Climate change policy, innovation and growth

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Assessing the impact of climate change policies on innovation: Why is it important?
Global emissions scenarios

Source: IPCC 2014
Europe’s commitments

• EU leaders have committed to cut greenhouse gas emissions by 40% by 2030, compared with 1990 levels
• Next steps: 60% by 2040; 80% by 2050
The challenge

- Stabilizing global emissions in 2050 requires 60% reduction in carbon intensity of GDP (Assuming 2.5% annual GDP growth)
- To achieve long term decarbonization we need a large change in the mix of technology we use
  - (or dramatic social and cultural changes)
Europe’s Energy Roadmap 2050

Trends since 2011

A comparison of the status of the low-carbon technologies presented in the Technology Map 2011 with the Technology Map 2013 highlights the following distinguishable trends.

• Some types of renewable energy sources (RES) have added significant capacity (e.g. solar photovoltaics (PV), onshore wind and technologies using biomass), whereas the development is slower for others (e.g. CCS, marine energy and geothermal energy).

• Costs for several low-carbon energy technologies have continued to decline (e.g. onshore wind and solar PV).

• Some low-carbon technologies are not yet competitive as compared to technologies using fossil fuels. This remains a key barrier to their large-scale deployment. Barriers to large-scale implementation of RES technologies have increased in some countries due to reduced financial support. In addition, the very low-carbon emission costs of the European Emissions Trading System (EU ETS) are disadvantageous for low-carbon technologies versus technologies using fossil fuels.

• The increasing share of variable renewables and their low operating costs reduce electricity costs and stalled investments in conventional fossil-based power production. These could disrupt the grid stability and the security of supply in the longer term if not addressed properly.

• A stable regulatory framework providing a predictable investment environment is needed for most technologies.
Innovation is key

- Climate change mitigation requires massive investments in innovation
  1. Developing new breakthrough technologies (hydrogen)
  2. Reducing the cost of existing technologies (wind, solar)
  3. Making the transition possible with enabling technologies (smart grids, storage)

➢ Ability of climate change policies to encourage innovation is critical
Innovation as a co-benefit from green policies?

• Innovation = one of the benefits of policies, along health improvements etc, to be evaluated against the policy’s costs

• Major concerns around competitiveness effects of environmental policies

• Porter hypothesis
  – Environmental regulations might lead private firms and the economy as a whole to become more competitive by providing incentives for environmentally-friendly innovation that would not have happened in the absence of policy
The impact of climate change policies on innovation: Recent econometric evidence

Research question 1

• Do firms respond to policies by changing the direction of innovation (“induced” innovation)?
• When firms face higher price on emissions relative to other costs of production, this provides an incentive to reduce the emissions intensity of output
• Hicks (1932): part of this investment will be directed toward developing and commercializing new emissions-reducing technologies
Research question 2

• How important is lock-in/path dependence in types of “clean” or “dirty” technologies?

• Some recent papers assume path-dependence in the direction of innovation (e.g. Acemoglu et al, 2012 AER)

• A crucial aspect in terms of policy consequences: this is consistent with a “tipping point” view of the world
  – Final resting point is complete dominance of one technology by another

• If this is true, clean policies only need to be temporary
Economics of Tipping Points

Relative Benefits Clean vs. Dirty

Relative Installed Base

All Dirty 0.2 0.5 All Clean

0.4 1.2
The government’s problem

All Dirty

All Clean

0.2

0.5
steady increase in dirty energy production and carbon emissions. Figure 5 shows an increase in temperature of an additional 11°C in the next 200 years.

5.1 Optimal Policy

We start with optimal policy. Throughout, we do not allow the social planner to correct for monopoly distortions, thus limiting ourselves to the policy instruments discussed above—carbon taxes and subsidies to clean research. In fact, our theoretical analysis makes it clear that what is relevant is the differential tax and subsidy rates for clean vs. dirty energy, motivating us to focus on taxes on dirty production, which we refer to as “carbon taxes,” and subsidies to clean innovation. Finally, for computational reasons, we model taxes and subsidies as quartic functions of calendar time. The resulting optimal policies are presented in Figure 6 (with the research subsidy shown on the left axis and the carbon tax on the right axis).

Figure 6. Optimal policies (carbon taxes and research subsidies) under baseline parameters.

