Lost in Transition: Financial Barriers to New Technologies

Philippe Aghion, Antonin Bergeaud, Maarten De Ridder, John Van Reenen

Motivation

Advanced economies are frequently reshaped by transitions from mature to emerging technologies

- Transition from typewriters to computers, steam to electricity, combustion to electric vehicles
- Can be ignited by general purpose innovations, consumer preferences, policy (e.g. green vs dirty)
- A stream of complementary innovations is needed for the transition to materialize

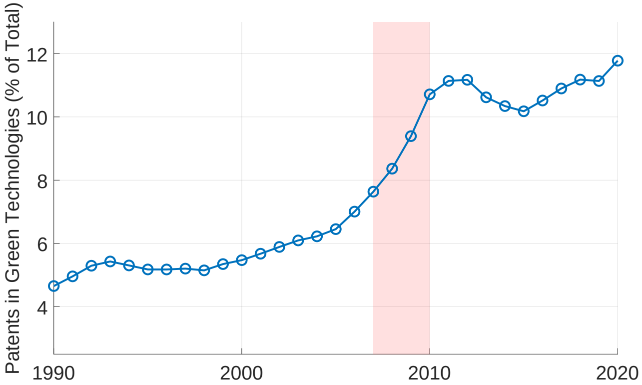
  e.g. Helpman and Trajtenberg (1994), Bresnahan and Trajtenberg (1995), Acemoglu, Akcigit, Hanley and Kerr (2016), Ribeiro (2025)

Concern: a disruption to these complementary innovations can slow down the transition

- Financial crisis affects firms' incentives and ability to invest in R&D

  e.g. Garicano and Steinwender (2016), Ates and Saffie (2021), Lenzu, Rivers and Tielens (2025), Akcigit, Alp, Ercan (2025)

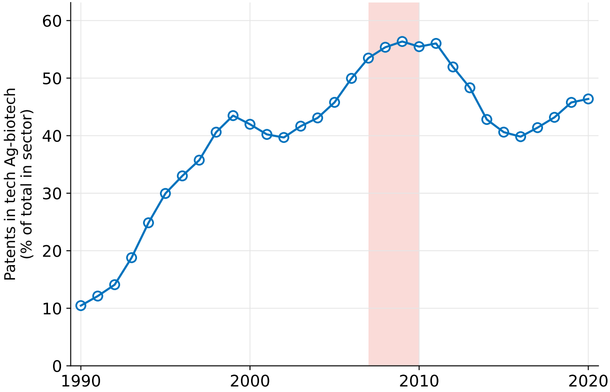
Example: Great recession and green innovation



Green patents: climate-change mitigation, environmental management, water-related adaptation technologies, biodiversity and ecosystem health

▸ Citation-weighted ▸ OECD only ▸ Triadic patents ▸ Country-by-country ▸ Other technologies ▸ Other technologies (adj for cit)

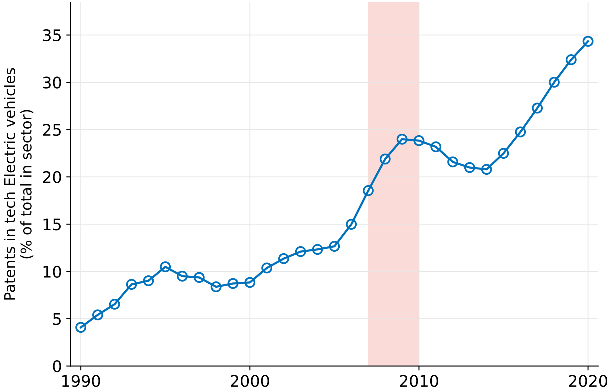
Example: innovation in biotech vs conventional agriculture



New technology: A01H, C12N15/82. Old technology: A01B, A01C, A01D, A01M, A01N

▸ Citation-weighted ▸ OECD only ▸ Triadic patents ▸ Country-by-country ▸ Other technologies ▸ Other technologies (adj for cit)

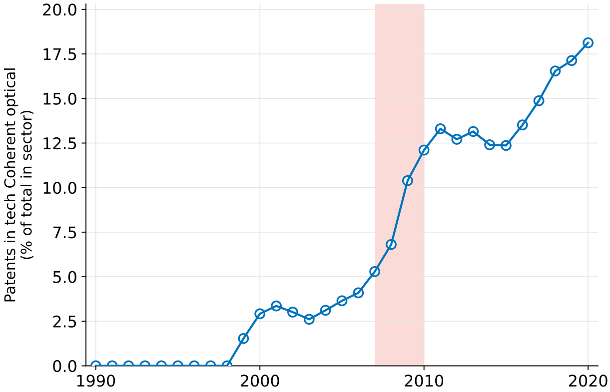
Example: innovation in electric vehicles vs internal combustion engines



New technology: B60L. Old technology: F02

▸ Citation-weighted ▸ OECD only ▸ Triadic patents ▸ Country-by-country ▸ Other technologies ▸ Other technologies (adj for cit)

Example: innovation in optic fiber transmission vs copper transmission



New technology: H04B10/60, /61, /108. Old technology: H04B10/12, /25, /40; H04B3

▸ Citation-weighted ▸ OECD only ▸ Triadic patents ▸ Country-by-country ▸ Other technologies ▸ Other technologies (adj for cit)

This paper

Do financial shocks disproportionately harm innovation in emerging technologies?

