Path Dependence in Clean Versus Dirty Innovation

College de France
29 October 2015

LSE

CENTRE *for* ECONOMIC PERFORMANCE

MOTIVATION

- **Climate change Policies**
  - Main climate change models (e.g. Nordhaus, Stern) assume exogenous technology
  - Then the debate revolves around discount rate considerations
- **Implications from introducing endogenous and directed technical change?**
  - Theory: Acemoglu, Aghion, Bursztyn & Hemous (2012), AABH
  - Empirics: Aghion, Dechezlepretre, Hemous, Martin & Van Reenen (2015)

QUESTIONS

- How important is lock-in/path dependence in types of “clean” or “dirty” technologies?
- (How) do firms respond to policies by changing “direction” of innovation?
- Econometric case study: auto industry
  - Distinction between dirty (internal combustion engine) & clean (e.g. electric vehicles) patents by OECD
  - Clear possibilities of substitution of 2 types car
  - Transport accounts for ~25% of global CO2 emissions

MOST CLOSELY RELATED PAPERS

- **Popp** (2002, AER) U.S. patent data 1970 to 1994. Positive effect of energy prices on energy-efficient innovations (focus on energy generation technologies).
  - US macro data so cannot control for time dummies
- **Newell, Jaffe and Stavins** (1999, QJE) air conditioning after energy price hikes

THEORY

ECONOMETRICS

DATA

RESULTS

SIMULATIONS

AABH MODEL

- Final output produced with clean and dirty inputs
- Dirty input production depletes the environment
- Each input produced with labor and machines
- Innovation improves productivity of machines, can be directed towards machines producing “clean” or “dirty” inputs

AABH MODEL

- Two main externalities:
  - Environmental externality
  - Knowledge externality: innovators build on the giant's shoulders in their own sectors

AABH MODEL

- Production of dirty input depletes environmental stock S:

$$S_{t+1} = -\xi Y_{dt} + (1+\delta) S_t \quad \text{if} \quad S \in (0, \bar{S}) \,. \tag{1}$$

- Reflecting at the upper bound $\bar{S}$ $(< \infty)$: baseline (unpolluted) level of environmental quality.
- Absorbing at the lower bound $S = 0 \Longrightarrow S = 0$ is a disaster.

AABH MODEL

- Scientists choose the sector with higher expected profits Π_{jt}:

$$\frac{\Pi_{ct}}{\Pi_{dt}} = \frac{\eta_c}{\eta_d} \underbrace{\left(\frac{p_{ct}}{p_{dt}}\right)^{\frac{1}{1-\alpha}}}_{\text{price effect}} \underbrace{\frac{L_{ct}}{L_{dt}}}_{\text{market size effect}} \underbrace{\frac{A_{ct-1}}{A_{dt-1}}}_{\text{direct productivity effect}}$$

  - The direct productivity effect pushes towards innovation in the more advanced sector
  - The price effect towards the less advanced, price effect stronger when ε smaller
  - The market size effect towards the more advanced when $\varepsilon > 1$

