Fondazione Eni Enrico Mattei

cmcc Centro Euro-Mediterraneo sui Cambiamenti Climatici

Threshold Policy Effects and Directed Technical Change in Energy Innovation

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Outline

- Motivation & contribution
- Non linear policy effects
- Empirical approach
- Descriptive evidence
- Main results
- Policy implications

Motivation

- **Issue:** Climate change calls for swift mitigation effort
  - Key role for innovation and creating a comparative advantage in low-carbon tech
  - Burden is on both developed and developing countries

Questions:

What policy mix should be used to redirect energy innovation when level of competencies/development is heterogeneous?

How can countries at different distances from the frontier fully benefit from dynamics incentives of environmental policies? (parallel: Acemoglu et al. 2006)

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Contribution

- **Hypothesis:** Effectiveness of different policy instrument changes with the level of competencies in REN vs FFS

- **Method:** Hansens' (1999) threshold model estimated in the context of "directed technical change", and modified to:
  - Include two policy variables of interest
  - Control for FE using pre-sample mean

- **Findings:** discontinuities in policy effectiveness (3 regimes)
  - Laggard countries should invest in R&D first (1st regime)
  - Policy mix required in the crucial phase (2nd regime)
  - Market-based reinforce a green advantage (3rd regime)

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Non Linear Policy Effects

- **Policy choice contingent on level of tech development**
  - Acemoglu et al. (2006): change from investment-based innovation-based growth: a discontinuous switch
  - Countries which increase competencies but do not change policy approach end up in a non-catching up trap

- **Important implications for climate change and sustainable development**
  - Lock-in/out with competing technologies (i.e. renewable versus fossil fuels, Arthur 1989)
  - Path dependency=>Extremely hard to redirect innovation
  - Key role of policy in making the lock-out possible, but scant empirical research

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Non Linear Policy Effects

- For **innovation scholars**, our paper can be seen as a case study of how policies may contribute to locking out from a mature technology in favor of a new technology

- We contribute to the debate on appropriate policy mix in **environmental economics**
  1. Direct policies: R&D investments, ↑ competencies & absorptive capacity
  2. Indirect policies, target environmental externality first:
     - Command-and-control instruments
     - Market-based instruments

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Empirical approach

- **We test how environmental policies effectiveness hinges upon accumulation of knowledge (direct policies)**

- Balanced panel of 34 countries, 1990-2015
- Adapt Hansen's (1999) threshold model to study the direction of low carbon innovation: different regimes of policy effectiveness, two types of instruments.
  - Dependent variable is renewable innovation wrt to fossil (patents w/ family>2)
  - Threshold variable is the ratio of stocks
  - Policy variables are CC and MB instruments
  - Account for heterogeneity using the pre-sample mean of the dep. var.
  - Control for GDP per capita, Total patent stock, Coal dependence, Electricity exports, Human capital, Year fixed effects

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Empirical approach: three steps

1. Base model: *policy independent on K*

$$y_{i,t} = \beta_{mb} MB_{it} + \beta_{cc} CC_{it} + \beta_K K_{it} + \mathbf{BX} + \mu_i + \lambda_t + e_{it}$$

2. Interaction model: *policy linearly dependent on K*

$$y_{i,t} = \beta_p MB_{it} + \beta_q CC_{it} + \beta_K K_{it} + \beta_{mbK} K_{it} MB_i + \beta_{ccK} K_{it} CC_{it} + \mathbf{BX} + \mu_i + \lambda_t + e_{it}$$

$$\partial y_{it} / \partial P = \beta_P + \beta_{PK} \times K,$$

3. Threshold model: *policy discontinuously dependent on K*

$$y_{i,t} = \beta_{mb_1}(\gamma) MB_{it} \mathbf{I}(K_{it} \leq \gamma) + \beta_{p_2}(\gamma) MB_{it} \mathbf{I}(K_{it} > \gamma) + \beta_{cc_1}(\gamma) CC_{it} \mathbf{I}(K_{it} \leq \gamma) + \beta_{cc_2}(\gamma) CC_{it} \mathbf{I}(K_{it} > \gamma) + \beta_K K_{it} + \mathbf{BX} + \mu_i + \lambda_t + e_{it},$$

