# Shock Therapy for Greener Growth

## The Dynamics of Firms' R&D Investments

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# Introduction

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- The fossil energy price or profitability is affected by:
  - Industrial policies directed towards these sectors
  - Carbon prices:
    - Push consumer prices up: Increase clean innovation from the demand side
    - Push producer prices down: Increase clean innovation from the supply side

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- The fossil energy price or profitability is affected by:
  - Industrial policies directed towards these sectors
  - Carbon prices:
    - Push consumer prices up: Increase clean innovation from the demand side
    - Push producer prices down: Increase clean innovation from the supply side
- A shock may lead to reallocation of resources:
  - Between firms and industries
  - Within firms

# Stylized fact 1: Inertia in R&D

Table: Annual transition rates

| Status year t | Status year t+1 | |
|---|---|---|
| | No R&D | R&D |
| No R&D | 0.862 | 0.138 |
| R&D | 0.098 | 0.902 |

# Stylized fact 2: Increase in clean R&D

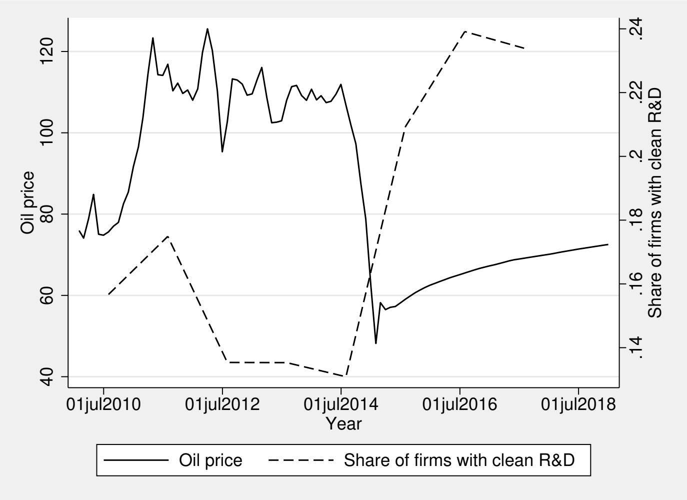
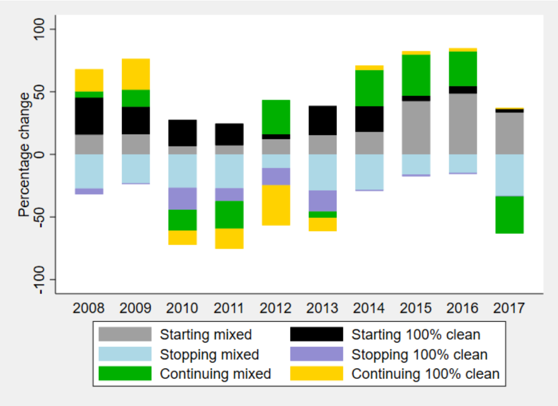



Figure: Oil prices and Clean Innovation

▸ Price evolution

# Stylized fact 3: Increase in clean R&D driven by firms that do both



# This paper

- Stylized theoretical model:
  - Directed technical change (clean and dirty) with heterogeneous firms
  - Explores how a persistent fall in price of oil may encourage clean innovation in the supply chain
  - Within-firm dynamics lead shock-exposed firms to react differently
- Empirical analysis
  - Uses rich firm-level data for Norway
  - Exploits that firms are differentially exposed to the 2014 oil price shock due to their supply linkages to the extractors of fossil energy
  - Findings indicate that shock-exposed firms react differently

# Theoretical Framework

# A stylized model of directed technical change

Production of two final (energy) goods: clean and dirty

- Exogenous final good prices (small, open economy)

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- Each variety produced by a monopolist
- One-period monopoly rights obtained by innovation for that variety

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Production of two final (energy) goods: clean and dirty

- Exogenous final good prices (small, open economy)

Production of a range of inputs for each final good

- Each variety produced by a monopolist
- One-period monopoly rights obtained by innovation for that variety