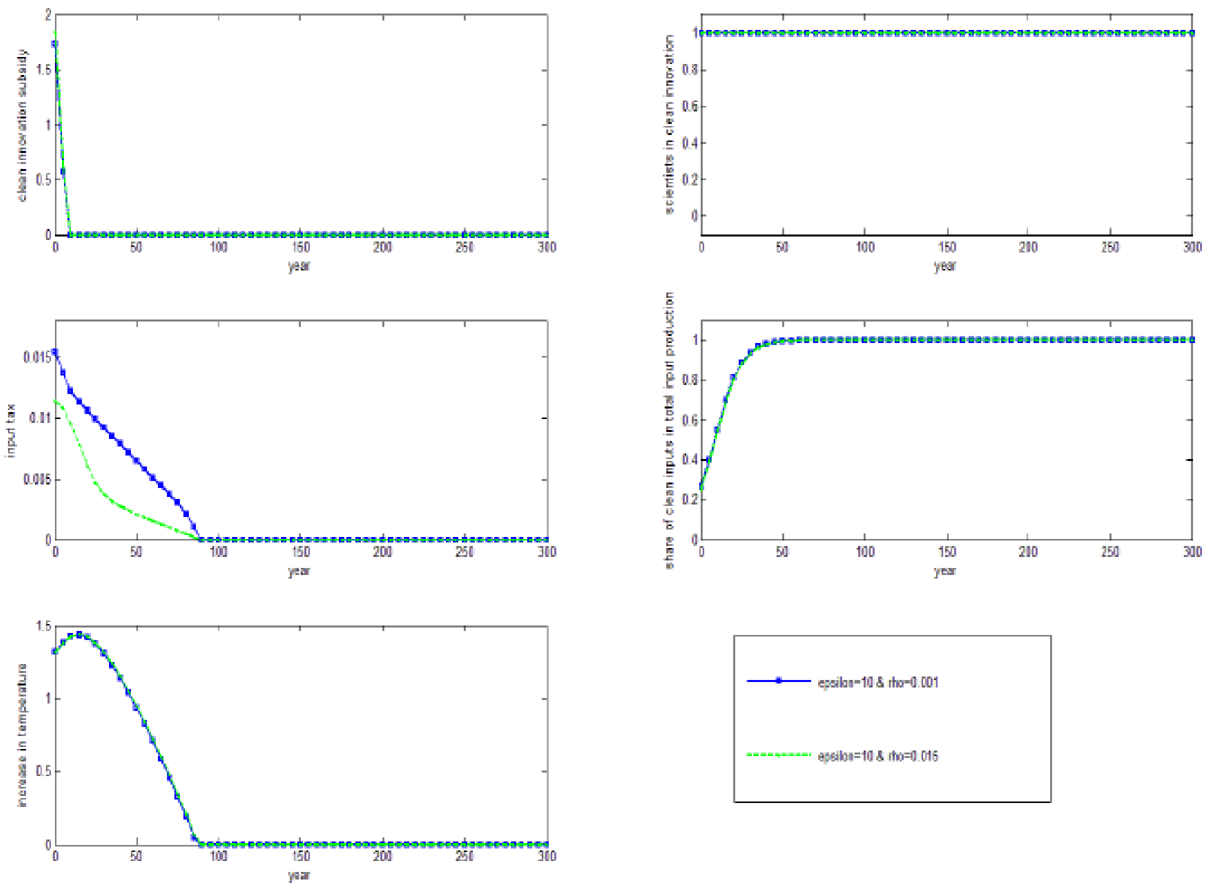
AABH MODEL

- Main findings:
  - If initially “dirty” machines are much more productive than “clean” machines and clean and dirty inputs are sufficiently close substitutes in producing final output, then the economy under laissez-faire will run into environmental disaster
  - Delaying intervention can be very costly
  - Disaster can be avoided through combining a carbon tax and subsidies to clean research

AABH MODEL

- Choose the elasticity of substitution between clean and dirty input as $\varepsilon = 3$ or 10 (low or high).
- Choose ρ, time discount rate (/year here) as $\rho = 0.001$ (Stern; discount factor$\simeq 0.999$) and $\rho = 0.015$ (Nordhaus; discount factor$\simeq 0.985$).

AABH MODEL



clean innovation subsidy
scientists in clean innovation
input tax
share of clean inputs in total input production
increase in temperature
year
epsilon=10 & rho=0.001
epsilon=10 & rho=0.015

TWO EXTENSIONS OF ABBH

- North-South model
  - Knowledge spillovers from North to South
  - But pollution heaven can happen under free trade
- Energy transition
  - Substitution versus scale effects of allowing for intermediate source of energy (shale gas)

AUTO INDUSTRY PAPER (ADHMV)

- Uses cross-country panel data on innovation in Auto industry
- Shows the existence of path-dependence in the clean versus dirty innovation
- Shows that increase in the fuel price will increases incentives for clean R&D relative to dirty

REGRESSION EQUATION

Number of clean triadic patents by firm *i* in year *t*

Clean and dirty spillovers

$$PAT_{CLEAN,it} = \exp(\beta_{C,P} \ln FP_{it} + \beta_{C,1} \ln SPILL_{C,it} + \beta_{C,2} \ln SPILL_{D,it}$$

$$+ \beta_{C,3} \ln K_{C,it} + \beta_{C,4} \ln K_{D,it}$$

Lagged firm's own innovation stocks

$$+ \beta_{C,w} w_{it} + \ln \eta_{C,i} + T_{C,t}) + u_{C,it}$$

Other controls (GDP, GDP/capita, other policies)

Firm fixed effect

Time dummies

Random error

DATA

- World Patent Statistical Database (PATSTAT) at European Patent Office (EPO)
  - All patents filed in 80 patent offices in world (focus from 1965, but goes further back for some countries)
- Extracted all patents pertaining to "clean" and "dirty" technologies in the automotive industry (Table 1 over follows OECD IPC definition)
- Tracked applicants and extracted all their patents. Created unique HAN firm identifier
  - 4.5m patents filed 1965-2005

INTERNATIONAL PATENT CLASSES (IPC)