The intuition for why optimal policy relies so much on subsidies to clean research is instructive. The social planner would like to divert R&D from carbon-intensive dirty technologies towards clean technologies. She can do so by choosing a sufficiently high carbon tax rate today and

\[ \Delta \text{temperature} = \lambda \ln S_t - \ln \bar{S} / \ln 2. \]

Because of the non-linear dynamics of atmospheric carbon concentration, optimal policy is not necessarily time-consistent. We ignore this problem by assuming that the social planner is able to commit to the future sequence of taxes and subsidies.

As mentioned above, in the one-sector version of our model (either with only dirty or only clean technology), taxes or subsidies to research would only affect relative wages of skilled workers (employed in the research sector), and crucially not the aggregate rate of innovation. For this reason, subsidies to clean research or taxes on dirty research are identical in our model.

Source: Acemoglu, Akcigit, Hanley & Kerr. “Transition to Clean Technology” (JPE)
This paper

• Look at both induced innovation hypothesis and path-dependence

• Econometric case study: auto industry
  – Contributor to greenhouse gases
  – Distinction between dirty (internal combustion engine) & clean (e.g. electric vehicles) innovations/patents by OECD
Simple model: basic idea

• Firms can invest in 2 types of R&D (clean or dirty)
• Previous firm/economy specialization in either clean or dirty influences direction of innovation
  – Path-dependence
• If expected market size to grow for cars using more clean technologies (e.g. electric/hybrid) then more incentive to invest in clean (relative to dirty)
• Higher fuel prices (a proxy for carbon price) increase demand for clean cars
  – Induces greater “clean” R&D and patenting
Explaining innovation

Clean Innovations (patents) for company $i$ at time $t$

Fuel price ($P$): Test $\alpha^C > 0$

Clean spillovers (stock): $\beta_1^C > 0$ if "path dependent"

$$CLEAN_{it} = \exp(\alpha^C \ln P_{it-1} + \beta_1^C \ln SPILL^C_{it-1} + \beta_2^C \ln SPILL^D_{it-1} + \gamma_1^C \ln KCLEAN_{it-1} + \gamma_2^C \ln KDIRTY_{it-1} + \delta^C X_{it-1} + \eta_i^C + T_t^C + u_{it}^C)$$

Own firm past clean innovations Stock: $\gamma_1^C > 0$ if "path dependent"

Own firm past dirty innovations stock, expect $\gamma_1^C > \gamma_2^C$

Dirty spillovers: Ambiguous, but Expect $\beta_1^C > \beta_2^C$

Other controls – GDP, fixed effects, time dummies, etc.
Dirty Innovations (patents) for assignee \( i \) at time \( t \)

\[
DIRTY_{it} = \exp(\alpha^D \ln P_{it-1} + \beta_1^D \ln SPILL_{it-1}^C + \beta_2^D \ln SPILL_{it-1}^D + \\
\gamma_1^D \ln KCLEAN_{it-1} + \gamma_2^D \ln KDIRTY_{it-1} + \delta^D X_{it-1} + \eta_i^D + T_t^D + u_{it}^D)
\]
DATA

- World Patent Statistical Database (PATSTAT) at European Patent Office (EPO)
  - All patents filed in 80 patent offices in world (focus from 1965)
- Extracted all patents pertaining to "clean" and "dirty" technologies in the automotive industry (follows OECD definition)
- Tracked applicants and extracted all their patents. Created unique firm identifier
  - 4.5m patents filed 1965-2005
International Patent Classification codes

**Electric vehicles**
- Electric propulsion with power supplied within the vehicle
- Electric devices on electrically-propelled vehicles for safety purposes;
- Monitoring operating variables, e.g. speed, deceleration, power
  consumption
- Methods, circuits, or devices for controlling the traction- motor speed
  of electrically-propelled vehicles
- Arrangement or mounting of electrical propulsion units
- Conjoint control of vehicle sub-units of different type or different
  function / including control of electric propulsion units, e.g. motors or
  generators / including control of energy storage means / for electrical
  energy, e.g. batteries or capacitors

**Hybrid vehicles**
- Arrangement or mounting of plural diverse prime-movers for mutual
  or common propulsion, e.g. hybrid propulsion systems comprising
  electric motors and internal combustion engines
- Control systems specially adapted for hybrid vehicles, i.e. vehicles
  having two or more prime movers of more than one type, e.g. electrical
  and internal combustion motors, all used for propulsion of the vehicle
- Regenerative braking
- Dynamic electric regenerative braking
- Braking by supplying regenerated power to the prime mover of
  vehicles comprising engine-driven generators

**Fuel cells**
- Conjoint control of vehicle sub-units of different type or different
  function; including control of fuel cells
- Electric propulsion with power supplied within the vehicle - using
  power supplied from primary cells, secondary cells, or fuel cells
- Fuel cells; Manufacture thereof

