Green Innovation and Financing Constraints

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Motivation

- Access to finance is one of the major barriers to firms' innovative activity

- Financial constraints are even more relevant in the context of green innovations
  - Green innovations suffer from a double externality problem
  - Access to debt is more difficult for new and immature technologies
  - Financing costs are aggravated in the absence of a lending relationship with a bank

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This Paper

- A directed technological change model with clean and dirty inputs

- Access to credit positively depends on the market share of each technology

- Policies that redirect investment towards clean technology incentivises innovation in this sector and ease credit constraints

Previous Literature

- Environment and directed technological change (Gerlagh, 2008, Acemoglu et al., 2012, 2016, Greaker et al., 2018, Lennox and Witajewski-Baltvilks, 2017, Fried, 2018, Hart, 2019, Smulders et al., 2020, Lemoine, 2020, Wiskich, 2021)

- Differently from this literature we introduce financial frictions (King and Levine, 1993, D'Orazio and Valente, 2019, Pan et al., 2021)

- Mostly empirical literature on green innovation and financing constraints (Ghisetti et al., 2017, Howell, 2017, Jensen et al., 2019, Cecere et al., 2020, Haas and Kempa, 2021, Noailly and Smeets, 2021)

The Model

The Economy

- The economy features three sectors:
    1. A manufacturing sector producing a homogeneous good using a clean intermediate input and a dirty intermediate input
    2. Two intermediate sectors, producing the two intermediate inputs using labour and a continuum of machines
    3. Two research sectors producing machines using foregone consumption good and innovating by employing scientists

- Footlose workers and scientists

- A representative infinitely-lived household inhabited by a unit mass of research firms in each sector, L workers, and H scientists with a CRRA utility function

The Final Good Sector

- The unique final good, Y_t, is produced competitively by a representative firm according to

$$Y_t = \left(Y_{ct}^{(\epsilon-1)/\epsilon} + Y_{dt}^{(\epsilon-1)/\epsilon} \right)^{(\epsilon-1)/\epsilon} \tag{1}$$

- The intermediate goods are gross substitute, i.e. the elasticity of substitution between the two intermediate inputs is $\epsilon \in (1, +\infty)$

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The Intermediate Sectors

- Each intermediate input is produced using labour and a unit mass of sector-specific machines,

$$Y_{jt} = L_{jt}^{1-\alpha} \int_0^1 A_{jit}^{1-\alpha} x_{jit}^{\alpha} di, \quad \forall j = \{c, d\}, \tag{2}$$

- L_{jt} is labour demand in sector j at time t
- A_{jit} is the quality of machine $i \in [0, 1]$ in sector j at time t
- x_{jit} is the quantity demanded of this machine

The Intermediate Sectors and Carbon Emissions

- Carbon emissions are $E_t = \kappa Y_{dt}$
- Cumulative emissions at time t are given by

$$S_t = \sum_{\tau=0}^{t} \kappa Y_{d\tau}. \tag{3}$$

- Peak warming is determined by cumulative carbon emissions rather than by the stock of atmospheric carbon (see e.g. Allen et al., 2009, Matthews et al., 2009, van der Ploeg, 2018, Dietz and Venmans, 2019, Dietz et al., 2021, van der Ploeg and Rezai, 2021)

The Research Sectors: Machine Production

- Each machine is supplied by monopolistically competitive firms
- One unit of each machine can be produced at cost $\psi \equiv \alpha^2$ units of the final good

The Research Sectors: Innovation

- A machine producer can hire H_{jit} scientists to increase the quality of its machine to

$$A_{jit} = A_{jt-1}\left(1 + \gamma H_{jit}^{\eta}\left(\frac{A_{t-1}}{A_{jt-1}}\right)^{\phi}\right), \tag{4}$$

  where $0 \leq \eta < 1$, $\gamma > 0$, and $0 \leq \phi \leq 1$

- $A_{jt} \equiv \int_0^1 A_{jit} di$ is the average quality of the machines in sector j at the end of period t
- $A_t \equiv A_{ct} + A_{dt}$ is aggregate technology

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The Research Sectors: Spillovers

- There are two types of spillovers

- Within a sector after one period, when discoveries are observed by other machine producers in the same sector and can be incorporated into their own innovation processes

- Across sectors, as a relatively backward sector *j* has a productivity advantage equal to the catch-up ratio

The Financing Constraints I

- We assume a flow mismatch between the payments of the factor of production and the realised revenues (Mendoza, 2010, Jermann and Quadrini, 2012)

- With perfect credit markets, there is no interest on the intra-period loan

- Costly monitoring of borrowers is necessary to induce compliance to credit rules (Townsend, 1979, Gale and Hellwig, 1985)

- Monitoring costs are proportional to the volume of credit (Bernanke et al., 1999)

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The Financing Constraints II

