Self-fulfilling Prophecies in the Transition to Clean Technology

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Motivation

ESG

Climate Change Now a Top 3 Priority for CxOs

C-suite leaders rank climate change among their most pressing issues, but while most are increasing sustainability investments, challenges remain

01 Aug 2022

82% of FTSE 100 companies now aim for 'Net Zero' emissions by 2050

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Countries are progressing too slowly on green growth

Intellectual property + Add to myFT

Green patents slow as net zero deadlines edge closer

Intellectual property offices globally are exploring how they can help the development of low-carbon technologies

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SUSTAINABLE FUTURE

UN's Mark Carney says 'enormous' stranded assets show the need for a rapid energy transition

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Sam Meredith SHARE

- Climate change has become a mainstream consideration
- But: Why is green growth so slow? Why do green patents slow down? Why are stranded assets still growing?
- This paper: coordination failure in innovation may be the explanation

This paper

- develops a standard workhorse model of directed technical change (DTC) with forward-looking innovators and shows:
  - investments by firms within a sector are strategic complements if substitutability between sectors strong
  - leading to coordination failure and multiple equilibria both in the long run and in terms of transition pathways
  - even under a Pigouvian tax, delayed transition and excess amount of asset-stranding are possible
  - optimal policy requires in addition a separate coordination device
- contributions
  - demonstrates that coordination failure is a common feature of DTC models
  - provides a rational expectation based explanation for transition risk and stranded assets
  - points out the limitation of relying on a carbon tax alone

Literature

- multiple equilibria in endogenous growth: Benhabib and Perli (1994), Benhabib and Farmer (1994), Boldrin and Rustichini (1994), Howitt and McAfee (1988), Benhabib et al. (2008)
- multiple equilibria in environmental economics: Millner and Ollivier (2016), van der Meijden and Smulders (2017), Bretschger and Schaefer (2017)
- rational-expectation-based indeterminacy: Cozzi (2005), Cozzi (2007), Gil (2013)
- directed technical change: Acemoglu et al. (2012), Hart (2019), Hassler et al. (2021), Lemoine (2022)
- asset stranding and transition risk: van der Ploeg and Rezai (2020), Bolton and Kacperczyk (2021)

The model (1/2)

- Household:
  - $U = \ln\left[(1 - D(S))C\right]$ wtih $C = \left[C_c^{\frac{\sigma-1}{\sigma}} + C_d^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}$
  - supply inelastically one unit of labor (mobile among all sectors)
- Climate externality
  - $1 - D(S)$: climate damage
  - S: current carbon concentration, $\partial S/\partial Y_d > 0$ Detail
- Final goods sectors
  - Technology: $Y_j = L_j^{1-\alpha} \int_0^1 q_{ji} x_{ji}^{\alpha} di,$ $j \in \{c, d\}$
  - q_{ji}: product quality

The model (2/2)

- Intermediate goods sector:
  - Per unit production cost: q_{ji} units of final goods j $\quad j \in \{c, d\}$
  - In-house innovation to raise q_{ji}
  - $Q_j = \int_{i=1}^{1} q_{ji}$: sectoral knowledge stock
- R&D
  - Research arbitrage: marginal benefit of innovation = wage of scientist

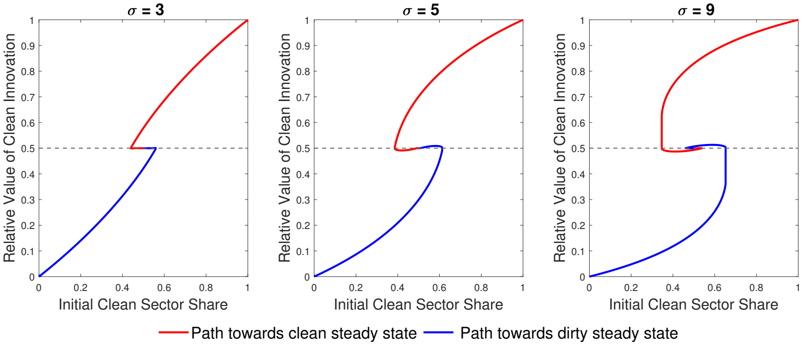
Equilibrium | Innovation Regimes | Steady States | Overlap