**Combustion engines**
- Combustion engines

“Clean”

“Dirty”
AGGREGATE NUMBER OF TRIADIC CLEAN AND DIRTY PATENTS PER YEAR

![Graph showing the aggregate number of triadic clean and dirty patents per year. The x-axis represents the years from 1980 to 2005, and the y-axis represents the number of patents from 0 to 1200. The graph includes a line for clean patents and a dashed line for dirty patents.](image-url)
POLICY VARIABLES: FUEL PRICES & TAXES

• Fuel prices vary over countries and time (e.g. because of different tax regimes)
• International Energy Agency EA (fuel prices & taxes)
EVOLUTION OF AVERAGE (TAX INCLUSIVE) FUEL PRICES OVER TIME

Source: International Energy Agency, 25 countries unweighted average
Residuals from a regression of fuel prices on country and year dummies

Source: International Energy Agency, 25 countries
POLICY VARIABLES: FUEL PRICES (FP) & TAXES

• Firms are affected differentially by fuel prices as (expected) market shares different across countries
  – Autos differentiated products: affected by national tastes
  – Government policies discriminate (e.g. tariffs & subsidies)
• Weight country prices & taxes by firm’s expected future market shares in different countries
  – Use information on where patents filed (use in pre-sample period & keep these weights fixed)
  – Compare with firm \( i \) sales by country \( c \)

\[
\ln FP_{it} = \sum_{c} w^P_{ic} \ln FP_{ct}
\]
Reasonable correlation between geographical market shares based on auto sales vs. Patent filings for major vendors (correlation = 0.95)

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Time Period</th>
<th>Car Sales shares</th>
<th>Patent Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toyota</td>
<td>2003-2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Japan</td>
<td>0.43</td>
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<td></td>
<td>North America</td>
<td>0.40</td>
<td>0.34</td>
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<tr>
<td></td>
<td>Europe</td>
<td>0.17</td>
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</tr>
<tr>
<td>VW</td>
<td>2002-2005</td>
<td></td>
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<td>Germany</td>
<td>0.35</td>
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<td>0.09</td>
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<tr>
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<td></td>
<td>Mexico</td>
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<td>0.00</td>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Japan</td>
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<td>0.02</td>
</tr>
<tr>
<td>Ford</td>
<td>1992-2002</td>
<td></td>
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<tr>
<td></td>
<td>US</td>
<td>0.66</td>
<td>0.61</td>
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<tr>
<td></td>
<td>Canada</td>
<td>0.04</td>
<td>0.01</td>
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<tr>
<td></td>
<td>Mexico</td>
<td>0.02</td>
<td>0.00</td>
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<tr>
<td></td>
<td>UK</td>
<td>0.09</td>
<td>0.08</td>
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<tr>
<td></td>
<td>Germany</td>
<td>0.07</td>
<td>0.15</td>
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<td></td>
<td>Italy</td>
<td>0.03</td>
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<tr>
<td></td>
<td>Spain</td>
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<td></td>
<td>France</td>
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<td>0.04</td>
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<tr>
<td></td>
<td>Australia</td>
<td>0.02</td>
<td>0.00</td>
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<tr>
<td></td>
<td>Japan</td>
<td>0.01</td>
<td>0.05</td>
</tr>
<tr>
<td>Peugeot</td>
<td>2001-2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Western Europe</td>
<td>0.82</td>
<td>0.83</td>
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<tr>
<td></td>
<td>Americas</td>
<td>0.04</td>
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</tr>
<tr>
<td></td>
<td>Asia-Pacific</td>
<td>0.13</td>
<td>0.04</td>
</tr>
<tr>
<td>Honda</td>
<td>2004-2005</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Japan</td>
<td>0.28</td>
<td>0.31</td>
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<tr>
<td></td>
<td>North America</td>
<td>0.62</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>Europe</td>
<td>0.10</td>
<td>0.20</td>
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</table>
Reasonable correlation (0.95) between geographical market shares based on auto sales vs. Patent filings: e.g. Ford