- Input produers can hire scientists for both types of R&D
  - Higher price of a final good gives higher profitability in R&D for inputs of that type
- Firms differ in their innovation probability:
  - Some firms have no R&D
  - Some firms do only one type of R&D
  - Some firms do both types of R&D

# Within-firm dynamics

- Spillovers from mature (dirty) to clean R&D activity
  - Imply positive relation between the two types of R&D within the firm

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- Spillovers from mature (dirty) to clean R&D activity
  - Imply positive relation between the two types of R&D within the firm
- Adjustment costs when rescaling total R&D activity
  - Imply negative relation between the two types of R&D within the firm

# A persistent oil price drop

A fall in $p_{dt}$ leads to:

- Lower dirty production
- Lower profits in dirty input production and thus in dirty R&D
- Lower dirty R&D in all exposed firms.

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All firms potentially increase clean innovation because scientist wage drops.

Exposed firms after the shock:

- Spillovers suggest <u>lower</u> clean innovation (relative to other firms)
- Adjustment costs suggest <u>higher</u> clean innovation (relative to other firms)

# Empirical Analysis

# Empirical Analysis

Question:

What is the impact of the 2014 oil price shock on clean innovation in exposed firms relative to other firms?

# Data and Sample

- Accounting data for all joint-stock firms in the manufacturing sector in Norway
  - operating income, operating profits, employment
- Product-level (HS8) trade data for the universe of firms
  - exports, imports
- R&D survey
  - R&D expenditure, R&D personell, Share of green R&D in total R&D
  - Clean R&D: renewable energy, other environment-related energy

- Sample
  - All joint stock firms in the manufacturing sector (nace #10 to 35) that are covered by the R&D survey
  - Unbalanced panel of approximately 1,300 firms per year
  - Covers 2007-2017

# The 2014 Oil Price Shock

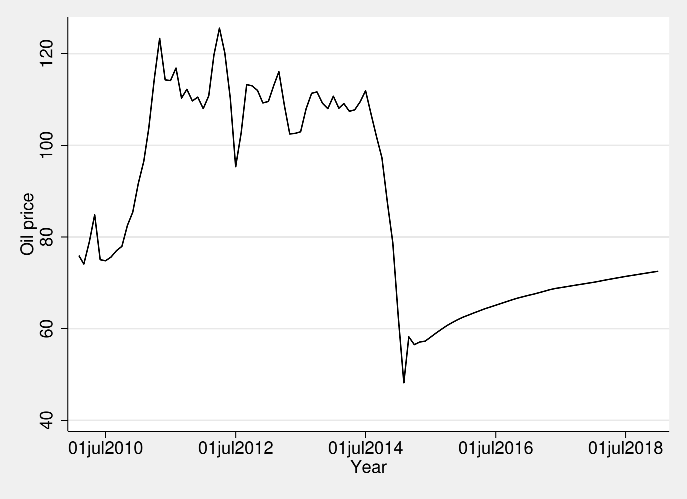


Figure: Oil price and Oil future prices (Source: Norges Bank)

# The 2014 Oil Price Shock

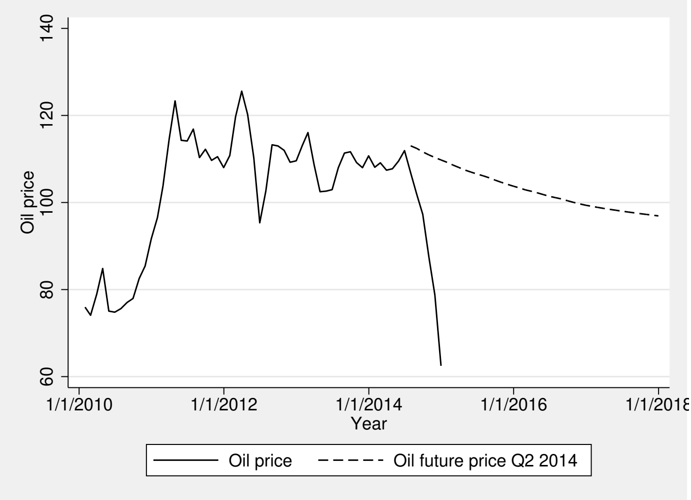


Figure: Oil price and Oil future prices (Source: Norges Bank)