Description	IPC code
Electric vehicles	
Electric propulsion with power supplied within the vehicle	B60L 11
Electric devices on electrically-propelled vehicles for safety purposes; Monitoring operating variables, e.g. speed, deceleration, power consumption	B60L 3
Methods, circuits, or devices for controlling the traction- motor speed of electrically-propelled vehicles	B60L 15
Arrangement or mounting of electrical propulsion units	B60K 1
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	B60W 10/08, 24, 26
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	B60K 6
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	B60W 20
Regenerative braking	
Dynamic electric regenerative braking	B60L 7/1
Braking by supplying regenerated power to the prime mover of vehicles comprising engine -driven generators	B60L 7/20
Fuel cells	
Conjoint control of vehicle sub-units of different type or different function; including control of fuel cells	B60W 10/28
Electric propulsion with power supplied within the vehicle - using power supplied from primary cells, secondary cells, or fuel cells	B60L 11/18
Fuel cells; Manufacture thereof	H01M 8
Combustion engines	
Combustion engines	F02 (excl. C/G/ K)

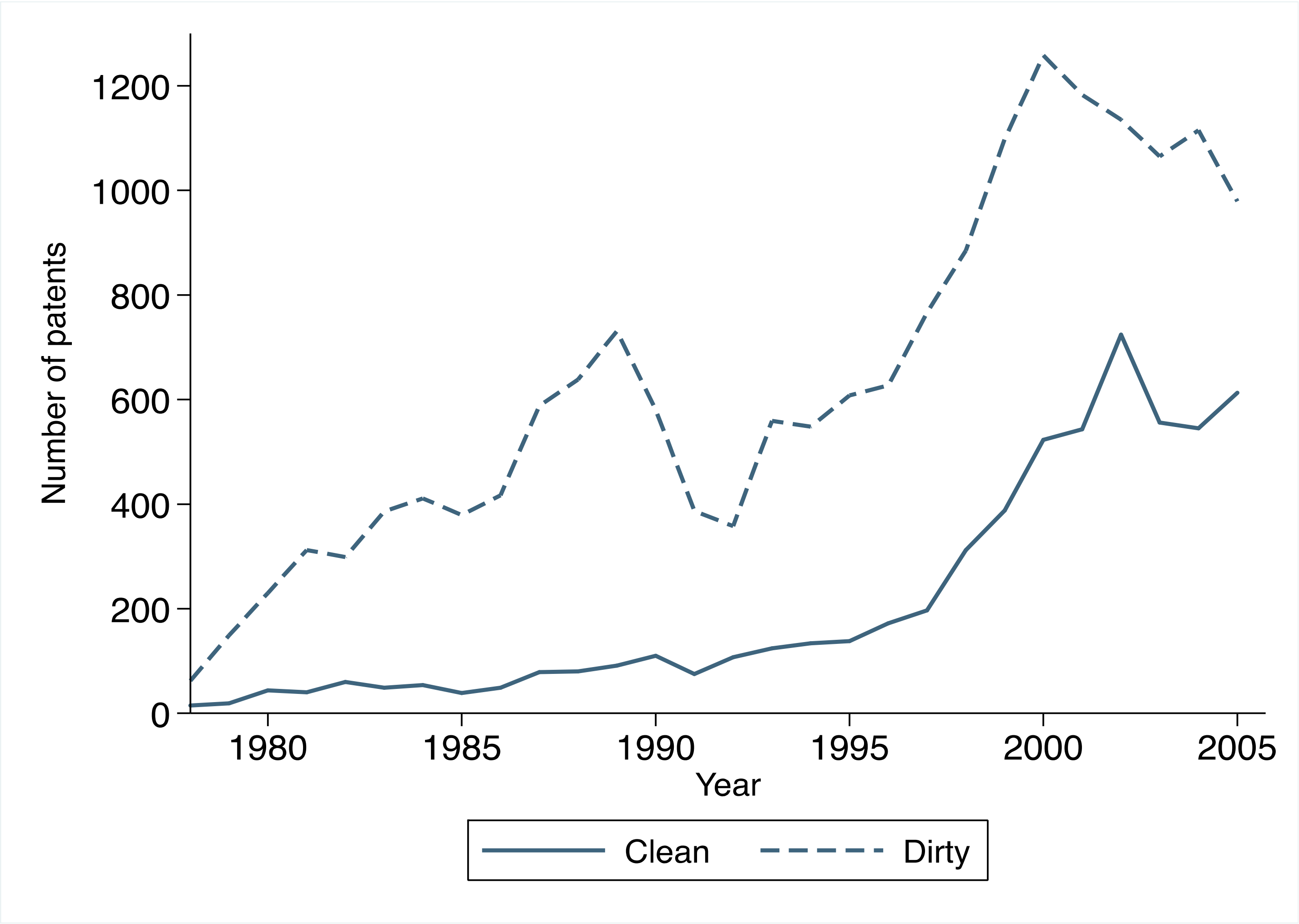
"Clean"