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>US</td>
<td>0.66</td>
<td>0.61</td>
</tr>
<tr>
<td>Canada</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Mexico</td>
<td>0.02</td>
<td>0.00</td>
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<tr>
<td>UK</td>
<td>0.09</td>
<td>0.08</td>
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<tr>
<td>Germany</td>
<td>0.07</td>
<td>0.15</td>
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<tr>
<td>Italy</td>
<td>0.03</td>
<td>0.03</td>
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<tr>
<td>Spain</td>
<td>0.02</td>
<td>0.02</td>
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<tr>
<td>France</td>
<td>0.02</td>
<td>0.04</td>
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<tr>
<td>Australia</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>Japan</td>
<td>0.01</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Source: Annual Company Accounts and PATSTAT
OWN & SPILLOVER INNOVATION STOCKS

OWN LAGGED INNOVATION STOCKS (K)
- Standard Griliches perpetual inventory formula (baseline $\delta = 0.2$, robust to alternative levels of depreciation, )
- $z = \{\text{CLEAN, DIRTY}\}$

$$K_{zit} = PAT_{zit} + (1 - \delta)K_{zit-1}$$

SPILLOVERS (SPILL)
- Country’s clean (dirty) innovation stock is aggregate of clean (dirty) patents of inventors located in the country
- Firm’s exposure to spillovers is average of country with weights based on where firm’s inventors located

$$\ln SPILL_{zit} = \sum_{c} w_{ic}^{S} SPILL_{zct}$$
# MAIN RESULTS

<table>
<thead>
<tr>
<th></th>
<th>Clean</th>
<th>Dirty</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel Price</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln(FP)</td>
<td>0.992**</td>
<td>-0.539***</td>
</tr>
<tr>
<td></td>
<td>(0.411)</td>
<td>(0.177)</td>
</tr>
<tr>
<td><strong>Clean Spillover</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPILL\textsubscript{C}</td>
<td>0.399***</td>
<td>-0.160***</td>
</tr>
<tr>
<td></td>
<td>(0.085)</td>
<td>(0.049)</td>
</tr>
<tr>
<td><strong>Dirty Spillover</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPILL\textsubscript{D}</td>
<td>-0.331***</td>
<td>0.231***</td>
</tr>
<tr>
<td></td>
<td>(0.076)</td>
<td>(0.054)</td>
</tr>
<tr>
<td><strong>Own Stock Clean</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K\textsubscript{C}</td>
<td>0.505***</td>
<td>0.212**</td>
</tr>
<tr>
<td></td>
<td>(0.111)</td>
<td>(0.107)</td>
</tr>
<tr>
<td><strong>Own Stock Dirty</strong></td>
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<td></td>
</tr>
<tr>
<td>K\textsubscript{D}</td>
<td>0.246***</td>
<td>0.638***</td>
</tr>
<tr>
<td></td>
<td>(0.054)</td>
<td>(0.080)</td>
</tr>
<tr>
<td><strong>#Observations</strong></td>
<td>68,240</td>
<td>68,240</td>
</tr>
<tr>
<td><strong>#Units (Firms and individuals)</strong></td>
<td>3,412</td>
<td>3,412</td>
</tr>
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</table>

Notes: Estimation by Conditional fixed effects (CFX), all regressions include GDP, GDP per capita & time dummies. SEs clustered by firm.
Disaggregating dirty patents into fuel efficiency (grey) and purely dirty

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Clean Patents</th>
<th>Grey Patents</th>
<th>Purely Dirty Patents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Price</td>
<td>0.848*</td>
<td>0.282</td>
<td>-0.832***</td>
</tr>
<tr>
<td></td>
<td>(0.461)</td>
<td>(0.398)</td>
<td>(0.214)</td>
</tr>
<tr>
<td>R&amp;D subsidies</td>
<td>0.031</td>
<td>0.081**</td>
<td>-0.02</td>
</tr>
<tr>
<td></td>
<td>(0.047)</td>
<td>(0.034)</td>
<td>(0.030)</td>
</tr>
<tr>
<td>Clean Spillover</td>
<td>0.333**</td>
<td>-0.171*</td>
<td>-0.014</td>
</tr>
<tr>
<td></td>
<td>(0.165)</td>
<td>(0.098)</td>
<td>(0.094)</td>
</tr>
<tr>
<td>Grey Spillover</td>
<td>0.215</td>
<td>0.173</td>
<td>0.235**</td>
</tr>
<tr>
<td></td>
<td>(0.228)</td>
<td>(0.112)</td>
<td>(0.102)</td>
</tr>
<tr>
<td>Purely Dirty Spillover</td>
<td>-0.509</td>
<td>0.045</td>
<td>-0.208</td>
</tr>
<tr>
<td></td>
<td>(0.377)</td>
<td>(0.136)</td>
<td>(0.161)</td>
</tr>
<tr>
<td>Own Stock Clean</td>
<td>0.379***</td>
<td>-0.005</td>
<td>0.047</td>
</tr>
<tr>
<td></td>
<td>(0.090)</td>
<td>(0.035)</td>
<td>(0.035)</td>
</tr>
<tr>
<td>Own Stock Grey</td>
<td>0.185*</td>
<td>0.418***</td>
<td>-0.141***</td>
</tr>
<tr>
<td></td>
<td>(0.106)</td>
<td>(0.035)</td>
<td>(0.025)</td>
</tr>
<tr>
<td>Own Stock Purely Dirty</td>
<td>-0.011</td>
<td>0.192***</td>
<td>0.544***</td>
</tr>
<tr>
<td></td>
<td>(0.066)</td>
<td>(0.038)</td>
<td>(0.026)</td>
</tr>
<tr>
<td>Observations</td>
<td>68240</td>
<td>68240</td>
<td>68240</td>
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<tr>
<td>Firms</td>
<td>3412</td>
<td>3412</td>
<td>3412</td>
</tr>
</tbody>
</table>