# Aggregate investments in clean R&D

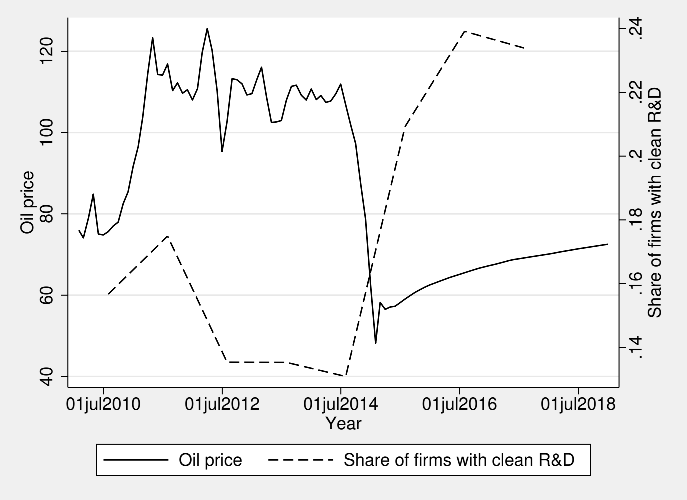


Figure: Oil prices and Clean Innovation

Price evolution

# Identification

- Challenge: identify which firms are most exposed to the shock
  - Standard approach in the literature: Input-output tables
  - Our approach: Firm-specific exposure measure based on trade data

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- Firm-specific oil industry exposure measure:
  - use firm-level imports by oil producers to identify which products they use in their production:
    - ⋆ identify the HS8 products imported by the oil extraction industry (nace #6) in the pre-shock period (2007-2013)
  - use firm-level exports by suppliers to identify which firms sell these products:
    - ⋆ identify the firms in manucfaturing that export products imported by the oil extraction industry ($j \in o$)
  - calculate firm-level exposure, $x_{oi} \in [0, 1]$, as the share of "oil products" in firms' total export basket in 2013
    - ⋆ $x_{oi} = \sum_{j \in o} x_{ijt} / \sum_j x_{ijt}$ for $t = 2013$

# Exposure measure: Pros and cons

Benefits:

1. Captures the fact that they oil price shock was global
2. Gives firm-level variation
3. Allows controlling for industry-level trends

Drawbacks:

1. Reduces sample to only manufacturing + exporting firms
2. Misses indirect exposure
3. Relies on assumption that share of exports is informative of share of production

# Shock exposure

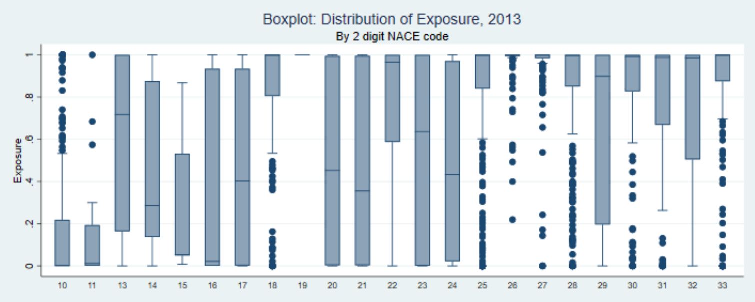


Figure: Within-industry Variation in Exposure

Details

# Empirical model

Diff-in-diff: Compare firms affected by the oil price shock through the supply chain to other firms pre/post 2014:

$$y_{it} = \alpha_i + \beta x_{oi} \times Post_t + \gamma Z_{it} + \delta_{st} + \varepsilon_{it},$$

- $x_{oi}$ measures firm $i$'s exposure
- $\alpha_i$ firm FE, $\delta_{st}$ industry-year FE (NACE 2-digit)
- $Post_t = 1$ if $t > 2013$