- Framework with no intrinsic difference in financing innovation in mature/emerging technologies
- Two assumptions:
  1. Young firms are more financially constrained than old firms
  2. Innovation is directed and path dependent: accumulate expertise
- Start from a steady state in which mature technology dominates followed by a transition shock
- Young firms: endogenous comparative advantage in new-technology innovation early in transition
- Financial crisis harms new technologies more because of identity of the innovators
- Lesson: tightening of financial constraints is extra costly during transitions to new technologies

The paper

Motivating facts for new technologies (see the paper)

- Young firms innovate in young technologies + reduce innovation after Global Financial Crisis
- Patenting rates in young technologies fall after Global Financial Crisis

Theoretical analysis

- Schumpeterian growth model with young and old technology, path dependence, financial constr.
- Financial crisis has a state-dependent detrimental effect on new (green) technologies

Evidence from firm-bank links: tight credit reduces green innovation, not non-green innovation

- Effect is driven by younger firms who disproportionately innovate green
- Quantify the model based on micro data: most of the patenting slowdown explained
- Financial shock later in the transition would not hurt green innovation disproportionally

Key related literature

- Models with creative destruction through (directed) technological change

  e.g. Klette and Kortum (2004), Acemoglu, Akcigit, Hanley and Kerr (2016)

- Path-dependence in innovation

  e.g. Aghion, Dechezlepretre, Hemous, Martin, Van Reenen (2016), Dugoua & Gerarden (2023), Crouzet, He, Lyonnet, Ma (2026)

- Age-dependent financial constraints

  e.g. Gertler and Gilchrist (1994), Bahaj et al. (2022), Cloyne et al. (2023), Clymo and Rozyspal (2022), Ottonello and Winberry (2024)

- Identifying real effect of credit shocks through firm-bank links

  e.g. Khwaja and Mian (2008), Chodorow-Reich (2014), Huber (2018), Amiti and Weinstein (2018)

- Links between finance and green (capital) investment

  e.g. De Haas, Martin, Muuls and Schweiger (2024), Lanteri and Rampini (2023), Capelle et al. (2025), Fornaro et al. (2026)

Today

Model

Empirical Evidence

Quantitative Analysis

Model

Framework

- Household derives log-utility from consumption, supplies labor inelastically
- Continuum of goods j, firms i produce one or multiple of them
- Each product can be produced with a modern or an old technology
- A patent enables production with a particular production technology, h
- Patent grants firm i the right to produce j, with quality q_{ij}^h

$$\ln C_t = \int_0^1 \ln \left(\sum_{h \in \{m,o\}} \sum_{i \in I_{jt}} q_{ij}^h \cdot y_{ijt}^h \right) dj$$

- Firms compete à la Bertrand: demand goes to firm with highest q_{ij}/p_{ijt}

Production

Two production technologies: modern and old. Say firm i produces good j:

- Old technology production is linear in a labor input

$$y_{ijt}^{o} = l_{ijt}^{o}$$

  - Productivity of producing with old technology normalized to 1

- Production with the modern technology comes with a different relative productivity:

$$y_{ij}^{m} = a_t^m l_{ij}^{m}$$

  - Initial steady state: $a_t^m < 1$. Final steady state: $a_t^m > 1$

- Minimum price a firm can charge is its marginal cost

$$mc_t^h = \begin{cases} w & \text{if } h = o \\ w \quad / \quad a^m & \text{if } h = m \end{cases}$$

Innovation

Firms expand their product portfolio through directed innovation

- Firms choose the Poisson arrival rate of patents using modern and old technologies
- Technologies improve random product's leading quality by quality step λ
- Innovation costs decline in stock of products in directed technology

Key assumption 1: there is path dependence in the direction of firms' R&D

$$rd_i = \frac{\phi}{\psi} N_i^{1-\psi/\zeta} \left[(x_i^m)^\zeta (N_i^m)^{1-\zeta} + (x_i^o)^\zeta (N_i^o)^{1-\zeta} \right]^{\psi/\zeta}$$

- where $1 < \zeta \leq \psi$ and where $N_i^h = n_i^h + \epsilon^h$. Entrants: $N_i^h = \epsilon^h$.
- κ: degree to which firms have comparative advantage in technologies they have experience with

Financial cost of innovation

Firms face earnings-based borrowing constraints when financing R&D spending (Lian and Ma 2021)

- Firm i with revenue $py_{it} \equiv \sum_{j \in J_i} py_{ijt}$ can at most finance

$$d_{it} \leq \theta_i \times \Theta_t \times py_{it}$$

- Covenant becomes more lenient with repeated interaction and as firms meet additional lenders

$$\begin{aligned} \theta' > \theta \quad & \text{with Poisson rate} \quad \nu^{\uparrow} \\ \theta' < \theta \quad & \text{with Poisson rate} \quad \nu^{\downarrow} \end{aligned}$$

Key Assumption 2: Young firms are more likely to be financially constrained

$$\nu^{\uparrow} > \nu^{\downarrow}$$

Evidence in, e.g. Evans and Jovanovic (1989), Gertler and Gilchrist (1994), Haltiwanger et al. (2013), Cloyne et al. (2023)

A product is displaced at the rate of creative destruction:

$$\tau = \int_{\mathcal{F}} X_i^m di + \int_{\mathcal{F}} X_i^o di + e^m + e^o$$

- Sum of displacement due to incumbent innovation and entrant innovation

Productivity growth:

$$g = \ln \lambda \cdot \tau$$

Optimization

Static optimization:

- Highest-quality producer will limit price its closest competitor. Markups:
  - Producer uses modern, closest competitor uses old technology: $\mu^{mo} = \lambda \times a^m$
  - Producer uses old, closest competitor uses modern technology: $\mu^{om} = \lambda \ / \ a^m$
  - Producer and competitor use the same technology: $\mu^{mm} = \mu^{oo} = \lambda$

Dynamic optimization:

$$X_i^h \propto N_i^h \left[V^h(\theta_i) \right]^{\frac{1}{\zeta - 1}} (1 + \mathcal{M}_i)^{-\frac{1}{\psi - 1}}$$

- $V^h(\theta_i)$ denotes the expected value of directing innovation to h

  $\Rightarrow$ innovation is proportional to N^h, innovation capacity depends on state

Derivation

Optimization - mechanism

Static optimization:

- Highest-quality producer will limit price its closest competitor. Markups:
  - Producer uses modern, closest competitor uses old technology: $\mu^{mo} = \lambda \times a^m$
  - Producer uses old, closest competitor uses modern technology: $\mu^{om} = \lambda \, / \, a^m$
  - Producer and competitor use the same technology: $\mu^{mm} = \mu^{oo} = \lambda$