"Dirty"

DATA

- Focus on “triadic” patents filed at all 3 main patent offices: USPTO, EPO & JPO
  - Screens out low value patents
- Over 1978-2005
  - 18,652 patents in “dirty” technologies (related to regular internal combustion engine)
  - 6,419 patents in “clean” technologies (electric vehicles, hybrid vehicles, fuel cells,..)
  - 3,423 distinct patent holders (2,427 firms & 996 individuals)

AGGREGATE TRIADIC CLEAN AND DIRTY PATENTS PER YEAR



POLICY VARIABLES: FUEL PRICES & TAXES

- Fuel prices vary over countries and time (mainly because of different tax regimes)
- Firms are likely to be affected differentially by fuel prices as (expected) market shares different across countries
  - We would like to weight country prices 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 sales by country

TABLE A1: REASONABLE CORRELATION (0.95) BETWEEN GEOGRAPHICAL MARKET SHARES BASED ON SALES VS. PATENT FILINGS: e.g. FORD

1992-2002	Car Sales shares	Patent Weights
US	0.59	0.59
Canada	0.04	0.01
Mexico	0.02	0.00
UK	0.08	0.08
Germany	0.06	0.15
Italy	0.03	0.03
Spain	0.02	0.02
France	0.02	0.04
Australia	0.02	0.00
Japan	0.01	0.05

Source: Annual Company Accounts

TABLE 2: REASONABLE CORRELATION BETWEEN GEOGRAPHICAL MARKET SHARES BASED ON AUTO SALES VS. PATENT FILINGS FOR MAJOR VENDORS (CORRELATION = 0.95)

		Car Sales shares	Patent Weights
Toyota	**2003-2005**		
	Japan	0.43	0.42
	North America	0.40	0.34
	Europe	0.17	0.23
VW	**2002-2005**		
	Germany	0.35	0.57
	UK	0.13	0.08
	Spain	0.11	0.03
	Italy	0.09	0.05
	France	0.09	0.09
	US	0.13	0.15
	Mexico	0.05	0.00
	Canada	0.04	0.00
	Japan	0.02	0.02
Ford	**1992-2002**		
	US	0.66	0.61
	Canada	0.04	0.01
	Mexico	0.02	0.00
	UK	0.09	0.08
	Germany	0.07	0.15
	Italy	0.03	0.03
	Spain	0.02	0.02
	France	0.02	0.04
	Australia	0.02	0.00
	Japan	0.01	0.05
Peugeot	**2001-2005**		
	Western Europe	0.82	0.83
	Americas	0.04	0.13
	Asia-Pacific	0.13	0.04
Honda	**2004-2005**		
	Japan	0.28	0.31
	North America	0.62	0.48
	Europe	0.10	0.20

OWN & SPILLOVER INNOVATION STOCKS

OWN LAGGED INNOVATION STOCKS

- Standard Griliches perpetual inventory formula (check levels of depreciation, baseline 20%)
- z = {CLEAN, DIRTY}

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

SPILLOVERS

- A country's clean (dirty) innovation stock is aggregation of clean (dirty) patents of inventors located in the country
- Firm's exposure to spillovers is average of countries with weights depending on where firm's inventors are located

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

TABLE 1: MAIN RESULTS

	Clean	Dirty
Fuel Price	0.886**	-0.644***
ln(FP)	(0.362)	(0.143)
Clean Spillover	0.266***	-0.058
$SPILL_C$	(0.087)	(0.066)
Dirty Spillover	-0.160*	0.114
$SPILL_D$	(0.097)	(0.081)
Own Stock Clean	0.303***	0.016
K_C	(0.026)	(0.026)
Own Stock Dirty	0.139***	0.542***
K_D	(0.017)	(0.020)
#Observations	68,240	68,240
#Units (Firms and individuals)	3,412	3,412

Notes: Estimation by Conditional fixed effects (CFX), all regressions include GDP, GDP per capita & time dummies. SEs clustered by unit.

ROBUSTNESS TESTS

- Split fuel efficiency innovations out from “dirty”
- Other policy variables – R&D, Emissions regulations
- Fuel taxes instead of prices
- Condition on firms with some positive pre-1985 patents
- Estimate 1991-2005 (instead of 1985-2005) & use weights 1965-1990 (instead of 1965-1985)
- 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.