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Empirical approach: remarks

- Discontinuous policy effect conditional on the level of specialization is coherent with (and called for by) the theoretical literature on technological lock-in (Arthur, 1989) and distance-to-frontier (Acemoglu et al., 2006)
- Innovation and level of competencies measured with patent statistics and knowledge stock variables
- The threshold model is estimated following Hansen (1999)
- We check the "superiority" of the threshold model: log-likelihood tests to discriminate between the three models → the threshold model outperforms the other two models (see)
  - Improve previous empirical works on directed technical change (Aghion et al., 2016; Noailly and Smeets, 2015)

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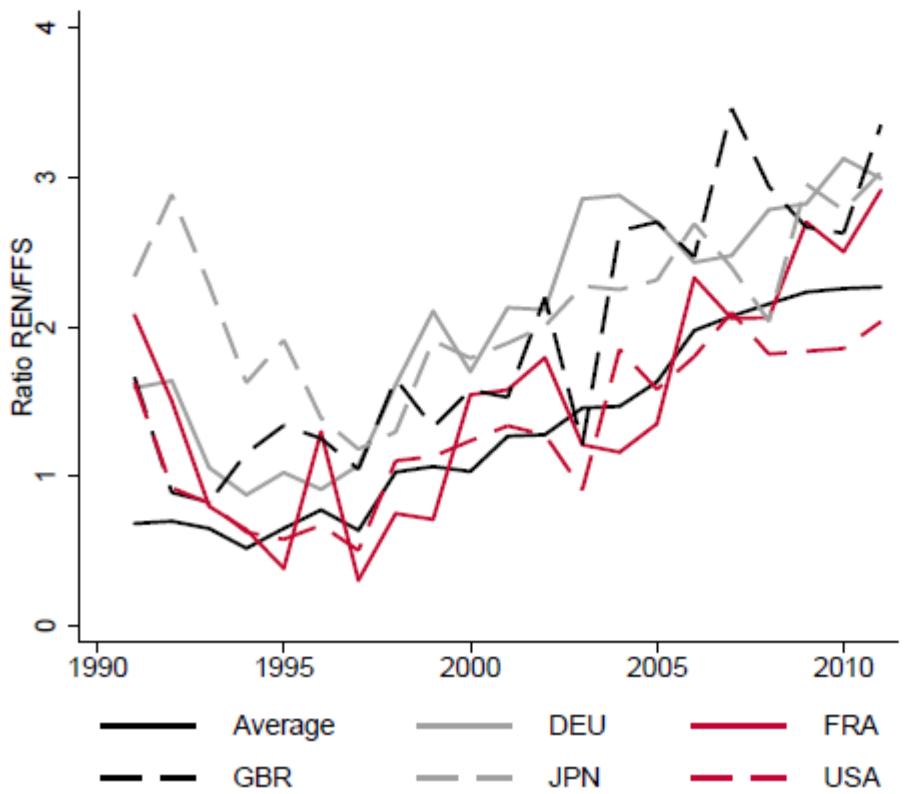
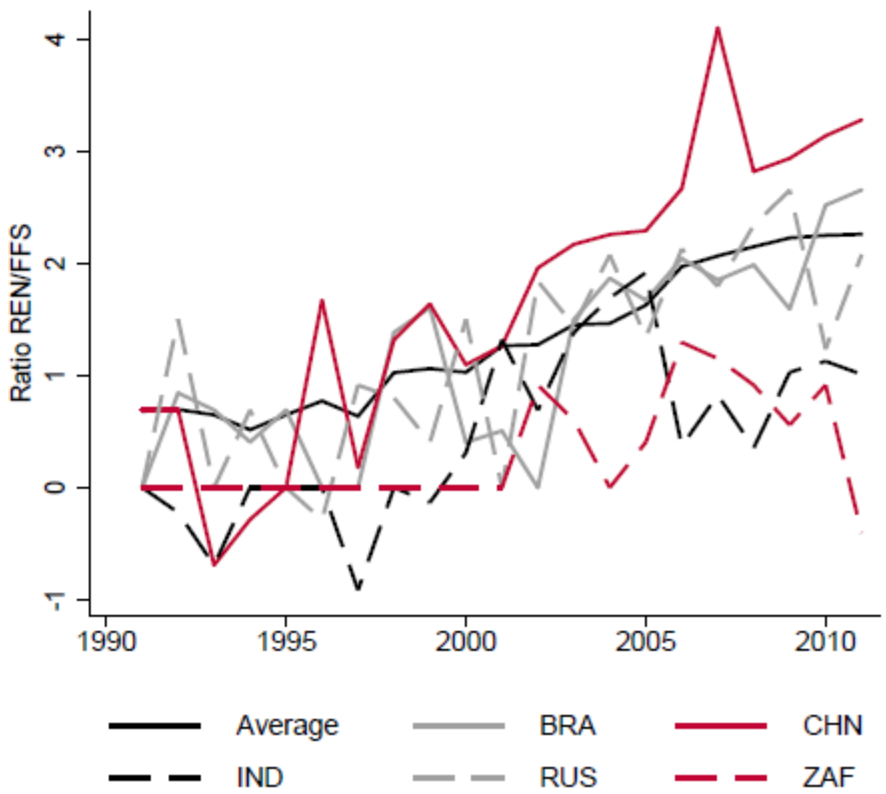
Descriptives