Notes: *,**,***= significant at 10, % 5%, 1%. Standard errors are clustered at the firm level. Estimation is by the CFX method. This table disaggregates the dirty patents into those that are “grey” (related to fuel efficiency) and those that are not (“purely dirty”). We construct all spillovers and own past stocks based on this disaggregation and include on the right hand side (hence two extra terms compared to Table 3). We estimate two dirty equations, one where grey innovations are the dependent variable (in column (2)) and one for the purely dirty in column (3). All regressions include controls for GDP per capita, year dummies, fixed effects and 4 dummies for no own innovations in (i) clean, (ii) grey (iii) dirty and (iv) no clean, grey nor purely dirty in the previous year. Fuel price is the tax-inclusive fuel price faced. R&D subsidies are public R&D expenditures in energy efficient transportation.
Robustness Tests

- Use fuel tax instead of fuel prices
- Alternative estimators (HHG, BGVR, OLS)
- Other policy variables – R&D, Emissions, electricity price
- Condition on firms with some positive pre-1985 patents
- Construct fuel price using only the largest countries
- Use biadic patents (or all patents) instead of triadic
- Drop individuals & just estimate on firms
- Cite-weighting patents
- Allow longer dynamics reaction, different depreciation rates, etc.
SIMULATIONS

• Take estimated model & aggregate to global level taking dynamics into account (spillovers & lagged dependent variables)
• Simulate the effect of changes in fuel tax compared to baseline case (where we fix prices & GDP as “today”, 2005)
• At what point (if ever) does the stock of clean innovation exceed stock of dirty innovation
• Just illustrative scenarios – sense of difficulty & importance of path dependence
BASELINE: NO FUEL PRICE INCREASE

Knowledge Stocks

Clean Knowledge

Dirty knowledge

Price increase of 0%
ALTERNATIVE: 10% INCREASE IN THE FUEL PRICE

Knowledge Stocks

- Clean Knowledge
- Dirty knowledge

Price increase of 10%
ALTERNATIVE: 20% INCREASE IN THE FUEL PRICE

Price increase of 20%

Knowledge Stocks

Clean Knowledge

Dirty knowledge
ALTERNATIVE: 30% INCREASE IN THE FUEL PRICE

Price increase of 30%
ALTERNATIVE: 40% INCREASE IN THE FUEL PRICE

Knowledge Stocks

2005 2010 2015 2020 2025 2030

Clean Knowledge

Dirty knowledge

Price increase of 40%
SWITCHING OFF SPILLOVER EFFECTS IN THE NO PRICE INCREASE SCENARIO – KNOWLEDGE STOCKS GROW MORE SLOWLY

Baseline (with spillovers)

Alternative (No spillovers)
SWITCHING OFF SPILLOVER EFFECTS IN THE 40% PRICE INCREASE SCENARIO – CLEAN DOESN’T OVERTAKE DIRTY NOW

Baseline (40% price increase with spillovers)

Alternative (40% price increase without spillovers)
CONCLUSIONS

• Economics works! – Technical change can be directed towards “clean” innovation through price mechanism

• Path dependence important: firm-level & spillovers
  – Bad news that clean stocks may never catch up with dirty without further policy intervention
  – Good news is that early action now can become self-sustaining later due

• Simulations suggest that FP rises of ~40% cause clean to overtake dirty
The economic consequences of switching to clean innovation
Green policies as growth policies?