- The maximisation problem of the producer of machine i is

$$\max_{p_{jit}, x_{jit}, H_{jit}} \left(p_{jit} - \frac{\psi}{\nu_{jt}} \right) x_{jit} - \frac{w_{jt}^{s}}{\nu_{jt}^{s}} H_{jit} \qquad \text{s.t. } x_{jit} = \left(\frac{\alpha p_{jt}}{p_{jit}} \right)^{\frac{1}{1-\alpha}} A_{jit} L_{jt}$$

$$A_{jit} = A_{jt-1} \left(1 + \gamma H_{jit}^{\eta} \left(\frac{A_{t-1}}{A_{jt-1}} \right)^{\phi} \right)$$

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The Equilibrium Allocation of Scientists

$$\frac{H_{dt}}{H_{ct}} = \left[\left(\frac{A_{dt-1}}{A_{dt-1}} \right)^{1-\phi} \left(\frac{p_{dt}}{p_{ct}} \right)^{1/(1-\alpha)} \left(\frac{L_{dt}}{L_{ct}} \right) \left(\frac{\nu^{s}_{dt}}{\nu^{s}_{ct}} \right) \left(\frac{\nu_{dt}}{\nu_{dt}} \right)^{1/(1-\alpha)} \right]^{\frac{1}{1-\eta}} \tag{5}$$

The Equilibrium Allocation of Scientists

$$\frac{H_{dt}}{H_{ct}} = \left[\left(\frac{A_{dt-1}}{A_{dt-1}} \right)^{1-\phi} \left(\frac{p_{dt}}{p_{ct}} \right)^{1/(1-\alpha)} \left(\frac{L_{dt}}{L_{ct}} \right) \left(\frac{\nu^{s}_{dt}}{\nu^{s}_{ct}} \right) \left(\frac{\nu_{dt}}{\nu_{dt}} \right)^{1/(1-\alpha)} \right]^{\frac{1}{1-\eta}} \tag{5}$$

- A productivity effect which directs innovation to the relatively more advanced sector

The Equilibrium Allocation of Scientists

$$\frac{H_{dt}}{H_{ct}} = \left[\left(\frac{A_{dt-1}}{A_{dt-1}} \right)^{1-\phi} \left(\frac{p_{dt}}{p_{ct}} \right)^{1/(1-\alpha)} \left(\frac{L_{dt}}{L_{ct}} \right) \left(\frac{\nu_{dt}^{s}}{\nu_{ct}^{s}} \right) \left(\frac{\nu_{dt}}{\nu_{dt}} \right)^{1/(1-\alpha)} \right]^{\frac{1}{1-\eta}} \quad (5)$$

- A productivity effect which directs innovation to the relatively more advanced sector
- A price effect directing innovation towards the more backward sector

The Equilibrium Allocation of Scientists

$$\frac{H_{dt}}{H_{ct}} = \left[\left(\frac{A_{dt-1}}{A_{dt-1}} \right)^{1-\phi} \left(\frac{p_{dt}}{p_{ct}} \right)^{1/(1-\alpha)} \left(\frac{L_{dt}}{L_{ct}} \right) \left(\frac{\nu^{s}_{dt}}{\nu^{s}_{ct}} \right) \left(\frac{\nu_{dt}}{\nu_{dt}} \right)^{1/(1-\alpha)} \right]^{\frac{1}{1-\eta}} \tag{5}$$

- A productivity effect which directs innovation to the relatively more advanced sector
- A price effect directing innovation towards the more backward sector
- A market size effect incentivising innovation in the largest market for machines

The Equilibrium Allocation of Scientists

$$\frac{H_{dt}}{H_{ct}} = \left[\left(\frac{A_{dt-1}}{A_{dt-1}} \right)^{1-\phi} \left(\frac{p_{dt}}{p_{ct}} \right)^{1/(1-\alpha)} \left(\frac{L_{dt}}{L_{ct}} \right) \left(\frac{\nu^s_{dt}}{\nu^s_{ct}} \right) \left(\frac{\nu_{dt}}{\nu_{dt}} \right)^{1/(1-\alpha)} \right]^{\frac{1}{1-\eta}} \tag{5}$$

- A productivity effect which directs innovation to the relatively more advanced sector
- A price effect directing innovation towards the more backward sector
- A market size effect incentivising innovation in the largest market for machines
- A credit effect, directing innovation towards the sector less prone to constraints

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Inefficiencies in the Decentralised Equilibrium

- Under-utilisation of machines due to monopoly pricing that can be corrected with a subsidy to machines use

- Environmental externality to the production of the dirty intermediate input that can be corrected by introducing a carbon tax on the use of this input in the production of the final good

- Knowledge externality that can be corrected by a research subsidy

- Monitoring costs distort choices by research firms; if asymmetric, they also chance the direction of research

Simulations

Calibration and Policy Experiments

- Calibration based on previous literature

- Three simulations, where the economy starts on the same balanced growth path and then it is shocked by policies (carbon tax and research subsidy)
  1. The baseline scenario excludes financing costs
  2. Constant and exogenous monitoring costs,