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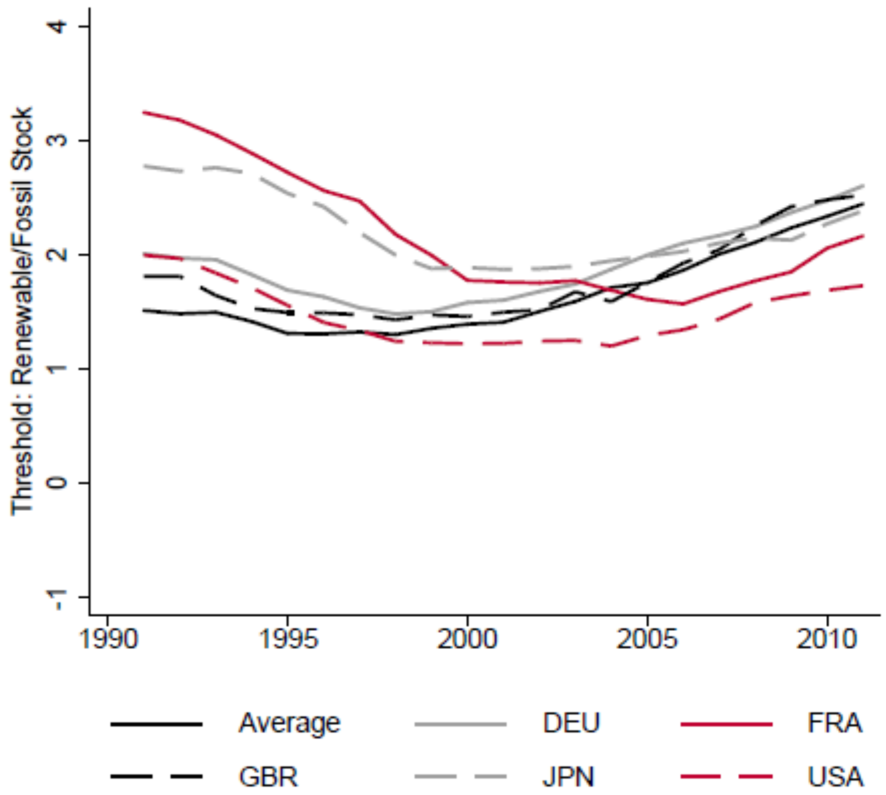