Dynamic optimization:

$$X_i^h \propto N_i^h \left[V^h(\theta_i)\right]^{\frac{1}{\zeta-1}} (1+\mathcal{M}_i)^{-\frac{1}{\psi-1}}$$

- $V^h(\theta_i)$ denotes the expected value of directing innovation to h

  $\Rightarrow$ innovation is proportional to N^h, innovation capacity depends on state

Derivation

Optimization - mechanism

Static optimization:

- Highest-quality producer will limit price its closest competitor. Markups:
  - Producer uses modern, closest competitor uses old technology: $\mu^{mo} = \lambda \times a^m$
  - Producer uses old, closest competitor uses modern technology: $\mu^{om} = \lambda \,/\, a^m$
  - Producer and competitor use the same technology: $\mu^{mm} = \mu^{oo} = \lambda$

Dynamic optimization:

$$X_i^h \propto N_i^h \left[V^h(\theta_i) \right]^{\frac{1}{\zeta - 1}} (1 + \mathcal{M}_i)^{-\frac{1}{\psi - 1}}$$

- $V^h(\theta_i)$ denotes the expected value of directing innovation to h

  $\Rightarrow$ innovation is proportional to N^h, innovation capacity depends on state

Derivation

Optimization - mechanism

Static optimization:

- Highest-quality producer will limit price its closest competitor. Markups:
  - Producer uses modern, closest competitor uses old technology: $\mu^{mo} = \lambda \times a^m$
  - Producer uses old, closest competitor uses modern technology: $\mu^{om} = \lambda \ / \ a^m$
  - Producer and competitor use the same technology: $\mu^{mm} = \mu^{oo} = \lambda$

Dynamic optimization:

$$X_i^h \propto N_i^h \left[V^h(\theta_i) \right]^{\frac{1}{\zeta - 1}} (1 + \mathcal{M}_i)^{-\frac{1}{\psi - 1}}$$

- $V^h(\theta_i)$ denotes the expected value of directing innovation to h

  $\Rightarrow$ innovation is proportional to N^h, innovation capacity depends on state

Derivation

Optimization - mechanism

Static optimization:

- Highest-quality producer will limit price its closest competitor. Markups:
  - Producer uses modern, closest competitor uses old technology: $\mu^{mo} = \lambda \times a^{o}$
  - Producer uses old, closest competitor uses modern technology: $\mu^{om} = \lambda \,/\, a^{m}$
  - Producer and competitor use the same technology: $\mu^{mm} = \mu^{oo} = \lambda$

Dynamic optimization:

$$X_i^h \propto N_i^h \left[V^h(\theta_i) \right]^{\frac{1}{\zeta - 1}} \left(1 + \mathcal{M}_i \right)^{-\frac{1}{\psi - 1}}$$

- $V^h(\theta_i)$ denotes the expected value of directing innovation to h

  $\Rightarrow$ innovation is proportional to N^h, innovation capacity depends on state

Derivation

Remainder of the model

- Aggregate variables: output and wages ▸ details
- Balanced growth path firm-size and financial maturity distribution ▸ details
- Balanced growth path share of production that uses old/modern technology ▸ details
- Model solution algorithm ▸ details

Empirical Evidence

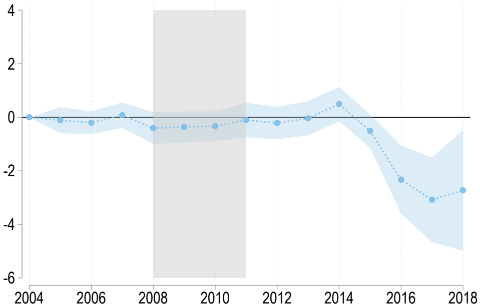
Empirical strategy

Effect of exposure to Global Financial Crisis on green and non-green innovation

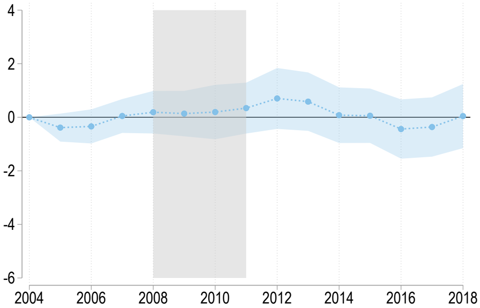
- Measure green and non-green innovation through patent classifications
- Exposure to the global financial crisis from firm-bank links
- Assume firms' innovation propensity orthogonal to bank identity
- German data on exposure to Commerzbank from Huber (2018)
  - Commerzbank incurred large trading losses in U.S.' subprime market
  - Huber: balance tests, effect on employment, investments, overall patents
- Difference-in-difference estimation using interaction of Commerzbank Exposure (CB_i), year effects:

$$\mathbb{E}_t[y_{it}|CB_i, i, t] = \exp(\gamma_t \mathrm{CB}_i + \phi_i + \psi_t)$$

Effect of financial tightness on patents over time



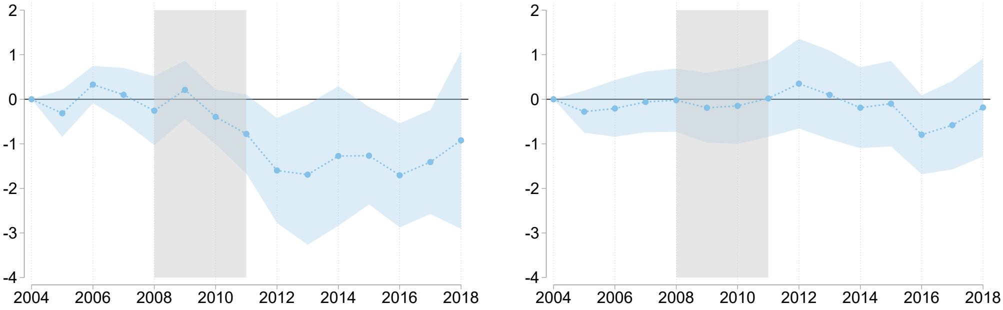
(a) Green Patents



(b) Non-Green Patents

The figure plots the effect of exposure to Commerzbank on patenting in the year on the horizontal axis. Estimates from PPML. Confidence bounds are at the 95% level using firm-clustered standard errors.