TABLE 2 –ADD OTHER POLICY VARIABLES

	Clean	Dirty
Fuel Price	1.032**	-0.447**
ln(FP)	(0.440)	(0.187)
R&D subsidies	0.001	0.016
ln(R&D)	(0.028)	(0.020)
Emission Regulation	0.040	0.138
	(0.328)	(0.213)
Clean Spillover	0.388***	-0.191***
	(0.092)	(0.057)
Dirty Spillover	-0.287***	0.252***
	(0.084)	(0.061)
Own Stock Clean	0.280***	0.210**
	(0.051)	(0.105)
Own Stock Dirty	0.153***	0.658***
	(0.050)	(0.083)
Observations	68,240	68,240
Firms	3,412	3,412

Notes: Estimation by Conditional fixed effects (CFX), all regressions include GDP, GDP per capita & time dummies. SEs clustered by unit.

TABLE 3: FUEL TAXES INSTEAD OF FUEL PRICES

	Clean	Dirty
Fuel Tax	0.421**	-0.226**
	(0.184)	(0.091)
Clean Spillover	0.387***	-0.146***
	(0.085)	(0.048)
Dirty Spillover	-0.312***	0.228***
	(0.079)	(0.054)
Own Stock Clean	0.500***	0.197*
	(0.091)	(0.108)
Own Stock Dirty	0.247***	0.612***
	(0.050)	(0.071)
Observations	68,240	68,240
Firms	3,412	3,412

Notes: Estimation by Conditional fixed effects (CFX), All regressions include GDP, GDP per capita, R&D & emission policies & time dummies. SEs clustered by unit.

SIMULATIONS

- Take estimated model to simulate the effect of changes in fuel tax compared to baseline case
- At what point (if ever) does the stock of clean innovation exceed stock of dirty innovation

