"Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry"

by Aghion et al. (2016)

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Research Question

- Examine whether firms redirect technical change away from dirty technologies and toward cleaner technologies in response to increase in fuel prices in the context of path dependency.
  1. Does directed technical change exist in the auto industry?
  2. Does path-dependent innovation exist in the auto industry?
  3. How important is path dependency in firms' directed innovation in response to increase in fuel prices?
- Main contribution: Compared to ealier work by Popp (2002), who uses aggregate data, the paper uses an **international firm-level panel data** to provide **microeconomic** evidence of directed technical change, of which the theory is developed by Acemoglu (2002).

Hypothesis

1. An increase in the price of the fossil fuel increases innovation in clean technologies, and decreases innovation in dirty technologies.
2. Firms with an initially higher level of clean (dirty) technologies will tend to innovate more in clean (dirty) technologies.
3. Firms are more likely to innovate in clean technologies when its inventors are located in countries where other firms have been undertaking more clean innovations.

Econometrics Model

- Dynamic fixed effect Poisson specification for count outcome data.
- Two main empirical equations: $z \in \{C, D\}$

$$\begin{aligned} \mathrm{PAT}_{z,it} = \exp(&\beta_{zp} \ln FP_{it-1} + \beta_{z1} \ln \mathrm{SPILL}_{C,it-1} + \beta_{z2} \ln \mathrm{SPILL}_{D,it-1} \\ &+ \beta_{z3} \ln K_{C,it-1} + \beta_{z4} \ln K_{D,it-1} + \beta_{z\omega}\omega_{it} + T_{z,t})\eta_{z,i} + \mu_{z,it}, \end{aligned} \tag{1}$$

- Lagged independent variables are to avoid contemporaneous feedback effects.
  1. FP_{it}: the number of patents applied for in clean technologies by firm i in year t;
  2. $\mathrm{SPILL}_{z,it}$: other firms knowledge stock in z technologies;
  3. $K_{z,it}$: firm's own stock of z technologies;
  4. ω_{it}: other control variables;

Data: PAT_{it}

- Clean patents are those related to electric, hybrid, and hydrogen vehicles; dirty patents are those related to internal combustion engine.
- Only count "triadic" patents: patents have been taken out in all three of the world's major patent offices in the United States, Europe, and Japan. These are most valuable inventions.
- Each invention is only counted once, no matter in how many patent offices it has been filed.
- Sample: All applicants that applied for at least one of these clean or dirty auto patterns between 1978 and 2005.

Data: Firm-specific Price

- Although variation of fuel prices is country-level, the profile of car sales across countries differs between auto firms. Firms' R&D decision will be more influenced by fuel prices in some countries that they sale more cars.
- Firm-specific fuel price is constructed by

$$\ln FP_{it} = \sum_c w_{ic}^{FP} \ln FP_{ct}$$

where w_{ic}^{FP} is the fraction of firm i's patents taken out in country c.

- Rationale: a firm will seek intellectual property protection in jurisdiction where it believes it will need to sell in the future.

Data: Firm-specific Price

- In constructing wrights, we use all patent files from sample firms (not only "triadic" patents).
- Since patent location could be influenced by shocks to innovation, the weights are calculated using patents portfolio of each company over the 1965∼1985 "pre-sample" period. → Regression period: 1986∼2005
- If a patent is filed in several countries, this patent enters several times in the firm's patent portfolio.

Data: Firm's Patent Stocks and Spillovers

- Firm's patent stocks are calculated

$$K_{z,it} = \text{PAT}_{z,it} + (1-\delta)K_{z,it-1} \tag{2}$$

where δ is depreciation rate, to be 20 percent.

- Firm-specific spillover pools in z technology is constructed

$$\text{SPILL}_{z,it} = \sum_{c} w_{ic}^{S}\text{SPILL}_{z,ct}$$

where w_{ic}^{S} is the share of firm i's inventors in country c (i.e. the inventors worked when they discovered the invention) between 1965 and 1985.

- Each invention in only counted once.