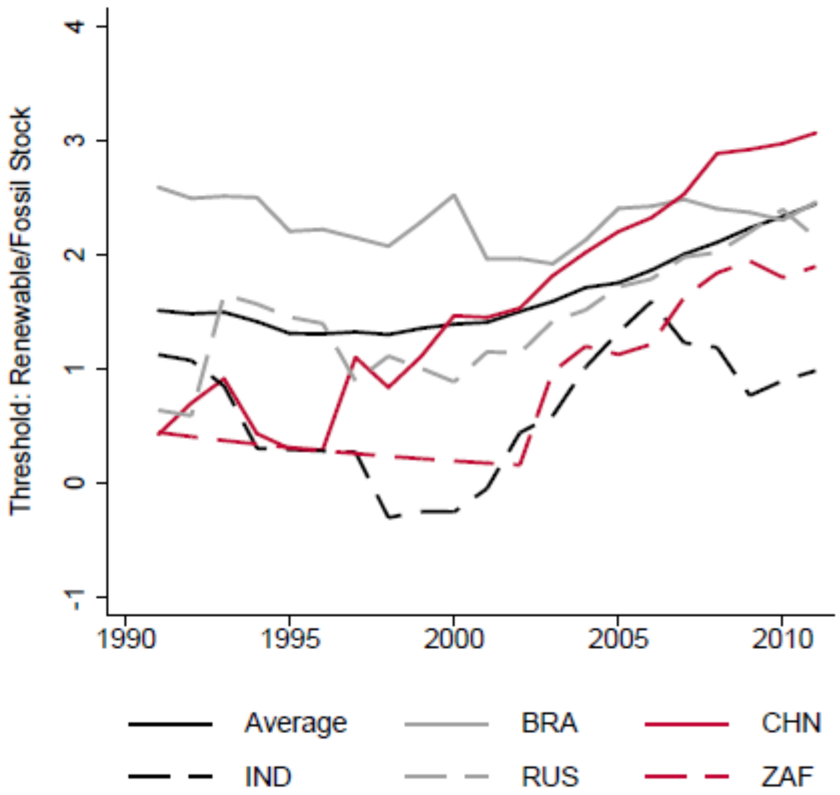

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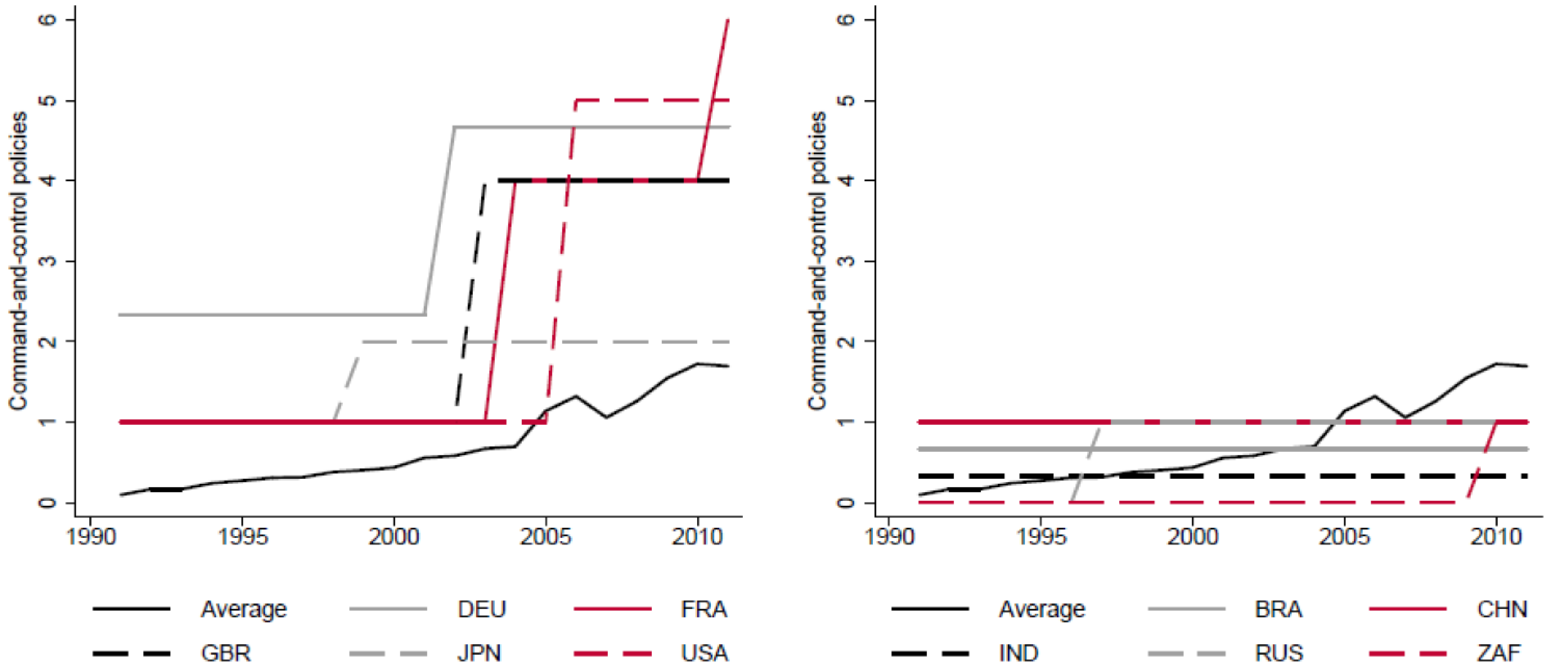