FIGURE 5A: BASELINE: NO FUEL PRICE INCREASE

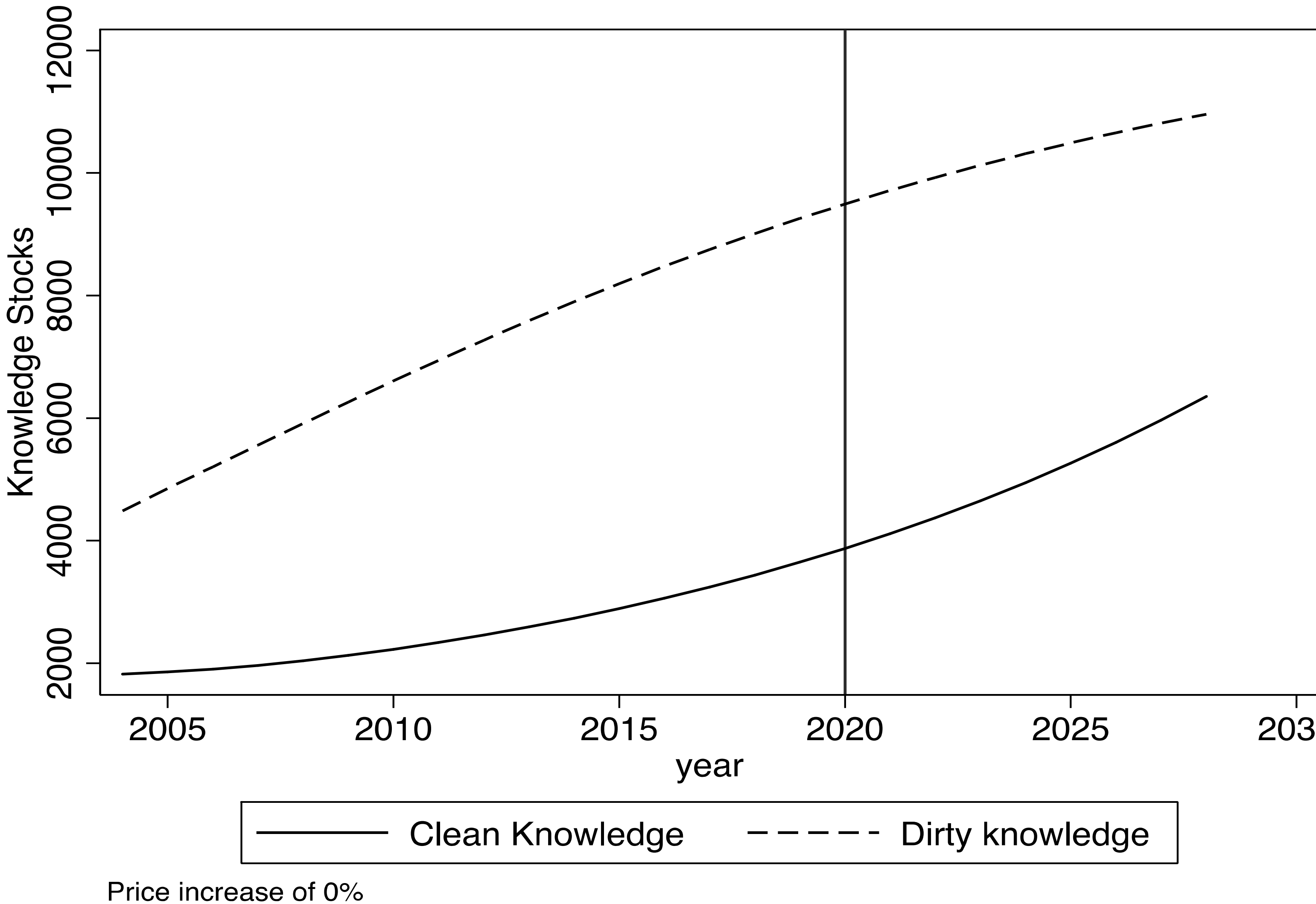