Effect of financial tightness on patents over time (extra controls)



(a) Green Patents

(b) Non-Green Patents

The figure plots the effect of exposure to Commerzbank on patenting in the year on the horizontal axis. Estimates from PPML. Confidence bounds are at the 95% level using firm-clustered standard errors.

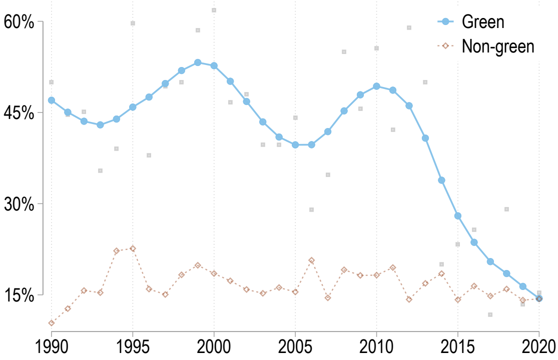
Green effect is concentrated in younger firms

$$\mathbb{E}[y_{it}] = exp\left(\gamma[CB_i \times Post_t \times Young_i] + \beta[CB_i \times Post_t] + \alpha[Y_i \times Post_t] + \phi_i + \psi_t\right)$$

	Average Effect		Age Below Median		Age Above Median	
	Green	Non-Green	Green	Non-Green	Green	Non-Green
Commerzbank Exposure	-0.506***	-0.107	-0.886***	-0.664*	0.950*	0.303
(Effect by Age)	(0.166)	(0.334)	(0.321)	(0.350)	(0.555)	(0.474)

Table presents $\gamma + \beta$. Firm-clustered standard errors.

Younger firms are green innovators



Percentage of green patents filed by firms with a below-median age in 2006.

Quantitative Analysis

Production

Two production technologies: dirty and clean. Say firm i produces good j:

- Production with the clean technology only requires a labor input

$$y_{ij}^c = l_{ij}^c$$

- Dirty technology requires both a labor input and a polluting input

$$y_{ij}^d = (l_{ij}^d)^\eta \cdot (o_{ij})^{1-\eta} \qquad \Rightarrow \qquad o_{ij} = \left(\frac{\eta}{1-\eta}\frac{w}{p^o}\right) l_{ij}^d$$

$$\Rightarrow \qquad y_{ij}^d = \underbrace{\left(\frac{\eta-1}{\eta}\frac{p^o}{w}\right)^{-\eta}}_{\text{efficiency of dirty production}(\tilde{p}^o)^{-1}} l_{ij}^d$$

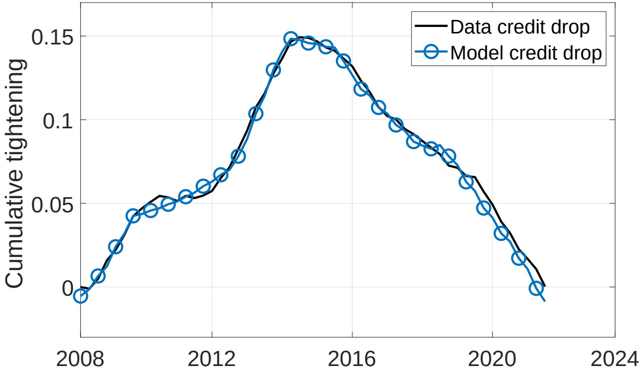
- Minimum price a firm can charge is its marginal cost

$$mc_t^h = \begin{cases} w & \text{if } h = c \\ w \quad \times \quad \tilde{p}^o & \text{if } h = d \end{cases}$$

Approach

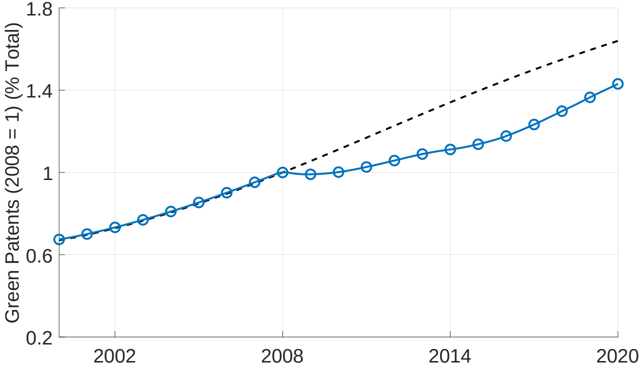
- Baseline parameters: structurally estimated to match pre-1995 German moments
- Model the financial crisis as an MIT shock within an MIT shock
- Transition: gradual increase in relative cost of dirty technology
  - Reduce steady-state emissions by 65% (IPCC 2023)
  - Speed to match increase in green patenting pre Global Financial Crisis
- Shock: temporary increase in financial costs
  - Match path of credit from ECB Lending Supply Indicator (Altavilla et al. 2019)
  - Decline θ across all firms, but binds for firms with lower levels of maturity
- Compare decline in green vs non-green patenting to the data

Preliminary calibration - financial shock



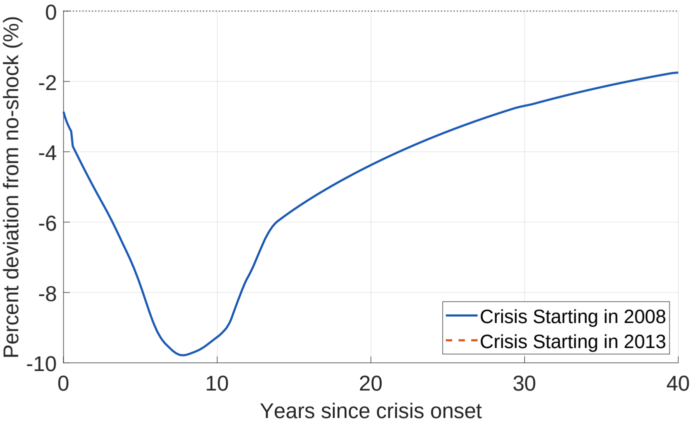
Data: Implied tightening of credit supply from ECB Lending Standards Index (Altavilla et al. 2019).