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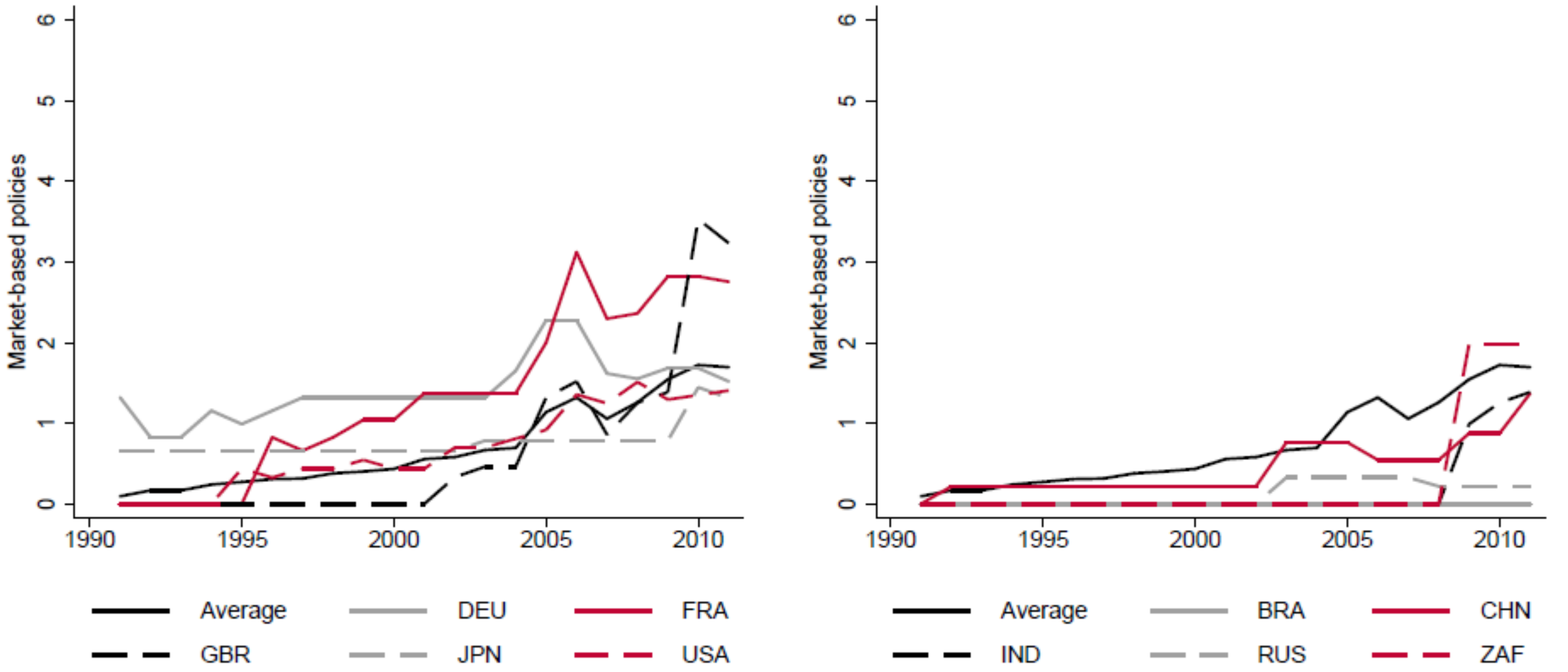