“Green policies can boost productivity, spur growth and jobs”

Angel Gurría, OECD Secretary-General
Climate policies and induced technical change

• Climate policies such as carbon pricing induce a switch of innovation activities away from dirty technologies and towards clean technologies

• What is the impact on the economy?
Clean R&D push & private benefits

Marginal Benefits from Clean R&D

Marginal Benefits from Dirty R&D

Optimal dirty R&D

Optimal clean R&D

Total R&D spending

Marginal private profit of R&D investor from dirty R&D

Marginal private (discounted future) profit of R&D investor from clean R&D

Gov’t pushing clean

Lost profit when being forced away from optimum

Total R&D
Spillovers

In addition to private benefits...
Adding in public benefits

Marginal Benefits from Clean Technology

Marginal Benefits from Dirty Technology

Gov’t pushing clean

Marginal profits of R&D investor and spillover recipients

Increased welfare

Total R&D spending

Higher spending on clean can improve social welfare if clean spillovers are larger than dirty spillovers
Double dividend?

If Clean > Dirty Spillovers

• A policy-induced redirection of innovation from dirty to clean technologies will reduce the net cost of environmental policies...
• ... and can even lead to higher economic growth
• One of the theoretical motivations for the Porter hypothesis [Mohr (2002); Smulders & de Nooij (2003); Hart (2004, 2007); Ricci (2007)]
The paper

• Antoine Dechezleprêtre, Ralf Martin & Myra Mohnen. “Knowledge spillovers from clean and dirty technologies” (Working paper, 2014)

• Compare relative degree of spillovers between clean and dirty technologies
  • Measure knowledge spillovers using patent citations
  • 2 sectors: transportation and electricity production
• Measure the economic value of these spillovers for potential growth impacts
# Technology groups

<table>
<thead>
<tr>
<th>Dirty</th>
<th>Group</th>
<th>Clean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil fuel based (coal &amp; gas)</td>
<td><em>Electricity generation</em></td>
<td>Renewables</td>
</tr>
<tr>
<td>Internal combustion vehicles</td>
<td><em>Automotive</em></td>
<td>Electric, Hybrid, Hydrogen</td>
</tr>
</tbody>
</table>
Measuring knowledge spillovers

- Count citations made by future patents

- Advantages
  - Mandatory for inventors to cite "prior art"
  - Data availability
  - Technological disaggregation
Data

- World Patent Statistical Database (PATSTAT) @ EU Patent Office

- 1.2 million inventions filed in 107 patent offices from 1950 to 2005, 3 million citations made to these inventions
References Cited

U.S. PATENT DOCUMENTS

Re. 28,075 7/1974 Kavanaugh .......... 310/49 R
3,783,313 1/1974 Mathur ............... 310/49 R
4,075,519 2/1978 Mr. Cun ............... 310/67 R
4,280,072 7/1981 Gotou et al. ........... 310/67 R
5,200,776 4/1993 Sakamoto .............. 310/68 B

FOREIGN PATENT DOCUMENTS

300126 1/1989 European Pat. Off. ....
2211030 12/1988 United Kingdom ....
A Self Powered Variable Direction Wheeled Task Chair, and a personal mobility device, providing additional ranges of motion in that it has an electrically powered height adjustable seat allowing the operator's seating position to range from standard table height seating to work bench or counter top seating. Additionally and more importantly, the chair, will have directional movement capabilities well beyond typical wheel chairs, or other wheel driven personal mobility devices in that it will utilize electro-mechanical directionally pivoting propulsion, capable of not only forward, backward, and pivot turning capabilities, but also sideways movement or more precisely, movement in any direction, and a rotational movement as may be required by the operator.
Spillovers from spillovers...
Ground-breaking spillovers from clean tech

COMBINED SOLAR POWERED FAN AND HAT ARRANGEMENT FOR MAXIMIZING AIRFLOW THROUGH THE HAT

SOLAR POWERED, SILENT, ENERGY EFFICIENT BABY ROCKER
Counting citations received by clean & dirty patents

<table>
<thead>
<tr>
<th>Citations received</th>
<th>Clean</th>
<th>Dirty</th>
<th>Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.399</td>
<td>2.295</td>
<td>1.104***</td>
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<tr>
<td></td>
<td>(8.256)</td>
<td>(5.921)</td>
<td>[0.016]</td>
</tr>
</tbody>
</table>

Table 2: Mean number of citations

50% higher
Patent citations flowers

Citations to 1000 dirty... ...and 1000 clean innovations
Econometric analysis

• Potential issues:
  • Recent increase in citations (web searches)
  • Clean patents younger
  • Differences across patent offices
  • Citation pool larger for dirty