Effect of Financial Crisis on Green Innovation



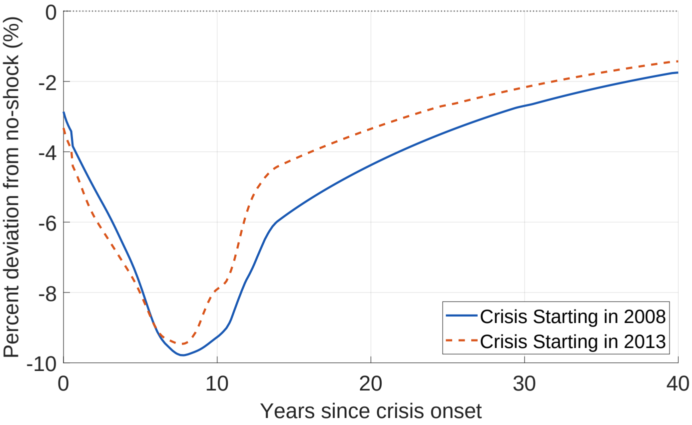
Data: Implied tightening of credit supply from ECB Lending Standards Index (Altavilla et al. 2019).

Effect of Financial Crisis on Green Innovation



Plot: deviation of green innovation (fraction of total) compared to baseline trajectory.

Effect of Financial Crisis on Green Innovation



Plot: deviation of green innovation (fraction of total) compared to baseline trajectory.

Conclusion

This paper:

- Young firms contribute disproportionately to innovations in young technologies
- This endogenously makes young technologies fragile to financial disruptions
- Recent example is the slowdown of green patenting down after the Global Financial Crisis
- Micro evidence: credit supply affected green innovation for younger firms
- Large quantitative effects in model with directed technological change and financial constraints
- Policy implication: crises more costly during young-firm led transitions

Appendix

Derivation: wage

$$
\begin{aligned}
\ln Y &= \int_0^1 \ln q_j + \ln y_j dj \\
&= \int_0^1 \ln q_j dj + \ln Y - \left(\int_0^F \ln p_j^c dj + \int_F^1 \ln p_j^d dj \right) \\
0 &= \int_0^1 \ln q_j dj - F \ln mc^c + (1-F) \ln mc^d + \left(\int_0^F \ln \mu_j^c dj + \int_F^1 \ln \mu_j^d dj \right) \\
\ln w &= \int_0^1 \ln q_j dj - (1-F) \ln \tilde{p}^o - \left(\int_0^F \ln \mu_j^c dj + \int_F^1 \ln \mu_j^d dj \right) \\
\ln w &= \int_0^1 \ln q_j dj - F \times \overline{\ln \mu^c} - (1-F) \times \overline{\ln \mu^d}
\end{aligned}
$$

Where I use $mc^d = mc^c \times \left(\frac{\eta}{1-\eta} \frac{w}{p^o} \right)^{-\eta} = w \times \left(\frac{\eta}{1-\eta} \frac{w}{p^o} \right)^{-\eta} = w \times \tilde{p}^o$

and where

$$
\begin{aligned}
\overline{\ln \mu^c} &= (\ln \mu^{cc})(\alpha + [1-\alpha]F) + (\ln \mu^{cd})(1-)(1-F) \\
\overline{\ln \mu^d} &= (\ln \mu^{dd})(\alpha + [1-\alpha][1-F]) + (\ln \mu^{dc})(1-)F + \ln \tilde{p}^o
\end{aligned}
$$

Derivation: consumption

$$
\begin{aligned}
L^p &= L^c + \tilde{L}^d \\
&= \int_0^F y_j^c \, dj + \int_F^1 y_j^d \, dj \\
&= C \left(\int_0^F (p_j^{-1})^c \, dj + \int_F^1 (p_j^{-1})^d \, dj \right) \\
&= C/w \times \left(\int_0^F \mu_i^{-1} \, dj + (\tilde{p}^o)^{-1} \int_F^1 \mu_j^{-1} \, dj \right) \\
C &= L^p \times w \times \left(F(\overline{\mu^c})^{-1} + (1-F)(\overline{\mu^d})^{-1} \right)^{-1} \\
&= L^p \times \exp\left(\int_0^1 \ln q_j \, dj \right) \times \frac{\exp(-F \times \overline{\ln \mu^c} - (1-F) \times \overline{\ln \mu^d})}{F(\overline{\mu^c})^{-1} + (\tilde{p}^o)^{-1}(1-F)(\overline{\mu^d})^{-1}}
\end{aligned}
$$

where

$$
\begin{aligned}
(\overline{\mu^c})^{-1} &= (\mu^{cc})^{-1}(\alpha + [1-\alpha]F) + (\mu^{cd})^{-1}(1-)(1-F) \\
(\overline{\mu^d})^{-1} &= (\mu^{dd})^{-1}(\alpha + [1-\alpha][1-F])(\tilde{p}^o)^{-1} + (\mu^{dc})^{-1}(1-)F(\tilde{p}^o)^{-1}
\end{aligned}
$$

Back

Notation: production inputs

$$
\begin{aligned}
L^p &= L^c + \tilde{L}^d \\
&= \int_0^F y_j^c \, dj + \int_F^1 y_j^d \, di \\
&= \int_0^F l_j^c \, dj + \int_F^1 \left(\frac{\eta}{1-\eta} \frac{w}{p^o} \right)^{\eta} l_{ij}^d \, di
\end{aligned}
$$

▸ Back

Entry

There is a continuum of identical entrepreneurs. Two conditions:

- Clean innovation:

$$e^c = \phi_e^c (rd^{ec})^{\frac{1}{\psi}} \quad \Rightarrow \quad e^c = \left(\frac{(\phi_e^c)^\psi}{\psi \cdot w \cdot \tilde{r}(0)} \frac{E(\pi^c)}{r - g + \tau} \right)^{\frac{1}{\psi - 1}}$$

