# Green Innovation and Financing Constraints

Emanuele Campiglio[§‡] Alessandro Spiganti[†‡] Anthony Wiskich[◊]

[§]University of Bologna
[†]Ca' Foscari University of Venice
[‡]RFF-CMCC European Institute on Economics and the Environment
[◊]Centre for Applied Macroeconomic Analysis, ANU

SURED 2022

European Research Council
Established by the European Commission

SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# 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

# 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)
- We introduce financial frictions (King and Levine, 1993, D'Orazio and Valente, 2019, Haas and Kempa, 2021, Pan et al., 2021)
- Empirical literature on green innovation and financing constraints (Olmos et al., 2012, Ghisetti et al., 2017, Howell, 2017, Jensen et al., 2019, Cecere et al., 2020, Kempa et al., 2021, Noailly and Smeets, 2021)

SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# 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

SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# The Final Good Sector

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

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

- The intermediate goods are gross substitute

# 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

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

# 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

# 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)

SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# The Financing Constraints II

- The maximisation problem of the producer of machine *i* is

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

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

# 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

SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# The Equilibrium Allocation of Scientists

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

- 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

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

- 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

# 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

SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# 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,

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

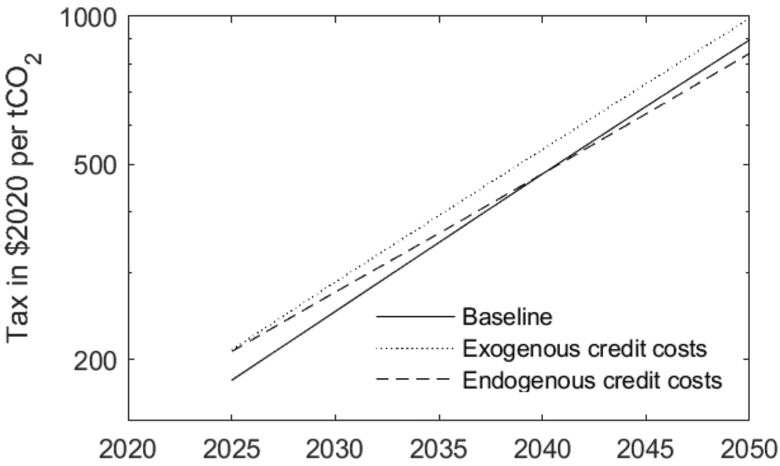
  3. Endogenous monitoring costs, inversely related to the market share of each technology,

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

▸ Calibration

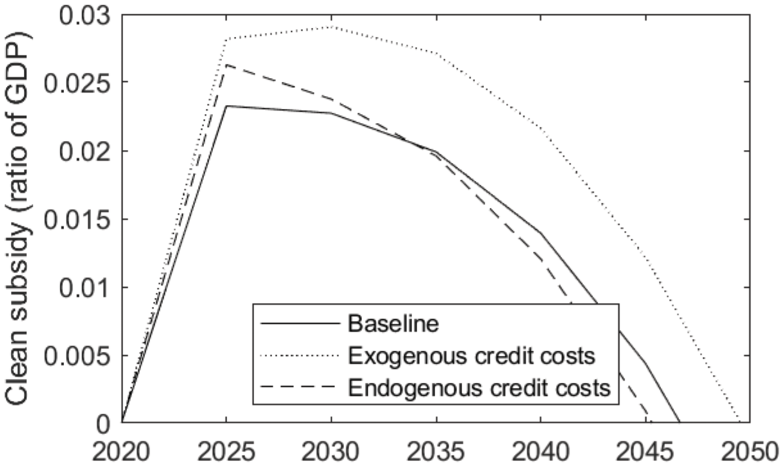
SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# Optimal Paths to 2°$C$




Second-Best
Other Variables

# Optimal Paths to 2°$C$




Second-Best Other Variables

# Conclusions and Next Steps

# 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 and credit guarantees

SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# A Possible Micro-Foundation