➢ Regression approach

\[ Cites_i = \exp(\beta Clean_i + \gamma X_i + \epsilon_i) \]
Not all citations are equal

• Economic value of citations vary greatly
  ➢ Weight citing patents on the basis of how many times they are themselves cited
  • Based on Google’s “Page rank” algorithm
## Results

Table 3: Basic results

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dep. var.</strong></td>
<td></td>
<td></td>
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<tr>
<td>Clean invention</td>
<td>0.398***</td>
<td>0.392***</td>
<td>0.430***</td>
<td>0.267***</td>
<td>0.264***</td>
<td>0.292***</td>
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<td></td>
<td>(0.015)</td>
<td>(0.015)</td>
<td>(0.014)</td>
<td>(0.013)</td>
<td>(0.014)</td>
<td>(0.014)</td>
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<tr>
<td>Number of patents</td>
<td>-0.092***</td>
<td>-0.057***</td>
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<td>-0.052***</td>
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<td>-0.031***</td>
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<td></td>
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<td>(0.006)</td>
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<td>(0.004)</td>
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<tr>
<td>Triadic</td>
<td>0.456***</td>
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<td>0.541***</td>
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<tr>
<td></td>
<td>(0.036)</td>
<td></td>
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</tr>
<tr>
<td>Granted</td>
<td></td>
<td></td>
<td>0.947***</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(0.031)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Notes:** Robust standard errors in parentheses ( * p<0.05, ** p<0.01, *** p<0.001). The dependent variable is the total number of citations received excluding self-citations by inventors (columns 1 to 3) and the PatentRank after 20 iterations (columns 4 to 6). All columns are estimated by fixed-effects Poisson pseudo-maximum likelihood.
### Regressions results by sector

<table>
<thead>
<tr>
<th>Sector</th>
<th>Transport</th>
<th>Electricity</th>
<th>Transport</th>
<th>Electricity</th>
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<tr>
<td>Dep. var.</td>
<td>Citation count</td>
<td>PatentRank</td>
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<tr>
<td>Clean invention</td>
<td>0.347***</td>
<td>0.488***</td>
<td>0.219***</td>
<td>0.333***</td>
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<td>Number of patents</td>
<td>-0.068***</td>
<td>-0.047***</td>
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<td>0.725***</td>
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<td>419,959</td>
<td>748,918</td>
<td>419,959</td>
<td>748,918</td>
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</tbody>
</table>

Notes: Robust standard errors in parentheses (* p<0.05, ** p<0.01, *** p<0.001). The dependent variables are the total number of citations received excluding self-citations by inventors in columns 1 and 2 and the PatentRank index in columns 3 and 4. The regressions are all estimated by Poisson pseudo-maximum likelihood. The sample includes inventions from the transport (columns 1 and 3) and electricity (columns 2 and 4) sectors. All columns include a patent office-by-year and month fixed effects.

Stronger effects in electricity
Spillovers higher in all clean technologies


Baseline = Coal/gas
## Clean, grey & dirty

<table>
<thead>
<tr>
<th>Sample</th>
<th>Clean vs. Grey and true Dirty</th>
<th>Clean vs. Grey</th>
<th>Grey vs. True Dirty</th>
<th>Clean vs. True Dirty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep. var.</td>
<td>Citations received</td>
<td>Clean/Grey invention</td>
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<td></td>
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<td>(0.014)</td>
<td>(0.016)</td>
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<td>-0.051***</td>
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<td></td>
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<td>(0.007)</td>
<td>(0.009)</td>
<td>(0.005)</td>
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<tr>
<td></td>
<td>Family size</td>
<td>0.073***</td>
<td>0.069***</td>
<td>0.072***</td>
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<tr>
<td></td>
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<td>(0.004)</td>
<td>(0.007)</td>
<td>(0.004)</td>
</tr>
<tr>
<td></td>
<td>Triadic</td>
<td>0.456***</td>
<td>0.481***</td>
<td>0.454***</td>
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</table>

Notes: Robust standard errors in parentheses (* p<0.05, ** p<0.01, *** p<0.001). The dependent variable is the total number of citations received, corrected for self-citations by inventors. The sample includes clean, grey and truly dirty (column 1), clean and grey (column 2), grey and truly dirty (column 3), and clean and truly dirty (column 4) inventions. All columns are estimated by Poisson pseudo-maximum likelihood and include patent office-by-year and month fixed effects.