- $Z_{it}$: firm level controls
  - log employment, log tangible assets, export share, energy share and a dummy for public funding
  - measured at baseline and interacted with year dummies

# Outcome variables

- Measures of clean (renewable energy) R&D activity
  - Clean energy R&D dummy
  - Clean energy share of R&D expenditures
  - Clean R&D expenditures
  - (Switchers)
- ( Measures of sales and profit: )
  - sales per employee
  - operating profits categorial variable (-1, 0, 1)
- ( Measures of R&D activity: )
  - R&D dummy
  - log R&D employment

# Results: Clean R&D

Table: Clean R&D

| Variable: | Dummy (1) | Share (3) | Log Value (5) |
|---|---|---|---|
| $Post_t * x_{oi}$ | 0.055*** | 1.575* | 0.346** |
| | (0.020) | (0.899) | (0.140) |
| Controls | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes |
| Ind.*year FE | Yes | Yes | Yes |
| Obs. | 11,695 | 11,695 | 11,695 |

▸ W/o controls ▸ PPML

Standard errors in parenthesis are clustered on firm. Log Value is measured as log(1 + Green R&D expenditures). Controls include baseline levels of log employment, log tangible assets, export share, energy share and a dummy for public funding, all interacted with year dummies. $*p < 0.1, **p < 0.05, ***p < 0.01$.

# Mechanisms & robustness

- R&D in general ▸ Link
- Sales and profits ▸ Link
- Pre-trends ▸ Link
- Placebo using other technology types ▸ Link
- Renewable prices ▸ Link

# Conclusion

- Carbon pricing can affect clean innovation not only through higher demand for clean alternatives, but also through higher supply
- We show theoretically that within-firm dynamics may lead diretly exposed firms in the energy sector to react differently to a drop in the oil price, compared to less exposed firms
- We show empircally that exposed firms in the Norwegian oil supply sector increase clean innovation in repsonse to the 2014 drop in the oil price

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- We show theoretically that within-firm dynamics may lead diretly exposed firms in the energy sector to react differently to a drop in the oil price, compared to less exposed firms
- We show empircally that exposed firms in the Norwegian oil supply sector increase clean innovation in repsonse to the 2014 drop in the oil price
- Carbon pricing (and other policy measures) may induce reallocation not only across, but also within, firms

# Thank you!

# Innovation and growth

- $A_{jt}$: Aggregate state of the technology of type j at time t:

$$A_{jt} \equiv \int_0^1 A_{jit} di.$$

- A successful innovation increases the quality of the input by: $(1 + \gamma) > 1$

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# How may an oil price drop affect clean innovation?

A persistent drop in $p^{oil}$ will:

- reduce profitability in fossil energy production and its supply chain
- lead to lower fossil energy related R&D
- lead to free resources for R&D activity in the market
  $\Rightarrow$ higher clean innovation in "all" firms.

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- reduce profitability in fossil energy production and its supply chain
- lead to lower fossil energy related R&D
- lead to free resources for R&D activity in the market
  $\Rightarrow$ higher clean innovation in "all" firms.
- In addition: Directly exposed firms (in supply chain):
  - may invest more in clean R&D if rescaling of R&D activity is costly.
  - may invest less in clean R&F if there are within-firm technologial spillovers from fossil to clean innovation.