Strategic complementarity and self-fulfilling prophecies

$$\partial \pi_{ji} / \partial q_{ji} \propto P_j Y_j / Q_j \propto Q_j^{\sigma - 2} \qquad \sigma\text{: elasticity of substitution}$$

- Innovation by an individual firm
  - raises overall revenue of the sector $P_j Y_j$ if $\sigma > 1$ and marginal profit of other firms in the same sector $\Rightarrow$ demand externality effect
  - but lowers other firms' revenue share $(1/Q_j)$ $\Rightarrow$ business-stealing effect
- If $\sigma > 2$: strategic complementarity $\Rightarrow$ coordination failure possible
- Condition further relaxed to $\sigma > 1$ when social value of innovation is internalized (i.e. monopoly power & research spillover corrected)

Mutliple equilibria for both the long run and the transition



Parameters: capital share $\alpha = 1/3$, time preference $\rho = 0.01$, research productivity $\mu_c = \mu_d = 0.08$ (yielding an annual growth rate of 1.25%)

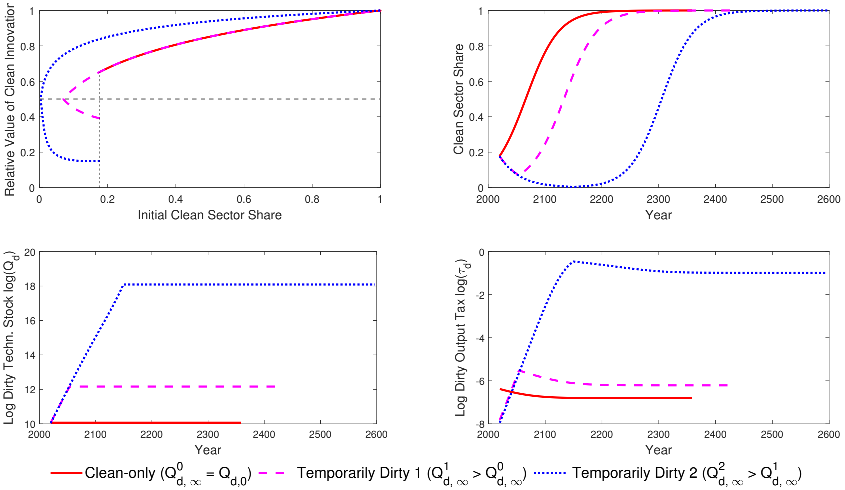
Social optimum and Pigouvian carbon tax

- A unique social optimum where innovation occurs only in the clean sector in the long run
- Pigouvian carbon tax = the marginal damage of carbon emission
- Can the social optimum be implemented using a Pigouvian carbon tax?
- No!
  - Pigouvian tax eliminates long-run dirty equilibrium
  - But cannot pin down the transition trajectory towards long-run clean equilibrium