Data: Firm's Patent Stocks and Spillovers

- w_{ic}^S measures the relative importance of country c's knowledge stock to firm i's innovation.
- Country's spillover poll is constructed by

$$\mathrm{SPILL}_{z,ct} = \sum_{j \neq i} w_{jc}^S K_{z,jt}$$

Explanation: Firm j has $K_{z,jt}$ stock of z technology. A fraction w_{jc}^S of these knowledge are developed by inventors in country c. Hence, firm j contributes $w_{jc}^S K_{z,jt}$ knowledge to country c.

Hypothesis 1

- Two regression equations are

$$\begin{aligned} \text{PAT}_{C,it} = \exp(&\beta_{Cp} \ln FP_{it-1} + \beta_{C1} \ln \text{SPILL}_{C,it-1} + \beta_{C2} \ln \text{SPILL}_{D,it-1} \\ &+ \beta_{C3} \ln K_{C,it-1} + \beta_{C4} \ln K_{D,it-1} + \beta_{C\omega}\omega_{it} + T_{C,t})\eta_{C,i} + \mu_{C,it}, \end{aligned} \tag{3}$$

$$\begin{aligned} \text{PAT}_{D,it} = \exp(&\beta_{Dp} \ln FP_{it-1} + \beta_{D1} \ln \text{SPILL}_{C,it-1} + \beta_{D2} \ln \text{SPILL}_{D,it-1} \\ &+ \beta_{D3} \ln K_{C,it-1} + \beta_{D4} \ln K_{D,it-1} + \beta_{D\omega}\omega_{it} + T_{D,t})\eta_{D,i} + \mu_{D,it}, \end{aligned} \tag{4}$$

Hypothesis 1

An increase in the price of the fossil fuel increases innovation in clean technology, and decreases innovation in dirty technologies. $\Leftrightarrow$ $\beta_{Cp} > 0$ and $\beta_{Dp} < 0$

Hypothesis 2

- Two regression equations are

$$\begin{aligned} \text{PAT}_{C,it} = \exp(&\beta_{Cp} \ln FP_{it-1} + \beta_{C1} \ln \text{SPILL}_{C,it-1} + \beta_{C2} \ln \text{SPILL}_{D,it-1} \\ &+ \beta_{C3} \ln K_{C,it-1} + \beta_{C4} \ln K_{D,it-1} + \beta_{C\omega}\omega_{it} + T_{C,t})\eta_{C,i} + \mu_{C,it}, \end{aligned} \tag{5}$$

$$\begin{aligned} \text{PAT}_{D,it} = \exp(&\beta_{Dp} \ln FP_{it-1} + \beta_{D1} \ln \text{SPILL}_{C,it-1} + \beta_{D2} \ln \text{SPILL}_{D,it-1} \\ &+ \beta_{D3} \ln K_{C,it-1} + \beta_{D4} \ln K_{D,it-1} + \beta_{D\omega}\omega_{it} + T_{D,t})\eta_{D,i} + \mu_{D,it}, \end{aligned} \tag{6}$$

Hypothesis 2

Firms with an initially higher level of clean (dirty) technologies will tend to innovate more in clean (dirty) technologies.

$\Leftrightarrow$ $\beta_{C3} > 0$, $\beta_{C3} > \beta_{D3}$, $\beta_{C3>\beta_{C4}}$ and $\beta_{D4} > 0, \beta_{D4} > \beta_{C4}, \beta_{D4} > \beta_{D3}$

Hypothesis 3

- Two regression equations are

$$\begin{aligned} \text{PAT}_{C,it} = \exp(&\beta_{Cp} \ln FP_{it-1} + \beta_{C1} \ln \text{SPILL}_{C,it-1} + \beta_{C2} \ln \text{SPILL}_{D,it-1} \\ &+ \beta_{C3} \ln K_{C,it-1} + \beta_{C4} \ln K_{D,it-1} + \beta_{C\omega}\omega_{it} + T_{C,t})\eta_{C,i} + \mu_{C,it}, \end{aligned} \tag{7}$$

$$\begin{aligned} \text{PAT}_{D,it} = \exp(&\beta_{Dp} \ln FP_{it-1} + \beta_{D1} \ln \text{SPILL}_{C,it-1} + \beta_{D2} \ln \text{SPILL}_{D,it-1} \\ &+ \beta_{D3} \ln K_{C,it-1} + \beta_{D4} \ln K_{D,it-1} + \beta_{D\omega}\omega_{it} + T_{D,t})\eta_{D,i} + \mu_{D,it}, \end{aligned} \tag{8}$$

Hypothesis 3

Firms are more likely to innovate in clean technologies when its inventors are located in countries where other firms have been undertaking more clean innovations.