- Dirty innovation:

$$e^d = \phi_e^d (rd^{ed})^{\frac{1}{\psi}} \quad \Rightarrow \quad e^d = \left(\frac{(\phi_e^d)^\psi}{\psi \cdot w \cdot \tilde{r}(0)} \frac{E(\pi^d)}{r - g + \tau} \right)^{\frac{1}{\psi - 1}}$$

Equilibrium

Endogenous variables:

- e^c, e^d, x^c, x^d, τ^c, τ^d, Π^c, Π^d, $\overline{\ln \mu^c}$, $\overline{\ln \mu^d}$, $(\overline{\mu^c})^{-1}$, $(\overline{\mu^d})^{-1}$
- L^c, $\tilde{L^d}$, C, w, $\tilde{p^o}$, F, $M(..)$, r, g

Equations:

- Free entry conditions (x2), R&D first order conditions (x2), creative destruction rates (x2), value definitions (x2), markup definitions (x4), labor market equations (x2), aggregate output, wage, fossil price definition, firm-size distribution (x2), Euler equation, equation for aggregate productivity growth

Back

Introducing the climate

The household's utility depends on consumption C and pollution S:

$$Y_t = exp(-\gamma S_t + C_t)$$

- S_t evolves endogenously: increases due to dirty sector's pollution

Utility over Y_t is logarithmic, labor supply is inelastic:

$$U = \int_0^{\infty} e^{-\rho t} \ln Y_t dt$$

$\Rightarrow$ To be implemented later Back

Calibration

Parameter	Description	Target	Value
ϕ^c	R&D productivity scalar: clean	Aggregate growth	0.3
ϕ^d	R&D productivity scalar: dirty	Aggregate growth	0.3
ϕ_e^c	Entry cost scalar: clean	Entry rate	0.1
ϕ_e^d	Entry cost scalar: dirty	Entry rate	0.1
α	Directed innovation success	TBD	1.0
ψ	R&D cost curvature	R&D cost elasticity	2.00
$\tilde{p}^o$	Relative dirty cost	5% green products	0.85
λ	Innovation step size	Average markup	1.2
ρ	Discount rate	Risk-free interest rate	0.02

Construction of counterfactual path

Assumption: time series path of patenting in new technology follows a Gompertz curve

- Generalized logistic curve to deliver *S-shaped* diffusion path
- Family has previously been used in (e.g.) Griliches (1957), Ribeiro (2025)
- Results are robust to assuming diffusion pattern is a simple logistic curve (more symmetric)

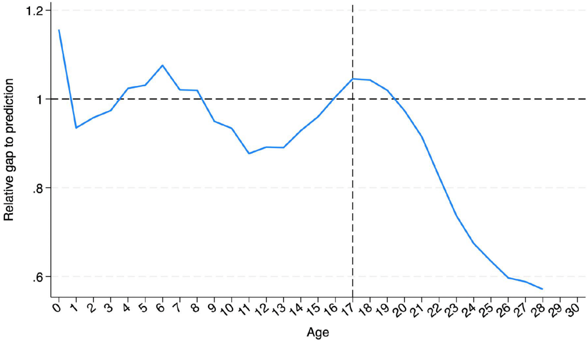
Estimate the parameters using first 10 years, where share of patents in year t that belongs to c is

$$s_c(a) = \mathcal{K}_c \times \exp\left(-\exp - (\gamma_c[a - \psi_c])\right)$$

- a: age of the technology (time since initial patenting burst)
- $\mathcal{K}$: governs upper bound for technology c's share in total patents
- γ: governs the speed of diffusion
- ψ: governs the location of the inflection point of diffusion

Back

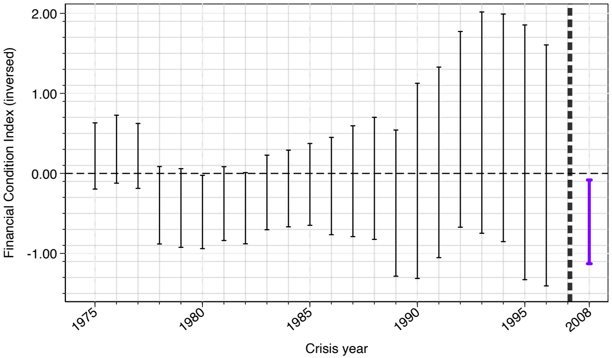
Example of young technology around Global Financial Crisis



G01Q: scanning probe microscopy, first burst of patents in 1993.

Back

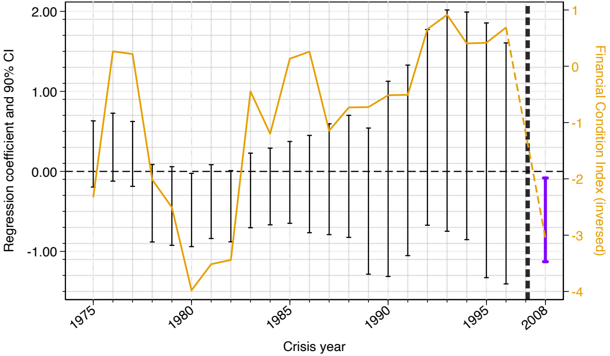
Effect of financial conditions on innovation in young technologies



Financial conditions: Inverted National Financial Conditions Index (Chicago Fed)

Back

Effect of financial conditions on innovation in young technologies



Financial conditions: Inverted National Financial Conditions Index (Chicago Fed)