- Imagine research firms are heterogeneous in unobservable quality
  - A proportion $\lambda_t$ is of high-quality, i.e. successful with probability $\nu_{jHt}$
  - The remaining $1 - \lambda_t$ is of low-quality, i.e. successful with probability $\nu_{jLt} < \nu_{jHt}$

- The zero-profit repayment for a loan to produce machine would be

$$\lambda_{jt}\nu_{jHt}D_{jt} + \left(1 - \lambda_{jt}\right)\nu_{jLt}D_{jt} = \psi x_{jit},$$

$$\text{i.e. } D_{jt} = \frac{\psi x_{jit}}{\lambda_{jt}\nu_{jHt} + \left(1 - \lambda_{jt}\right)\nu_{jLt}} \equiv \frac{\psi x_{jit}}{\nu_{jt}},$$

SMOOTH
SUSTAINABLE FINANCE FOR A SMOOTH LOW-CARBON TRANSITION

# Bibliography I


Acemoglu, D., Aghion, P., Bursztyn, L., and Hemous, D. (2012). The environment and directed technical change. *American Economic Review*, 102(1):131–166.

Acemoglu, D., Akcigit, U., Hanley, D., and Kerr, W. (2016). Transition to clean technology. *Journal of Political Economy*, 124(1):52–104.

Bernanke, B. S., Gertler, M., and Gilchrist, S. (1999). The financial accelerator in a quantitative business cycle framework. In Taylor, J. B. and Woodford, M., editors, *Handbook of Macroeconomics*, volume 1 part C, pages 1341–1393. Elsevier.

Cecere, G., Corrocher, N., and Mancusi, M. L. (2020). Financial constraints and public funding of eco-innovation: Empirical evidence from European SMEs. *Small Business Economics*, 54(1):285–302.

D'Orazio, P. and Valente, M. (2019). The role of finance in environmental innovation diffusion: An evolutionary modeling approach. *Journal of Economic Behavior and Organization*, 162:417–439.

Fried, S. (2018). Climate policy and innovation: A quantitative macroeconomic analysis. *American Economic Journal: Macroeconomics*, 10(1):90–118.

Gale, D. and Hellwig, M. (1985). Incentive-compatible debt contracts: The one-period problem. *The Review of Economic Studies*, 52(4):647–663.

Gerlagh, R. (2008). A climate-change policy induced shift from innovations in carbon-energy production to carbon-energy savings. *Energy Economics*, 30(2):425–448.

Ghisetti, C., Mancinelli, S., Mazzanti, M., and Zoli, M. (2017). Financial barriers and environmental innovations: Evidence from EU manufacturing firms. *Climate Policy*, 17(sup1):S131–S147.

Greaker, M., Heggedal, T. R., and Rosendahl, K. E. (2018). Environmental policy and the direction of technical change. *Scandinavian Journal of Economics*, 120(4):1100–1138.

Haas, C. and Kempa, K. (2021). Low-carbon investment and credit rationing. Available at SSRN: `https://ssrn.com/abstract=3521332`.

Hart, R. (2019). To everything there is a season: Carbon pricing, research subsidies, and the transition to fossil-free energy. *Journal of the Association of Environmental and Resource Economists*, 6(2):349–389.

Howell, S. T. (2017). Financing innovation: Evidence from R&D grants. *American Economic Review*, 107(4):1136–1164.

Jensen, F., Schäfer, D., and Stephan, A. (2019). Financial constraints of firms with environmental innovation. *Quarterly Journal of Economic Research (Vierteljahrshefte zur Wirtschaftsforschung)*, 88(3):43–65.

Jermann, U. and Quadrini, V. (2012). Macroeconomic effects of financial shocks. *American Economic Review*, 102(1):238–271.

Kempa, K., Moslener, U., and Schenker, O. (2021). The cost of debt of renewable and non-renewable energy firms. *Nature Energy*, 6(2):135–142.