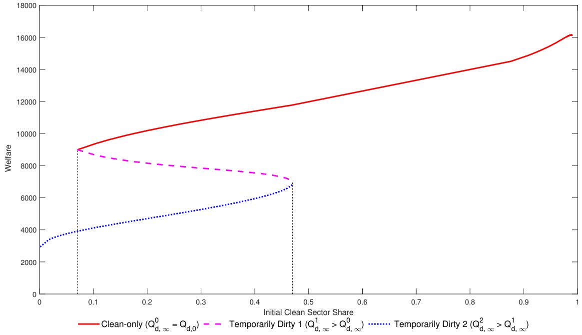
Calibration

Parameter	Value	Moment/Source
ρ (time preference)	0.01	Standard
α (capital share)	1/3	Standard
μ_j (research productivity)	0.08	baseline growth rate of 1.25%
σ (elasticity of substitution clean/dirty)	**1.5**	**Assumption**
$\theta_{c,0}$ (initial clean sector share)	**0.177**	**2019 global renewable energy share (IEA, 2022)**
$Q_{d,0}$ (initial dirty technology stock)	**23.57k**	**2019 world GDP p.c. of $11k constant 2015 USD (World Bank, 2022a)**
a_d (emission intensity)	0.198 tC/kUSD	2019 per capita carbon emission of 1.22 metric tons (World Bank, 2022b)
γ (damage parameter)	0.0002	Golosov et al. (2014)
ϕ_L (share of the permanent carbon)	0.2	Golosov et al. (2014), adjusted to annual frequency
ϕ_D (share of slow decaying carbon)	0.32	Golosov et al. (2014), adjusted to annual frequency
δ (geometric decay rate)	0.002	Golosov et al. (2014), adjusted to annual frequency
S_0 (initial dirty technology stock)	877 GtC	Golosov et al. (2014), updated to 2019
$\bar{S}$ (pre-industrial carbon concentration)	581 GtC	Golosov et al. (2014), updated to 2019

Delayed transition and stranded assets under Pigouvian tax



Welfare ranking of equilibrium paths under Pigouvian tax



- optimal transition may involve temporary dirty research when the clean sector is very small
- with a sufficiently large clean sector, fast transition is optimal
- multiple equilibria exist even under a Pigouvian tax
- coordination device necessary (e.g. emission trading, dirty R&D taxes)

Conclusions

- Self-fulfilling prophecies easily arise in standard workhorse model of directed technical change with forward-looking innovators
- Multiple equilibria exist both in the long run and in terms of transition pathways
- Even under a Pigouvian tax, delayed transition and excess amount of asset-stranding are possible
- Provides a rational expectation based explanation for transition risk and stranded assets
- Points out the limitation of relying on a carbon tax alone

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Atmospheric carbon concentration

$$S_t = \bar{S} + \int_{-\infty}^{t} \left[\phi_L + (1-\phi_L)\phi_0(1-\phi)^{s-t}\right] a_d Y_{d,s} ds$$

$$S_t = S_{1,t} + S_{2,t}$$

$$S_{1,t} = S_{1,t-dt} + \phi_L \int_{t-dt}^{t} a_d Y_{d,s} dt$$

$$S_{2,t} = (1-\phi)^{dt} S_{2,t-dt} + (1-\phi_L)\phi_0 \int_{t-dt}^{t} (1-\phi)^{t-s} a_d Y_{d,s} ds$$

Back

Dynamics of the Model

- Clean innovation regime:

$$\left\{ \begin{array}{l} \dot{\theta}_c = \theta_c(1-\theta_c)(\sigma-1)\mu_c(L^S - L) \\ \dot{L} = L\left[(\alpha\theta_c + 1)\mu_c L - (\mu_c L^S + \rho)\right] \\ \dot{m}_c = m_c\left[\alpha\mu_c L(m_c - \theta_c) + \mu_c(L^S - L)(1 - m_c)\right], \end{array} \right.$$

- Dirty innovation regime:

$$\left\{ \begin{array}{l} \dot{\theta}_c = -\theta_c(1-\theta_c)(\sigma-1)\mu_d(L^S - L) \\ \dot{L} = L\left[(\alpha(1-\theta_c) + 1)\mu_d L - (\mu_d L^S + \rho)\right] \\ \dot{m}_c = -(1-m_c)\left[\alpha\mu_d L(\theta_c - m_c) + \mu_d(L^S - L)m_c\right], \end{array} \right.$$

- Simultaneous regime

$$\left\{ \begin{array}{l} \dot{\theta}_c = \theta_c(1-\theta_c)(\sigma-1)\alpha L(\mu_c + \mu_d)(\theta_c - \kappa_c) \\ \dot{L} = L\left[(\alpha+1)\kappa_c\mu_c L - (\kappa_c\mu_c L^S + \rho)\right] \\ \dot{m}_c = 0, \end{array} \right.$$

Equilibrium characterized in three variables

- $\theta_c = \frac{P_c C_c}{PC} = \frac{Q_c^{\sigma-1}}{Q_c^{\sigma-1}+Q_d^{\sigma-1}}$

  market share for clean goods $\rightarrow$ captures the relative advancement of clean technology (the state of the economy)