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Result I: *policy effect depends on competencies*

	(1)	(2)	(3)	(4)
Pre-Sample Mean	0.386***	0.315***	0.022	-0.003
	(0.90)	(0.095)	(0.144)	(0.132)
$K_{R/F}$	0.353***	0.337***	0.295***	0.105
	(0.076)	(0.070)	(0.082)	(0.067)
MB Policies		0.388	0.457*	-1.495***
		(0.263)	(0.258)	(0.463)
MB $\times K_{R/F}$				0.951***
				(0.255)
CC Policies		0.462*	0.266	-0.358
		(0.252)	(0.184)	(0.320)
CC $\times K_{R/F}$				0.226
				(0.151)
Observations	776	776	776	776
R-squared	0.541	0.555	0.597	0.624
LL	-829.0	-817.0	-778.4	-751.6
RSS	384.8	373.1	337.8	315.3
LR-test	-	24.0	77.20	53.57
P. value	-	0.000	0.000	0.000

Result II: *location of the threshold*

	$\hat{\gamma}_1$	$\hat{\gamma}_2$	$\hat{\gamma}_3$
Threshold percentile	88	47	~~63~~
Threshold value for $K_{R/F}$	2.598	1.709	2.006
95 % CI for $K_{R/F}$	[2.483, 2.678]	[1.664, 1.757]	[NA, NA]
F-statistics	33.47	19.06	6.75
P-value	.000	.042	0.682

The obtained thresholds are estimated from model 5 of Table 3 with 500 bootstrapped samples. See Appendix A about inference of the estimated thresholds and on the determination of their confidence intervals.

$$\begin{aligned} y_{i,t} = \quad & \beta_{mb_1}(\gamma)MB_{it}\mathbf{I}(K_{it} \leq \gamma_1) + \beta_{mb_2}(\gamma)MB_{it}\mathbf{I}(\gamma_1 < K_{it} \leq \gamma_2) + \beta_{mb_3}(\gamma)MB_{it}\mathbf{I}(K_{it} > \gamma_2) + \\ & \beta_{cc_1}(\gamma)CC_{it}\mathbf{I}(K_{it} \leq \gamma_1) + \beta_{cc_2}(\gamma)CC_{it}\mathbf{I}(\gamma_1 < K_{it} \leq \gamma_2) + \beta_{cc_3}(\gamma)CC_{it}\mathbf{I}(K_{it} > \gamma_2) + \\ & \beta_K K_{it} + \mathbf{BX} + \mu_i + \lambda_t + e_{it}. \end{aligned}$$