$\Leftrightarrow \beta_{C1} > 0,\ \beta_{C1} > \beta_{D1},\ \beta_{C1 > \beta_{C2}}$ and $\beta_{D2} > 0, \beta_{D2} > \beta_{C2}, \beta_{D2} > \beta_{D1}$

Results

Table 1 Regressions of Clean and Dirty Patents

	Dependent Variable: Clean Patents			Dependent Variable: Dirty Patents		
	(1)	(2)	(3)	(4)	(5)	(6)
Fuel price (ln *FP*)	.970***	.962**	.843**	−.565***	−.553***	−.551***
	(.374)	(.379)	(.366)	(.146)	(.205)	(.194)
R&D subsidies (ln R&D)		−.005	−.006		−.006	−.005
		(.025)	(.024)		(.021)	(.020)
Emission regulation			−.008			.04
			(.149)			(.120)
Clean spillover (ln $SPILL_C$)	.268***	.301***	.266***	−.093*	−.078	−.089
	(.076)	(.087)	(.088)	(.048)	(.067)	(.063)
Dirty spillover (ln $SPILL_D$)	−.168**	−.207**	−.165*	.151**	.132	.138*
	(.085)	(.098)	(.098)	(.064)	(.082)	(.077)
Own stock clean (ln K_C)	.306***	.320***	.293***	−.002	−.004	.021
	(.026)	(.027)	(.025)	(.022)	(.022)	(.020)
Own stock dirty (ln K_D)	.139***	.135***	.138***	.557***	.549***	.539***
	(.017)	(.017)	(.017)	(.031)	(.022)	(.017)
Observations	68,240	68,240	68,240	68,240	68,240	68,240
Firms	3,412	3,412	3,412	3,412	3,412	3,412

Simulation Methods

- Knowledge stocks evolve according three equations:

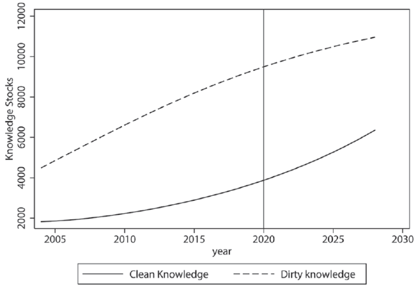
$$\begin{cases} \hat{\text{PAT}}_{z,it} & = \exp(\hat{\beta}_{zp} \ln FP_{it-1} + \hat{\beta}_{z1} \ln \text{SPILL}_{C,it-1} + \hat{\beta}_{z2} \ln \text{SPILL}_{D,it-1} \\ & + \hat{\beta}_{z3} \ln K_{C,it-1} + \hat{\beta}_{z4} \ln K_{D,it-1} + \hat{\beta}_{z\omega} y_{it} + T_{z,t})\eta_{z,i} \\ K_{z,it} & = \hat{\text{PAT}}_{z,it} + (1-\delta)K_{z,it-1} \\ \text{SPILL}_{z,it} & = \sum_c w_{ic}^S \sum_{j \neq i} w_{jc}^S K_{z,jt} \end{cases}$$

- Recursively compute values of expected patenting under different scenarios and use those to update the knowledge stock variables (i.e $K_{z,it}$ and $\text{SPILL}_{z,it}$)
- We do this for every sample firm and then aggregate across the world economy in each period