- $L = L_c + L_d$

  total production labor $\rightarrow$ determines total available research labor

- $m_c = \frac{\lambda_c Q_c}{\lambda_c Q_c + \lambda_d Q_d}$

  relative market evaluation of clean investment ($\lambda_j Q_j$: market value of the marginal unit of R&D investment in sector j)

  $m_c \lesseqgtr$ relative costs of clean innovation $\kappa_c \Rightarrow$ 3 innovation regimes

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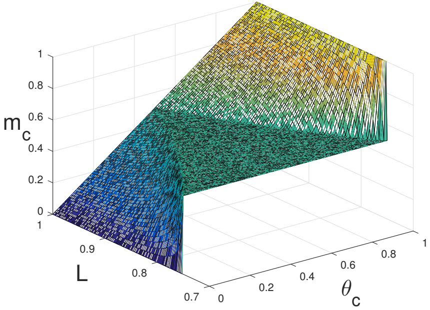
Innovation regimes

- Three innovation regimes: dirty-only ($s_c = 0$), simultaneous ($s_c, s_d > 0$), and clean-only ($s_d = 0$), separated by:

$$m_c \lesseqgtr \kappa_c \equiv \frac{1/\mu_c}{1/\mu_c + 1/\mu_d}, \qquad (\kappa_c\text{: relative costs of clean innovation})$$

- The regime shift is governed by $\dot{m}_c$



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Innovation regimes and steady states

- Three innovation regimes: dirty-only ($s_c = 0$), simultaneous ($s_c, s_d > 0$), and clean-only ($s_d = 0$), separated by:

$$m_c \lesseqgtr \kappa_c \equiv \frac{1/\mu_c}{1/\mu_c + 1/\mu_d}, \qquad (\kappa_c\text{: relative costs of clean innovation})$$

- The regime shift is governed by $\dot{m}_c$
- Three steady states:
  - An unstable interior steady state with simultaneous R&D in both sectors
  - Two saddle-path stable, asymptotic corner steady states with innovation only in the dirty or the clean sector.

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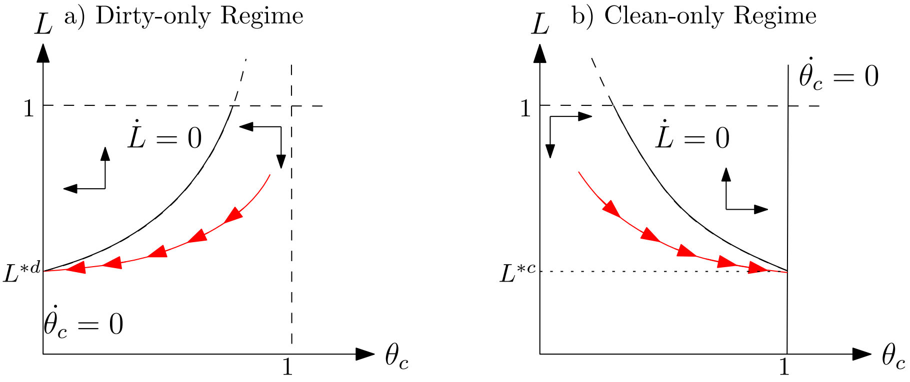
Steady states



Three steady states:

- An unstable interior steady state with simultaneous R&D in both sectors
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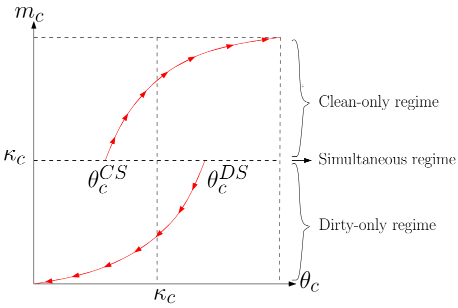
The overlap and self-fulfilling prophecies



- Overlap: a region of initial conditions ($\left[\theta_c^{CS}, \theta_c^{DS}\right]$) consistent with both the clean and dirty equilibrium paths
- For sufficiently large elasticity of substitution ($\sigma > 2$), an overlap exists and its size increases with σ
- Depending on σ, various types of transition delays possible

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