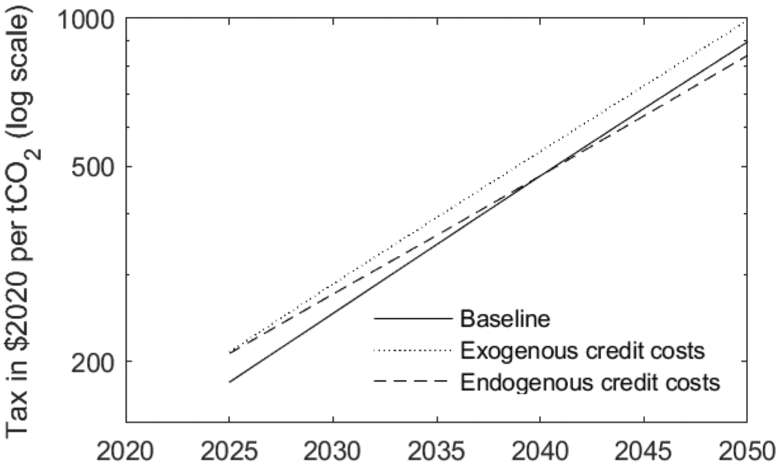
$$\nu_{dt} = \nu^s_{dt} = 100\% \qquad \nu_{ct} = \nu^s_{ct} = 90\%$$

  3. Endogenous monitoring costs, inversely related to the market share of each technology,

$$\nu_{jt} = \nu^s_{jt} = \left(\frac{Y_{jt}}{Y_{dt} + Y_{ct}} \right)^{\omega} \tag{6}$$

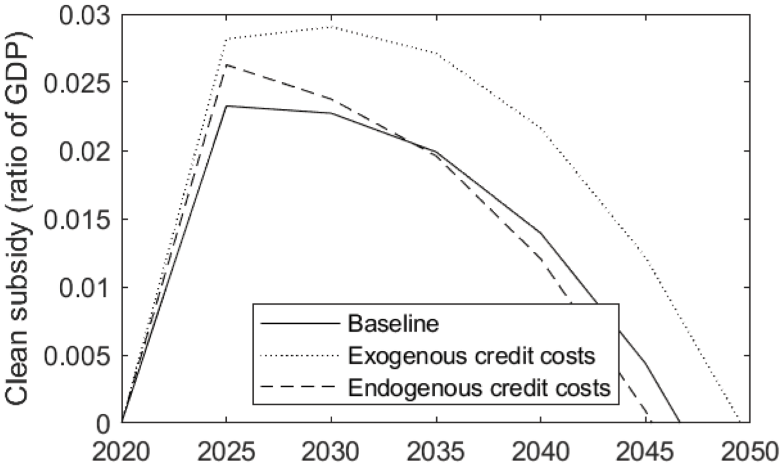
▸ Calibration

Optimal Paths to $2^\circ C$



Second-Best

Optimal Paths to 2° C



Second-Best

Conclusions

Conclusions

- Access to finance is more difficult for green technologies than for incumbent and widely-known technologies

- Heterogeneous credit constraints are a threat to the transition to a decarbonised economy as they stifle innovation in the green sector

- If credit constraints endogenously depend on the market share of the technology, climate policies becomes relatively more effective in incentivising the green transition

- In reality, certain frictions may not be solved by carbon tax and research subsidies, but may need policies directed to ease the green financial gap, e.g. state investment banks à la Mazzucato and Penna (2016)

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Calibration

Description	Parameter	Value
Annual discount rate	ρ	4%
Relative risk aversion	σ	1.5
Elasticity of substitution	ϵ	3
Machines share	α	1/3
Number of workers	L	1
Initial global GDP	Y_0	US$100 trillion
Initial clean energy share	$Y_{c0}/(Y_{d0}+Y_{c0})$	20%
Number of scientists	H	1
Scientist efficiency	γ	0.02
Returns in research	η	0.7
Cross-sector spillovers	ϕ	0.933
2020 carbon emissions (GtCO2)	Y_{d0}	35
Emission Intensity	κ	1
Cumulative emissions limit (GtCO2)		1150
Exogenous credit constraints	ν_{c0}, ν_{d0}	90%, 100%
Endogenous credit constraints	ω	0.0655

Back

Fixed Carbon Tax

- Second-best scenario where a carbon tax is introduced to respect a carbon budget of 1150GtCO2 and kept fixed (as a share of output)

- Under the baseline scenario, the required starting tax in the first period (2025) is $\$278/tCO2$, which then grows with output by assumption.

- Constant clean finance constraints imply a higher tax of $431 is required to meet the climate target, an increase of $69.

- If financing constraints are endogenous, with clean costs reducing and dirty costs increasing under the clean transition, the tax required to meet the degree target is only $13 higher than the baseline

Back