of Bologna
[3]Centre International de Recherche en Environnement et Développement (CIRED)
[4]Environment Agency Austria
[5]Offshore Renewable Energy Catapult

Motivation

- Urgent to mitigate climate change
  - $\rightarrow$ Transition to low-carbon technologies
  - $\rightarrow$ More investments in low-carbon capital needed
- How do firms choose investments?
  - Our assumption: relative future profit expectations
- Profit expectations are heterogeneous across firms
  - Technological and financial variables
  - Transition speed expectations
  - Time preferences (e.g. discount rate; planning horizon)

Our contribution

- Research question: how are investment choices affected by
  - Heterogeneity of expectations;
  - Time preferences?
- We develop small electricity model with:
  - Low- and high-carbon capital stocks
  - Heterogeneous transition expectations $\rightarrow$ stranding expectations
  - Heterogeneity of expectations increasing in psychological time
  - Finite planning horizons

Overview of results

- Expectations of more rapid transition → higher low-carbon investment share
- Heterogeneity matters
  - Lower heterogeneity → Bang-bang solutions
  - Higher heterogeneity → Convergence to a 'full hedging' investment allocation
- Discounting
  - Higher discount rate → Lower low-carbon investment
  - Heterogeneity effects non-linearly exacerbated by higher discount rate
- Investment planning horizon
  - Ambiguous non-linear effects

The model

The setting

- Exogenously expanding electricity demand e^d
- Two technologies $(i = l, h)$
  - High-carbon incumbent K_h with productivity ξ_H
  - Low-carbon niche K_l with productivity ξ_L
- Merit order in electricity system
  - K_L first in merit order $\rightarrow$ K_L always fully utilised $(u_L = u_L^f)$
  - K_H provides the remainder $\rightarrow$ High-carbon capacity utilisation:

$$u_H = \frac{e_H}{\xi_i K_i}$$

Technological choice

- Firm j chooses investments calculating relative return rates of technologies $i \in \{l, h\}$, within planning horizon S
  - Sum of discounted stream of expected profits obtainable from a unit of K (e.g. a GW of installed capacity)

$$r_{i,t} = \sum_{s=t}^{S} \beta^{s} \, \mathbb{E}_t^j(\pi_{i,s})$$

- Firms compare return rates. If $\varphi = r_L - r_H > 0$ they will invest in K_L; if not, in K_H

Three components of unitary profit rate π_i

- Revenues
  - Electricity price p_e fixed through PPA
  - Capital productivity ξ_i fixed in capital vintage available
  - Capital utilisation u_H depends on transition expectations
- Capital costs
  - Fixed installation costs in each period c_i^k
  - A portion ψ_i of investment is financed via bank lending
  - α_i is capital recovery ratio, given interest rate and loan tenure
- Variable costs
  - Purchase of fossil fuel for high-carbon firms

$$\mathbb{E}(\pi_{L,s}) = p_e \xi_L - \alpha_L \psi_L c_L^k$$

$$\mathbb{E}(\pi_{H,s}) = p_e \xi_H \, \mathbb{E}_t^j(u_{H,s}) - \frac{p_f}{\xi_f} \xi_H \, \mathbb{E}_t^j(u_{H,s}) - \alpha_H \psi_H c_H^k$$

→ Only u_H remains subject to uncertainty

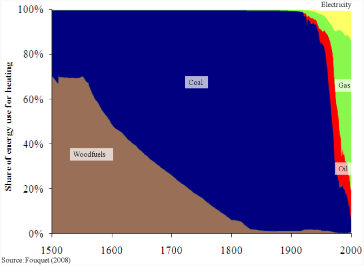
Heterogeneous stranding expectations

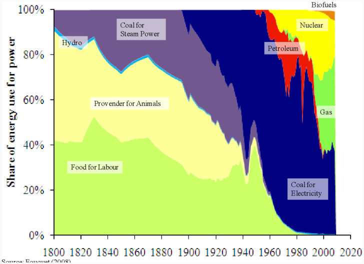
- We assume stranding expectations to be normally distributed around a central expectation path