Back

Finding the equilibrium

The change in the measure is given by:

$$\begin{aligned}
\dot{M}_{n^c=\overline{n}^c,n^d=\overline{n}^d,a=\overline{a}} &= M_{n^c=\overline{n}^c+1,n^d=\overline{n}^d,a=\overline{a}}\tau^c(\overline{n}^c+1) + M_{n^c=\overline{n}^c,n^d=\overline{n}^d+1,a=\overline{a}}\tau^d(\overline{n}^d+1) \\
&+ M_{n^c=\overline{n}^c-1,n^d=\overline{n}^d,a=\overline{a}}\alpha x^c(\overline{a})(\overline{n}^c-1) + M_{n^c=\overline{n}^c-1,n^d=\overline{n}^d,a=\overline{a}}(1-)x^d(\overline{a})\overline{n}^d \\
&+ M_{n^c=\overline{n}^c,n^d=\overline{n}^d-1,a=\overline{a}}(1-)x^c(\overline{a})\overline{n}^c + M_{n^c=\overline{n}^c,n^d=\overline{n}^d-1,a=\overline{a}}\alpha x^d(\overline{a})(\overline{n}^d-1) \\
&+ \nu \cdot M_{n^c=\overline{n}^c,n^d=\overline{n}^d,a=\overline{a}-1} - \nu M_{n^c=\overline{n}^c,n^d=\overline{n}^d,a=\overline{a}} \\
&- \left((x^d(\overline{a})+\tau^d(\overline{a}))n^d - (x^d+\tau^d)\overline{n}^c\right) M_{n^c=\overline{n}^c,n^d=\overline{n}^d,a=\overline{a}}
\end{aligned}$$

Steady state has constant measure of firms of all states:

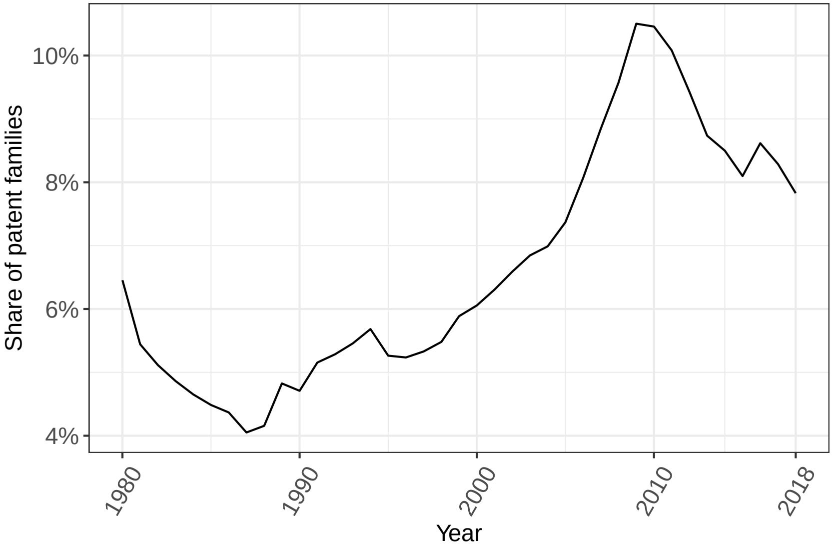
$$\dot{M}_{n^c=\overline{n}^c,n^d=\overline{n}^d,a=\overline{a}} = 0 \qquad \forall \quad \overline{n}^c, \overline{n}^d, \overline{a}$$

Solution: define transition matrix T that has $(n^{max})^2 \cdot \|\mathcal{A}\| \times (n^{max})^2 \cdot \|\mathcal{A}\|$

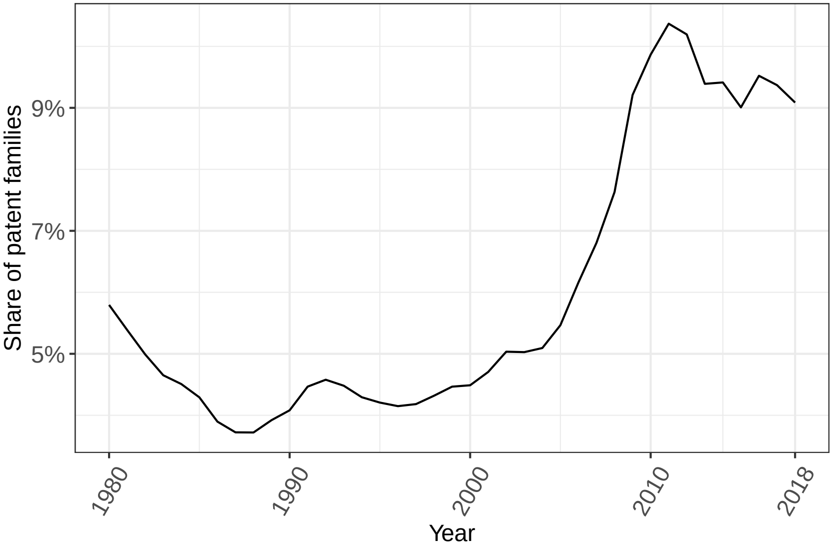
$$\dot{M} = T \times M + E \quad \Rightarrow \quad M = -(T)^{-1}E$$

▸ Back

Weighting patents by citations



OECD countries



Aggregate variables

Equilibrium wage:

$$w = \exp\left(\int_0^1 \ln q_j dj\right) (a^m)^F \left(\exp\left(\overline{\ln \mu^m}\right)^F \exp\left(\overline{\ln \mu^o}\right)^{(1-F)}\right)^{-1},$$

where

$$\overline{\ln \mu^m} = F \ln \lambda + (1-F)\ln(\lambda \div a^m) \quad \text{and} \quad \overline{\ln \mu^d} = F \ln \ln(\lambda \times a^m) + (1-F)\ln \lambda.$$

Aggregate output:

$$Y = L^p \exp\left(\int_0^1 \ln q_j dj\right) (a^m)^F \mathcal{W}.$$

back

Distributions

Value of innovations and direction of innovation depend on expected markup

- Markup depends on fraction F of goods produced with modern technology
- Law of motion for vector M with measure of firm states:

$$\dot{M} = TM + E$$

- T: transition matrix between states (number of modern/old products, financial maturity)
- In a stationary equilibrium, $\dot{M} = 0$, so that