▸ Back

# Shock exposure

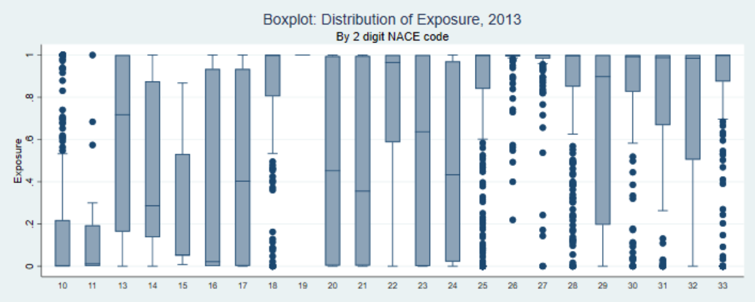


Figure: Within-industry Variation in Exposure

Details Back

# Box plot

- Median value: the line splitting the box in two represents the median value
  - shows that 50 % of the data lies below the median value and 50 % lies above
- Lower Quartile: the bottom edge of the box represents the lower quartile
  - shows the value at which the first 25 % of the data falls up to
- Upper Quartile: the upper edge of the box shows the upper quartile
  - shows that 25 % of the data lies to the right of the upper quartile value
- Upper and lower values of the data: the horizontal lines stop at are the values of the upper and lower values of the data
- Outliers: the single points on the diagram

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# Switchers

- "New Green"
  - Dummy=1 if no Green energy R&D=0 in $t-1$ & Green energy R&D>0 in $t$
  - otherwise Dummy=0
  -
- "From R&D to Green"
  - Dummy=1 if R&D=1 in $t-1$ & New Green=1 in $t$
  - Dummy=0 if R&D=1 $t-1$ & & New Green=0 in $t$
  - Column 2: Dummy=0 if R&D=0 in $t-1$
  - Column 3: Dummy=missing if R&D=0 in $t-1$

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# Results: Clean R&D

Table: Clean R&D

| Variable: | Dummy (1) | Dummy (2) | Dummy (3) | Dummy (4) |
|---|---|---|---|---|
| $Post_t{*}x_{oi}$ | 0.044** | 0.039** | 0.042** | 0.055*** |
| | (0.019) | (0.020) | (0.020) | (0.020) |
| Controls exl. energy | No | No | Yes | Yes |
| Controls incl. energy | No | No | No | Yes |
| Firm FE | No | Yes | Yes | Yes |
| Ind.*year FE | Yes | Yes | Yes | Yes |
| Obs. | 11,695 | 11,695 | 11,695 | 11,695 |

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Standard errors in parenthesis are clustered on firm. Controls include baseline levels of log employment, log tangible assets, export share, energy share and a dummy for public funding, all interacted with year dummies. $*p < 0.1, **p < 0.05, ***p < 0.01$.

# Results: R&D

Table: R&D

| Variable: | R&D dummy (1) | log R&D emp (2) | R&D emp share (3) |
|---|---|---|---|
| $Post_t \times x_{oi}$ | -0.015 | -0.008 | -0.001 |
| | (0.028) | (0.007) | (0.001) |
| Controls | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes |
| Industry*year FE | Yes | Yes | Yes |
| Observations | 11,695 | 11,695 | 11,695 |

Standard errors in parenthesis are clustered on firm. Log R&D employment is log(1+R&D employees). Controls include baseline levels of log employment, log tangible assets, export share, energy share and a dummy for public funding, all interacted with year dummies. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

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# Results: Sales and profits

Table: Sales per employee and Profits indicator

| Variable: | Sales per emp. (1) | Sales per emp. (2) | Profits (3) | Profits (4) |
|---|---|---|---|---|
| $Post_t \times x_{oi}$ | -0.082*** | -0.043* | -0.179*** | -0.081 |
| | (0.026) | (0.026) | (0.049) | (0.060) |
| Controls | Yes | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes | Yes |
| Year FE | Yes | No | Yes | No |
| Industry FE | Yes | No | Yes | No |
| Industry*year FE | No | Yes | No | Yes |
| Observations | 11,695 | 11,695 | 11,695 | 11,695 |

Back

Standard errors in parenthesis are clustered on firm. Controls include baseline levels of log employment, log tangible assets, export share, energy share and a dummy for public funding, all interacted with year dummies. The indicator for operating profits takes on 0, -1 and 1 depending on whether the firms makes zero, negative or positive profits. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

# Results: Placebo using other tech fields

Table: Placebo

| Variable: | Bio tech R&D | ICT R&D |
|---|---|---|
| | (1) | (2) |
| $Post_t \times x_{oi}$ | -0.015 | -0.032 |
| | (0.015) | (0.024) |
| Controls | Yes | Yes |
| Firm FE | Yes | Yes |
| Industry*year FE | Yes | Yes |
| Observations | 11,695 | 11,695 |