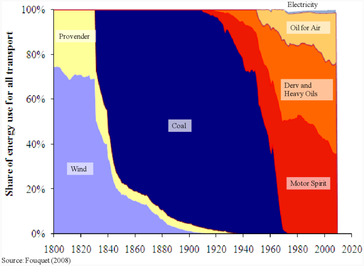
$$\mathbb{E}_t^j(u_{H,s}) = u^*_{H,s} + \varepsilon^j_{u,s}$$

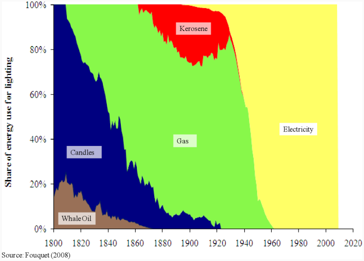
- $u^*_{H,s}$ is the benchmark 'rational stranding' scenario
    - I_{H_s} is expected to either satisfy e^d_s at $u_{H_s} = u^f_H$ or be zero
    - Calibrated to reflect 'dominant narratives'
- $\varepsilon_{u,s} \sim \mathcal{N}(0, \sigma_{u,s})$ represents heterogeneity of expectations
    - Higher $\sigma_u \rightarrow$ Higher stranding expectations heterogeneity

Technological transitions follow a logistic pattern









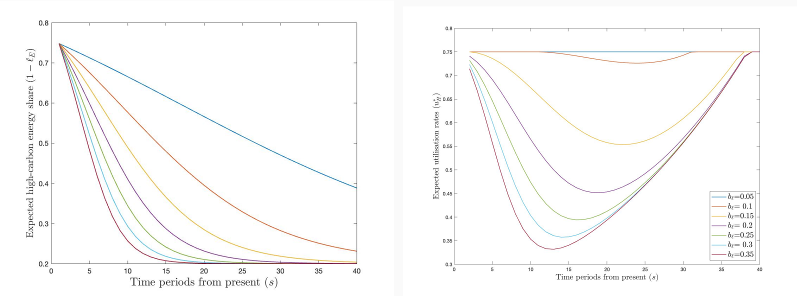
Source: Fouquet (2008)

Central transition expectations

- Firms expect share of low-carbon energy ℓ to follow logistic pattern with intrinsic growth rate b_ℓ:

$$\mathbb{E}(\ell_{s+1}) = \mathbb{E}(\ell_s)\left[1 + b_\ell\left(1 - \frac{\mathbb{E}(\ell_s)}{\mathbb{E}(\bar{\ell})}\right)\right]$$

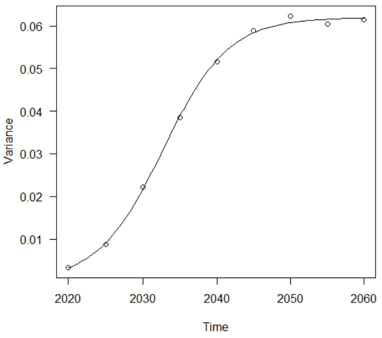
- $\rightarrow$ We derive expected path for $u^*_{H,s}$



Expected dynamics of $\mathbb{E}(1-\ell)$ and $\mathbb{E}(u^*_H)$ for different values of b_ℓ

Heterogeneity time profile

- Heterogeneity in IPCC AR6 projections increases logistically $\rightarrow \sigma_{u,s}$ moves logistically in time s
- Firms mostly agree in the short run but rapidly disagree over the medium/long-run

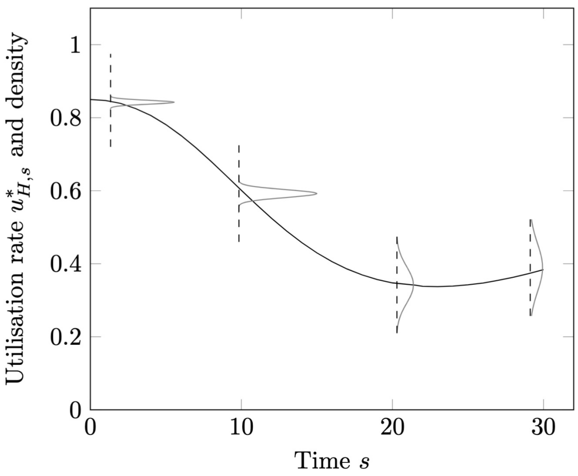


Variance of IPCC AR6 projections of the shares of renewables in electricity production

$$\sigma_{u,s+1} = \sigma_{u,s}\left[1 + b_{\sigma_t}\left(1 - \frac{\sigma_{u,s}}{\bar{\sigma}_u}\right)\right]$$