King, R. G. and Levine, R. (1993). Finance, entrepreneurship and growth: Theory and evidence. *Journal of Monetary Economics*, 32(3):513–542.

Lemoine, D. (2020). Innovation-Led Transitions in Energy Supply. University of Arizona Working Paper 17-10.

# Bibliography II


Lennox, J. A. and Witajewski-Baltvilks, J. (2017). Directed technical change with capital-embodied technologies: Implications for climate policy. *Energy Economics*, 67:400–409.

Mendoza, E. G. (2010). Sudden stops, financial crises, and leverage. *American Economic Review*, 100(5):1941–1966.

Noailly, J. and Smeets, R. (2021). Financing energy innovation: Internal finance and the direction of technical change. *Environmental and Resource Economics*, 114.

Olmos, L., Ruester, S., and Liong, S.-J. (2012). On the selection of financing instruments to push the development of new technologies: Application to clean energy technologies. *Energy Policy*, 43:252 – 266.

Pan, D., Chen, C., Grubb, M., and Wang, Y. (2021). Financial policy, green transition and recovery after the COVID-19. Available at SSRN: `https://ssrn.com/abstract=3719695`.

Smulders, S., Zhou, S., Carattini, S., Cozzi, G., Gerlagh, R., Hart, R., Kollenbach, G., Mattauch, L., Peretto, P., Ricci, F., and Schütt, F. (2020). Self-fulfilling Prophecies in Directed Technical Change. Mimeo.

Townsend, R. M. (1979). Optimal contracts and competitive markets with costly state verification. *Journal of Economic Theory*, 21(2):265–293.

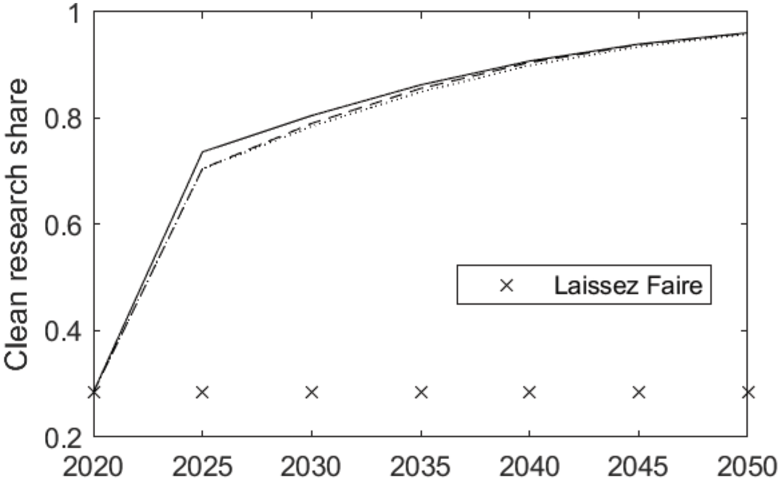
Wiskich, A. (2021). A comment on innovation with multiple equilibria and “The environment and directed technical change”. *Energy Economics*, 94(C).

# Calibration

| Description | Parameter | Value |
|---|---|---|
| Annual discount rate | $\rho$ | 4% |
| Relative risk aversion | $\sigma$ | 1.5 |
| Elasticity of substitution | $\epsilon$ | 3 |
| Machines share | $\alpha$ | 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 | $\gamma$ | 0.02 |
| Returns in research | $\eta$ | 0.7 |
| Cross-sector spillovers | $\phi$ | 0.933 |
| 2020 carbon emissions (GtCO2) | $Y_{d0}$ | 35 |
| Emission Intensity | $\kappa$ | 1 |
| Cumulative emissions limit (GtCO2) | | 1150 |
| Exogenous credit constraints | $\nu_{c0}, \nu_{d0}$ | 90%, 100% |
| Endogenous credit constraints | $\omega$ | 0.0655 |