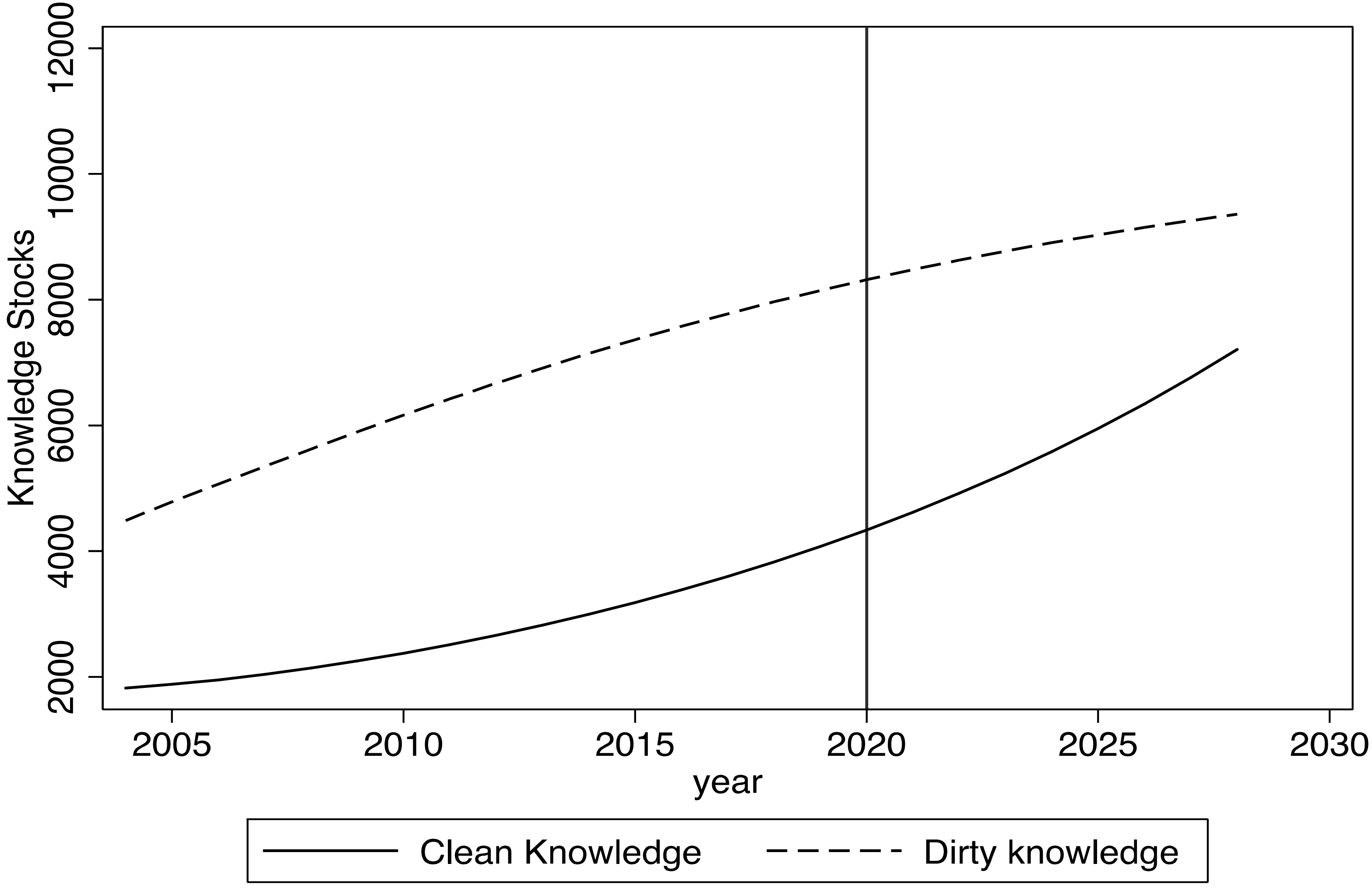
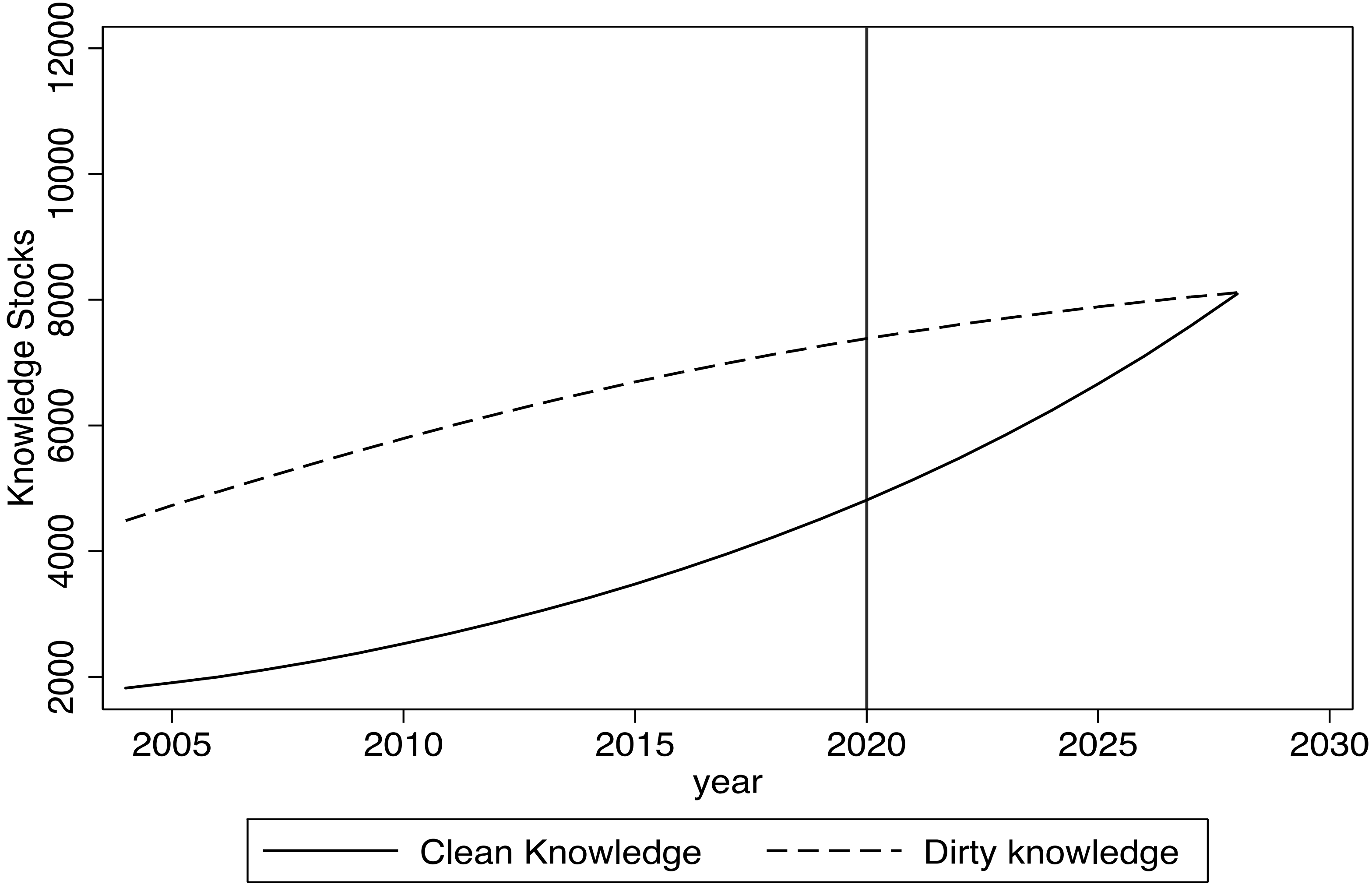