A schematic representation of expectation densities

- For a given central expectation scenario, σ_u becomes larger in psychological time s



Aggregate investment decisions

- We want to compute low-carbon share of investments ℓ_I
  - In our setting, this is equivalent to the probability for an individual firm to find a positive φ (i.e. $r_L > r_H$)
- We exploit the properties of Gaussian distribution to move from u_s distributions to r_H and φ distributions

$$\ell_I = \mathcal{P}(r_{L,t} > r_{H,t}) = \mathcal{P}(\varepsilon_\varphi < \varphi^*) = \Phi(\varphi^*)$$

Calibration

Technological and financial parameters

Symbol	Variable	Value	Unit
g_e	Energy demand growth	0.0048	n.a.
ξ_H	Productivity of high-carbon capital	4.38	TWh/GW
ξ_L	Productivity of low-carbon capital	3.15	TWh/GW
ξ_f	Productivity of fossil fuels	1/8.75	TWh/tlnBtu
δ_H	Depreciation of high-carbon capital	0.03	n.a.
δ_L	Depreciation of low-carbon capital	0.045	n.a.
c_H^K	High-carbon capital cost	1.5	bln$/TWh
c_L^K	Low-carbon capital cost	1.75	bln$/TWh
ψ_H	Debt-to-investment ratio (high-carbon)	0.55	n.a.
ψ_L	Debt-to-investment ratio (low-carbon)	0.75	n.a.
ι_H	Interest rate on loans (high-carbon)	0.045	n.a.
ι_L	Interest rate on loans (low-carbon)	0.05	n.a.
LT_H	Loan tenor (high-carbon)	15	years
LT_L	Loan tenor (low-carbon)	15	years
u^f	Full utilisation rate	0.75	n.a.
p_f	Price of fossil fuels	0.002	bn$/tlnBtu
p_e	Price of electricity	0.2	bn$/TWh

Behavioural parameters

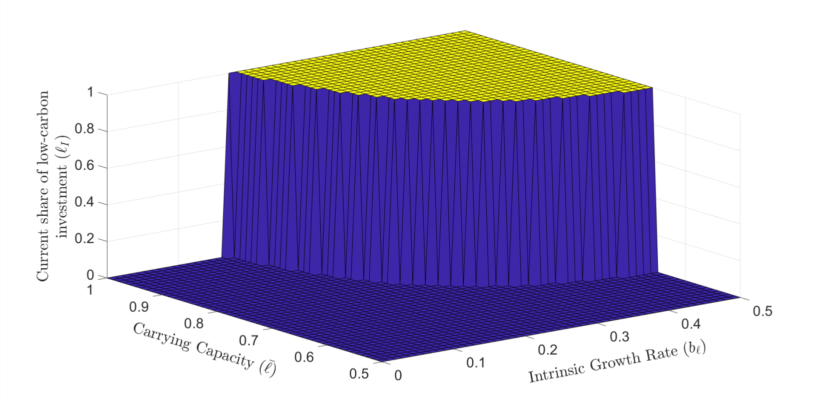
- No data to base behavioural parameters on → Sensitivity analysis on their effect on ℓ_I

Variable	Meaning	Reference value	Sensitivity range	Step
S	Length of planning horizon	20	[2, 40]	1
g_e	Expected growth of demand	0.048	[0, 0.1]	0.01
b_ℓ	Intrinsic growth rate for ℓ	0.2	[0.01, 0.35]	0.01
b_σ	Intrinsic growth rate for σ	0.5	[0.1, 1]	0.1
σ_{min}	Opinion diversity at time t	0.01	[0, 0.1]	0.01
σ_{max}	Maximum opinion diversity	1	[0.01, 5]	0.1
ρ	Corporate discount rate	0.05	[0.01, 0.1]	0.01
$\bar{\ell}$	Maximum expected ℓ	0.8	[0.6, 1]	0.1