Back

Standard errors in parenthesis are clustered on firm. Controls include baseline levels of log employment, log tangible assets, export share, energy share and a dummy for public funding, all interacted with year dummies. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

# Falling Renewable Prices

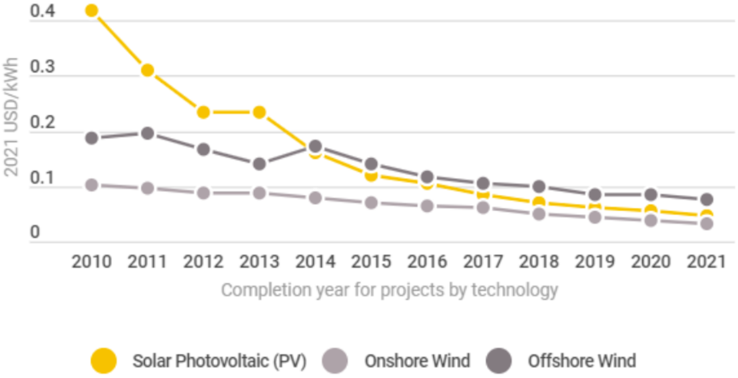


Figure: Global renewable prices (IRENA)

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# The Oil Price Shock 2014

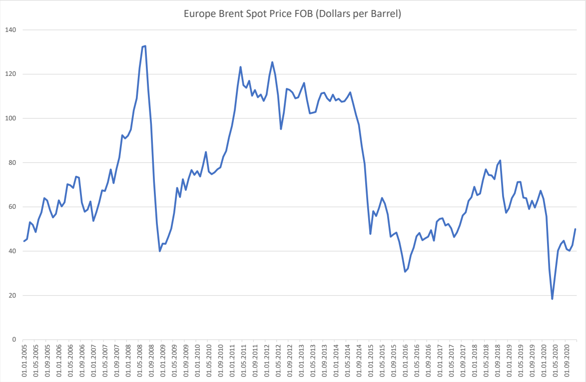


Figure: Oil price: Brent Blend (Source: U.S. Energy Information administration)

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# Results: Clean R&D PPML

Table: Clean R&D PPML

| Variable: | Dummy (1) | Share (3) | Value (5) |
|---|---|---|---|
| $Post_t * x_{oi}$ | 0.499** | 0.358* | 0.716 |
| | (0.199) | (0.218) | (0.470) |
| Controls | Yes | Yes | Yes |
| Firm FE | Yes | Yes | Yes |
| Ind.*year FE | Yes | Yes | Yes |
| Obs. | 3,024 | 3,024 | 3,024 |

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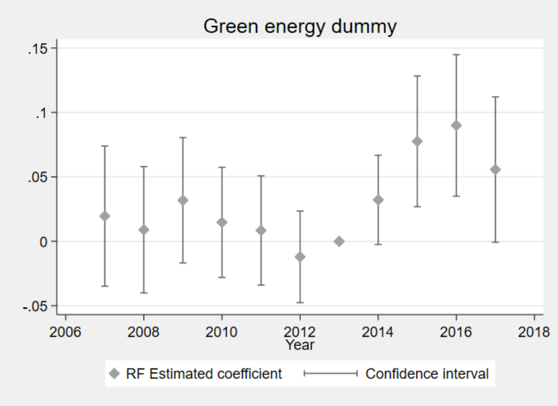
Standard errors in parenthesis are clustered on firm. Controls include baseline levels of log employment, log tangible assets, export share, energy share and a dummy for public funding, all interacted with year dummies. $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