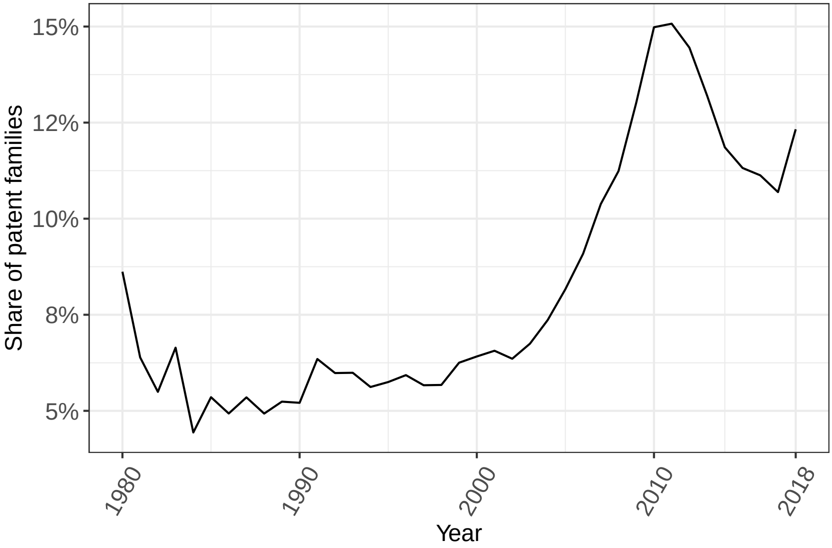
$$M = -T^{-1}E$$

- Derive equilibrium technology shares:

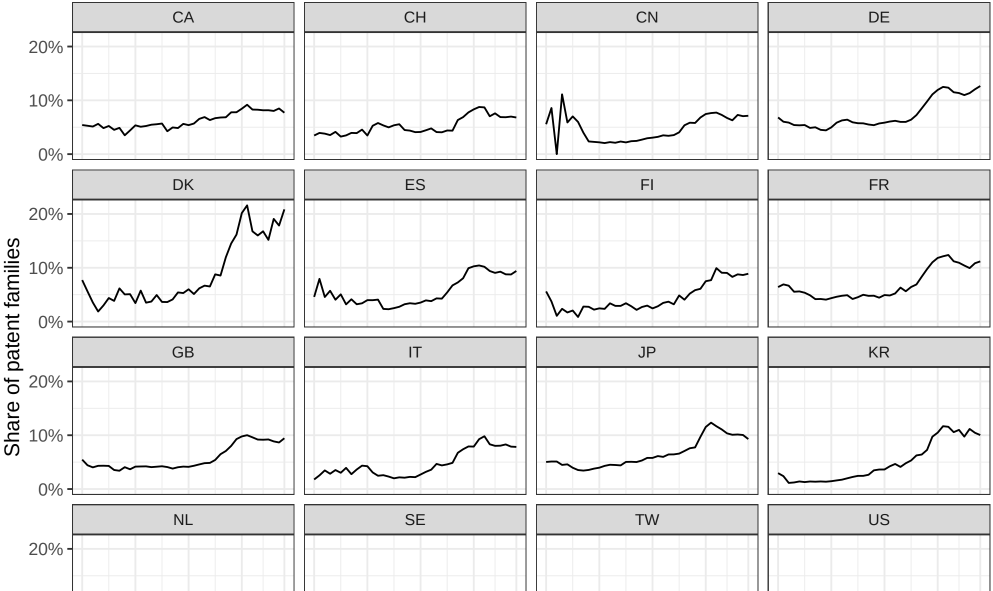
$$F = \frac{\sum_{\theta} \sum_{n^m, n^o} n^m M_{n^m, n^o}(\theta)}{\sum_{\theta} \sum_{n^m, n^o} (n^m + n^o) M_{n^m, n^o}(\theta)}.$$

back

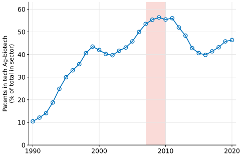
Triadic patents



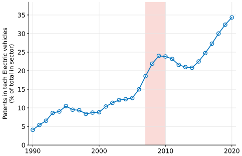
Individual countries



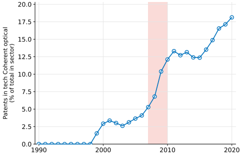
Other Technologies



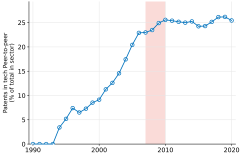
(a) Ag-biotech



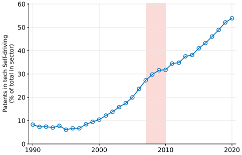
(b) Electric vehicles



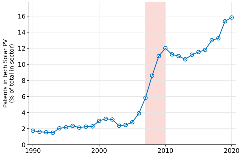
(c) Coherent optical



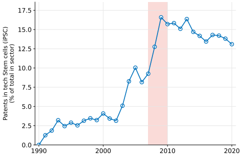
(d) Peer-to-peer



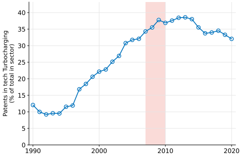
(e) Self-driving



(f) Solar PV



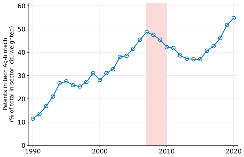
(g) Stem cells (iPSC)



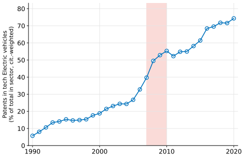
(h) Turbocharging

Back

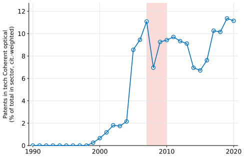
Other Technologies - adjusting for citations



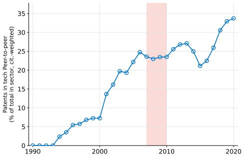
(i) Ag-biotech



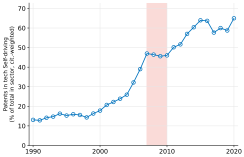
(j) Electric vehicles



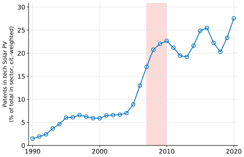
(k) Coherent optical



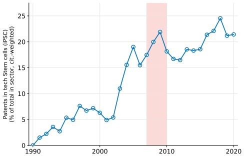
(l) Peer-to-peer



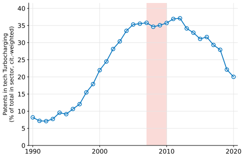
(m) Self-driving



(n) Solar PV



(o) Stem cells (iPSC)



(p) Turbocharging

Back