Numerical results

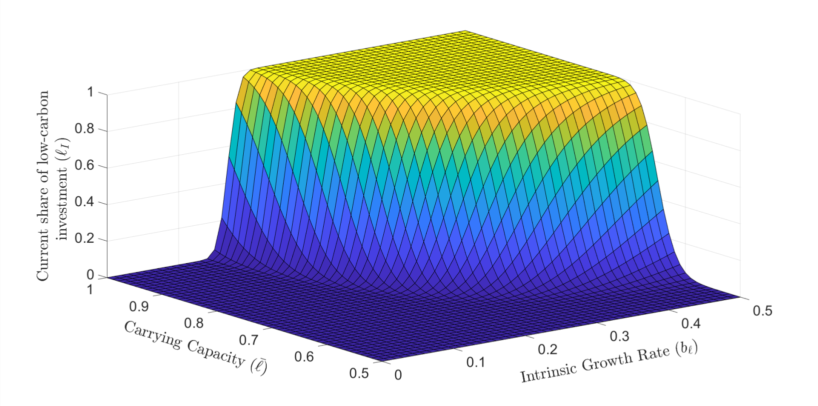
The no-heterogeneity benchmark

- $\sigma_{u,s} = 0, \forall s \rightarrow$ bang-bang solution
- High enough b_ℓ and $\bar{\ell} \rightarrow$ Fully decarbonised investments



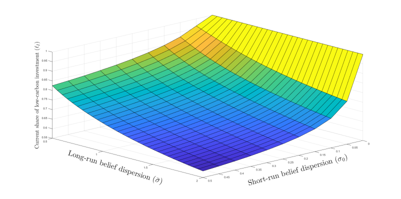
Introducing expectations heterogeneity

- Expectations heterogeneity ($\sigma_{u,s} \neq 0$) makes investment decisions smoother

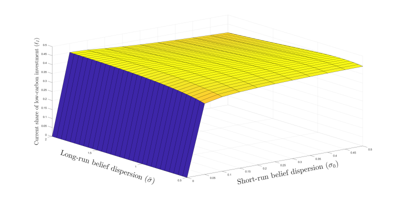


The balancing effect of opinion diversity

- Higher heterogeneity (higher σ_0, $\bar{\sigma}$ or b_σ) $\rightarrow$ Convergence to a 'full hedging' investment allocation $\ell_I \approx 0.5$
  - Ambitious central scenarios $\rightarrow$ heterogeneity tames ℓ_I
  - Unambitious $\rightarrow$ heterogeneity tames ℓ_I (only up to a point)
- Short-term opinion diversity has stronger effects than long-term one



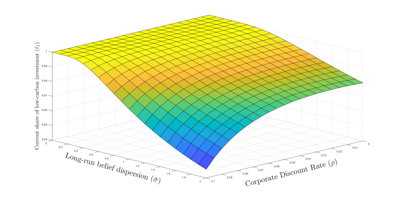
Ambitious central expectations



Unambitious central expectations

Opinion diversity and the discount rate

- The discount rate ρ has an overall expected negative effect on low-carbon investment
- Heterogeneity effects non-linearly exacerbated by higher discount rate



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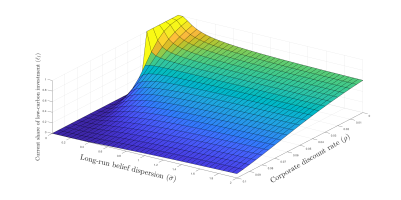
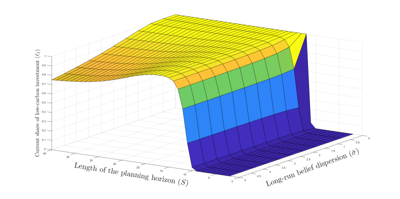