# Dynamic DID

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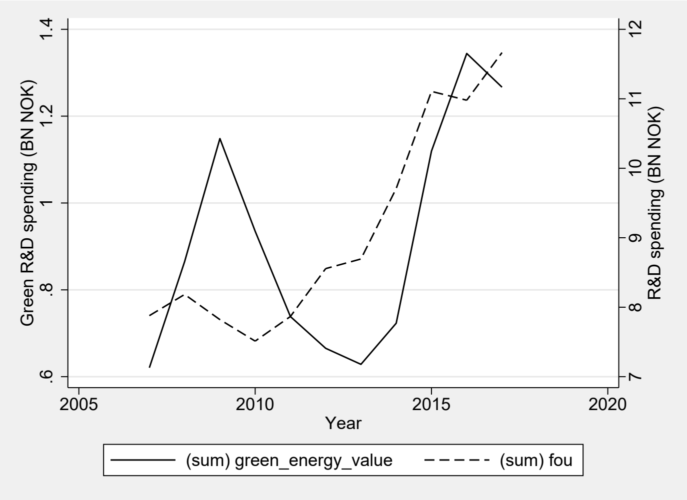
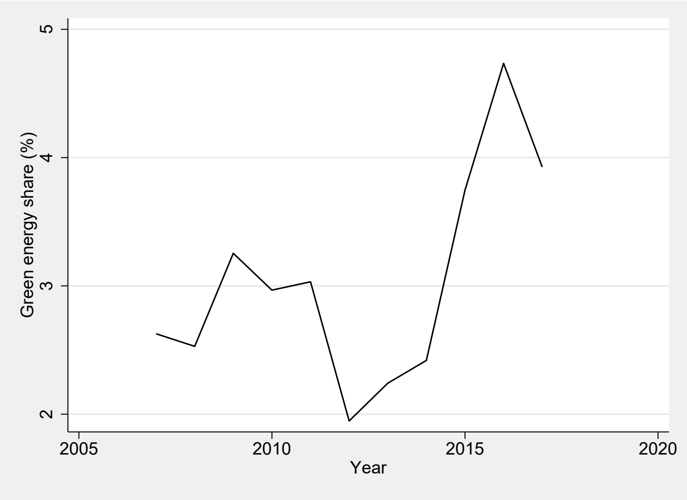
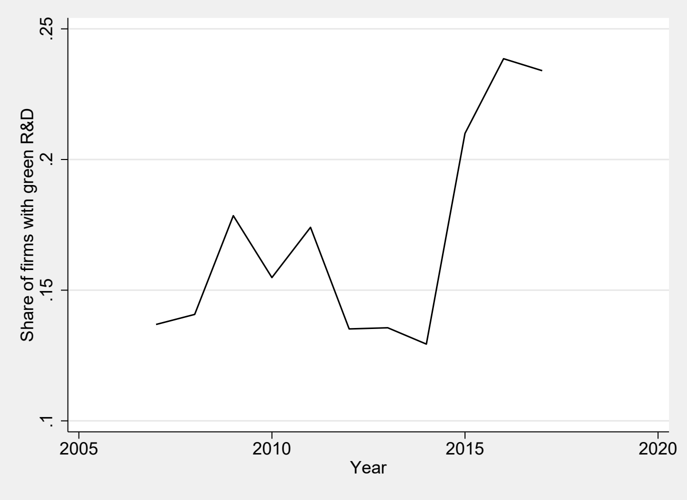
# R&D expenditure



# Green energy share in R&D



# Share of firms with green R&D



# Two propositions

## Proposition

*W/o spillovers or adjustment costs:*

$$\frac{ds^{I}_{kct}}{dp_{dt}} = \frac{ds^{III}_{kct}}{dp_{dt}}$$

$\longrightarrow$ All firms engaged in clean R&D, independently of whether the firms are also active in dirty R&D or not, will respond equally

## Proposition

*With spillovers and adjustment costs:*

$$\frac{ds^{III}_{kct}}{dp_{dt}} \lesseqgtr \frac{ds^{I}_{kct}}{dp_{dt}}$$

$\longrightarrow$ Exposed firms will respond more or less depending on whether the spillover effect dominates the effect of the adjustment costs or vice versa

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