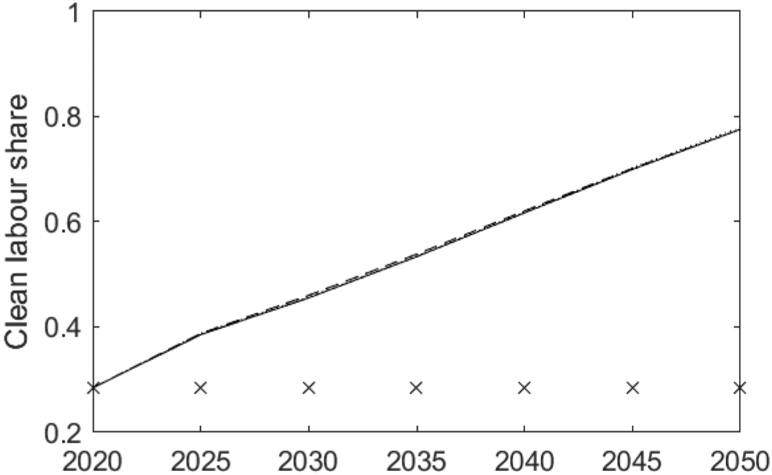
Back

# Optimal Paths to 2$^\circ C$



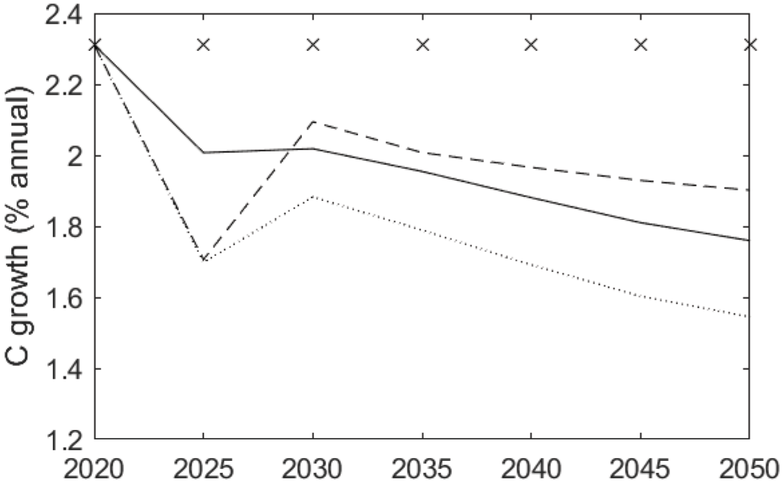

▸ Back

# Optimal Paths to 2$^{\circ}C$



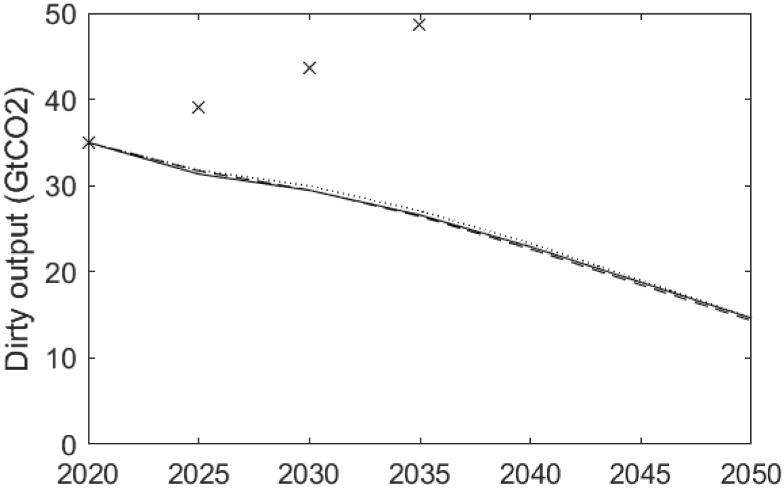

‣ Back

# Optimal Paths to 2°$C$




▸ Back

# Optimal Paths to $2^\circ C$




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