FIGURE 5B: BASELINE: 10% INCREASE IN FUEL PRICE



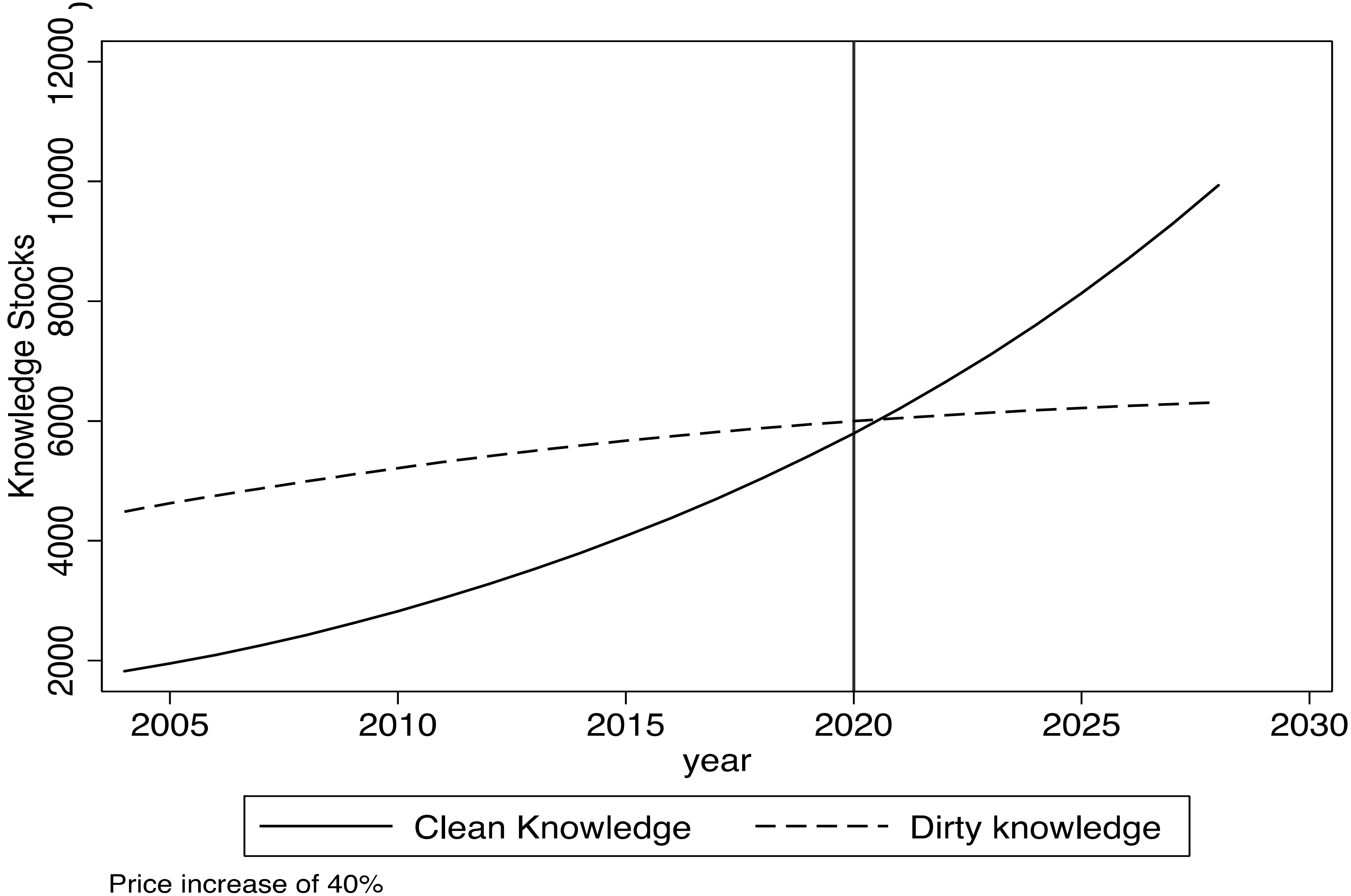
Price increase of 10%

FIGURE 5B: BASELINE: 20% INCREASE IN FUEL PRICE



Price increase of 20%

FIGURE 5D: BASELINE: 40% INCREASE IN FUEL PRICE



CONCLUSIONS

- Technical change can be directed towards “clean” innovation through price mechanism
- Path dependence important because of 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 pretty big increases in prices needed to meet goal, so mixture of policies needed
- Next Steps – other policies; further implications of theory; better simulations