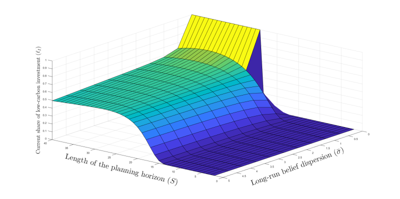
Unambitious central expectations

Farsightedness and opinion diversity

- Ambiguous effects of planning horizon length S
  - Positive: higher S allow to look further along the transition path $\rightarrow$ higher stranding
  - Negative: farsightedness gives more room to heterogeneity and uncertainty



Ambitious central expectations



Unambitious central expectations

Conclusions

Conclusions

- We propose a simple way to introduce heterogeneity in agents' transition expectations and link it to investment behaviours
- We show that:
  - Transition expectations affect investment choices
  - Expectation dispersion can push/hamper transition dynamics, depending on central scenario ambitions
  - Long-termism: ambiguous effects on investment allocation
- Further work:
  - Full analytical study of the paper
  - Dynamical version with belief switching
  - Apply other distributions

Thank you!

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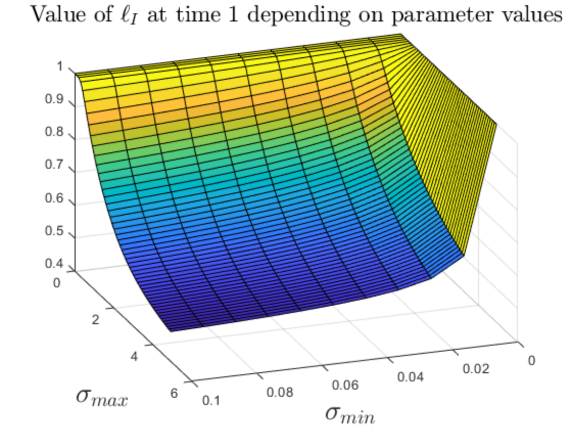
Modulating dissensus

- We now focus on $\sigma_{u,min}$ and $\sigma_{u,max}$
- A higher variance means a flatter distribution around u_s^*, converging towards $\ell_I \approx 0.5$ (almost equal shares of investments due to censoring)



Farsightedness

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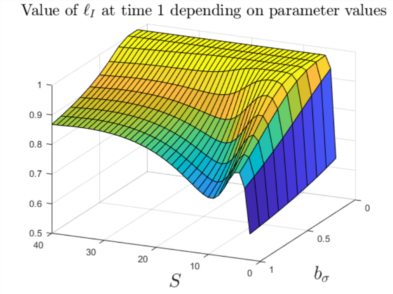

Figure: Sensitivity analysis on parameters S and b_σ

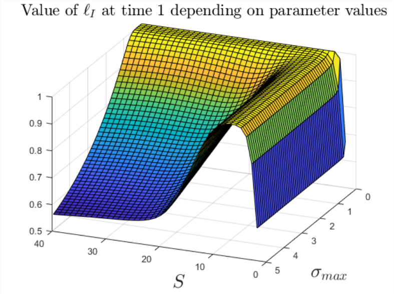

Figure: Sensitivity analysis on parameters S and σ_{max}

Discount Rate

- Finally: discount rate ρ exacerbates the role of the central expectation

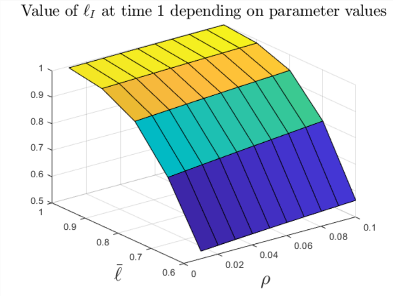

Figure: Sensitivity analysis on parameters $\bar{\ell}$ and ρ

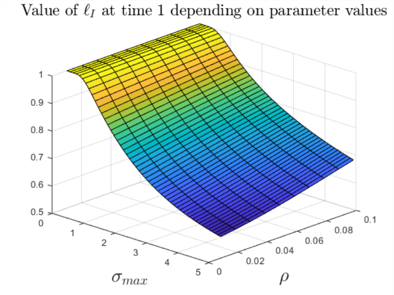

Figure: Sensitivity analysis on parameters σ_{max} and ρ