Clean > Grey > Dirty
Robustness

• Compare clean & dirty patents developed by same inventor / company
• Look at university/company/individuals patents
• Control for R&D subsidies
• Citations made by applicants only (not by examiners)
• Different subsamples (triadic patents, US, EPO)
• Correct for self-citations within applicant
• Adding controls (# IPC codes, # inventors, # claims, # citations made, etc)
The drivers – comparing clean to other emerging technologies

Baseline = average technology
The monetary value of spillovers

Griliches’ (1981) market valuation equation:

\[ V_{it} = q_t (A_{it} + \beta K_{it})^\sigma \]

Knowledge assets:

\[ K_{it} = f_1 \times R\&D_{it} + f_2 \times BCIT_{it} + f_3 \times \frac{PAT_{it}}{R\&D_{it}} + f_4 \times \frac{FCIT_{it}}{PAT_{it}} \]
As Deng (2008), we use the following value function to evaluate the firm’s knowledge assets
\[ K_{it} = f(R&D_{it}, BCIT_{it}, !_{it}) \]
where \( R&D_{it} \) denotes the accumulated R&D spendings, \( BCIT_{it} \) the accumulated backward citations the firm has made as a proxy of the knowledge inflows received by the firm, and \( !_{it} \) the accumulated idiosyncratic productivity shocks in the firm’s inventive activities.

Taking first-order Taylor expansion of equation 6 yields
\[ K_{it} = f_1 \cdot R&D_{it} + f_2 \cdot BCIT_{it} + f_3 \cdot \frac{PAT_{it}}{R&D_{it}} + f_4 \cdot \frac{FCIT_{it}}{PAT_{it}} \]
where \( PAT_{it} \) and \( FCIT_{it} \) are firm i’s patent stock and forward citations stock in year t respectively. Combining equations 5 and 7 leads to
\[ \log Q_{it} = \log q_t + \log (1 + \beta_1 \frac{R&D_{it}}{A_{it}} + \beta_2 \frac{BCIT_{it}}{PAT_{it}} + \beta_3 \frac{PAT_{it}}{R&D_{it}} + \beta_4 \frac{FCIT_{it}}{PAT_{it}}) + \varepsilon_{it} \]
Decomposing knowledge spillovers

\[
\beta_2 \frac{BCIT_{it}}{PAT_{it}} = \beta_{21} \frac{BCIT_{it}^{clean}}{PAT_{it}} + \beta_{22} \frac{BCIT_{it}^{dirty}}{PAT_{it}} + \beta_{23} \frac{BCIT_{it}^{other}}{PAT_{it}}
\]

Knowledge inflow

Clean

Dirty

Other
Data

• Firm-level patent data + financial data
• 8735 firms, 2000-2011
  – Market value, assets, R&D, patents
• Citations between firms to capture knowledge spillovers
## Results

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
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<tbody>
<tr>
<td><strong>Dep. var.</strong></td>
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<tr>
<td>ln Tobin’s Q</td>
<td>0.438***</td>
<td>0.436***</td>
<td>0.427***</td>
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<td></td>
<td>-0.097**</td>
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<tr>
<td><strong>Clean spillovers</strong></td>
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<td>0.146***</td>
<td>0.125***</td>
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<td><strong>Dirty spillovers</strong></td>
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<td>(0.033)</td>
<td>(0.033)</td>
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<td><strong>Other spillovers</strong></td>
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</tbody>
</table>

Notes: Clustered standard errors in parentheses (* p<0.1, ** p<0.05, *** p<0.01). The dependent variable is the ln Tobin’s Q defined as the stock market value over the book value of physical assets. We restrict the sample to patents applied for between 2000 and 2008. All columns are estimated by OLS and include year dummies.
Where do spillovers occur?

- Who captures these spillovers and the benefits that go with them?
- On average, 50% of knowledge spillovers in clean occur within the country of the inventor
  - The figure is smaller for small open economies (ex: UK 20%)

- Good news from unilateral policy perspective
Where do spillovers occur?
Conclusion & policy implications

• Clean innovations generate significantly more spillovers than dirty technologies; the marginal value of clean spillovers is also greater
  ➢ This comes from the relative novelty of clean technologies
  ➢ Climate policies that induce a switch away from dirty and towards clean innovation can have economic co-benefits
  ➢ Crowding out of dirty is key

• Spillovers are localized
  ➢ This might lower concerns that unilateral climate policies lead to negative competitiveness effects
  ➢ The share of benefits from innovation will be larger than benefits from avoided climate damage
Thanks

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http://personal.lse.ac.uk/dechezle/