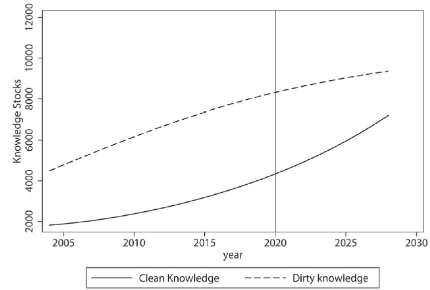
Experiments

- Experiment 1: the effect of fuel prices under path dependence
  1. Keep fuel prices at 2005 values;
  2. Increase worldwide fuel prices in 2006 (and fixed at this level therefore) by 10%, 20%, 30%, 40% and 50%;
- Experiment 2: the important of path dependency in firms' response to the increase in fuel prices
  1. Fixing innovation stock variables (i.e $K_{z,it}$ and $\text{SPILL}_{z,it}$) at their 2005 level
- In each scenario, GDP per capita grows at 1.5% per year

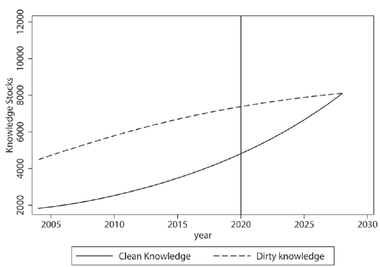
Experiment 1 Results: Effect of Fuel Prices



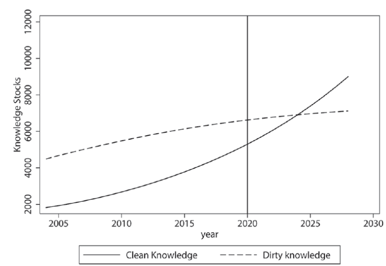
(a) Price Increase of 0%



(b) Price Increase of 10%

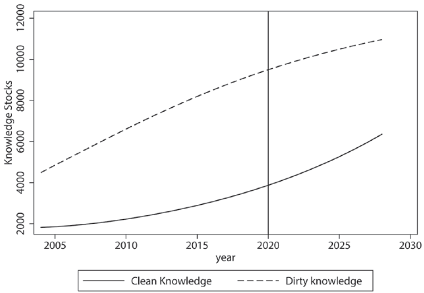


(c) Price Increase of 20%

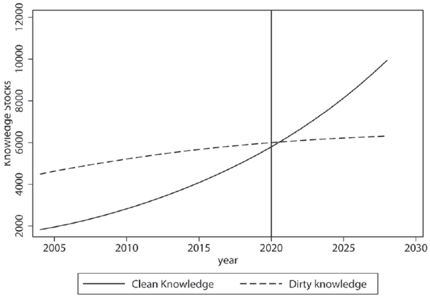


(d) Price Increase of 30%

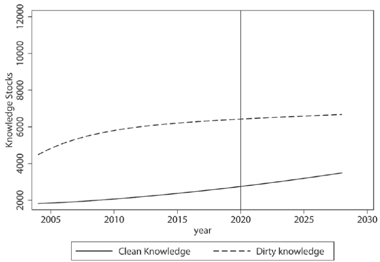
Experiment 2 Results: The Effect of Path Dependency



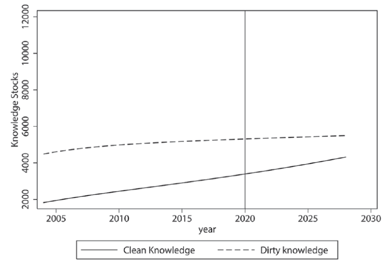
(a) Price Increase of 0% with PD



(b) Price Increase of 40% with PD



(c) Price Increase of 0% without PD



(d) Price Increase of 40% without PD

Conclusion

- Clean innovation is simulated by increase in the fuel prices whereas dirty innovation is depressed.
- There is strong evidence for "path-dependency":
  1. Firms more exposed to clean (dirty) innovation from other firms are more likely to direct their research to clean (dirty) innovation;
  2. Firms with a history of clean (dirty) innovation in the past are more likely to focus on clean (dirty) innovation in the future;
- Path-dependency increases the response of innovation trends to tax policy:
  1. Since the stock of dirty innovation is greater than that of clean, the path dependency effect tend to lock economies into high carbon emissions;
  2. With effective policies, path dependency can help reinforce the growth of clean innovation;

References

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