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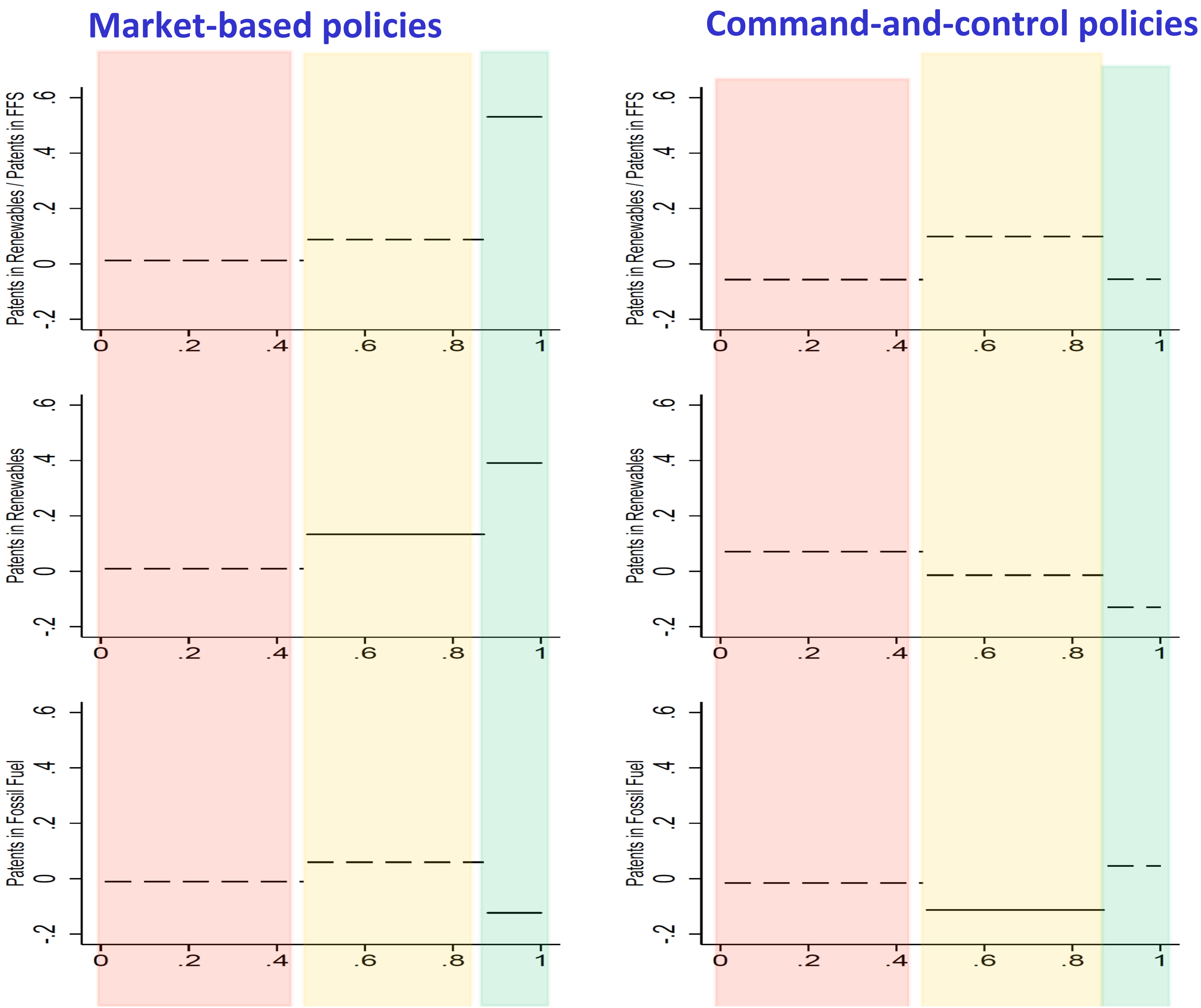
Result III: *three policy regimes*

	$P_{R/F}$ [a] (5)
Pre-Sample Mean	0.006 (0.128)
$K_{R/F}$	0.134* (0.066)
MB $\times \mathbf{I}(K \leq \hat{\gamma}_2)$	0.053 (-0.293)
MB $\times \mathbf{I}(\hat{\gamma}_2 < K \leq \hat{\gamma}_1)$	0.377 (-0.299)
MB $\times \mathbf{I}(K \leq \hat{\gamma}_1)$	2.276*** (-0.592)
CC $\times \mathbf{I}(K \leq \hat{\gamma}_2)$	-0.207 (-0.214)
CC $\times \mathbf{I}(\hat{\gamma}_2 < K \leq \hat{\gamma}_1)$	0.361 (-0.247)
CC $\times \mathbf{I}(K \geq \hat{\gamma}_1)$	-0.2 (-0.384)
Observations	782
R-squared	0.631

Quantification: one-std dev. change



Robustness

- IV approach to account for **endogeneinty (see)**
  - Reverse causality: policy response depends positively on present and future competence of the country (↑)
  - Measurement error in the policy variables (↓)
  - Omitted variable bias (fossil subsidies) (↓)
  - ➢ *Location of threshold unaffected, if any downward bias confirmed*
- Higher value patents; supporting technologies
  - ➢ *MB policies more important for high quality patents*
- **Using RES diffusion as a dependent variable**
  - ➢ Behavior of innovation and diffusion are similar in the regimes

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Take away points

Two discontinuities in policy effectiveness depending on relative competencies <> three regimes:

- *First regime*: Low competencies (~ up to median competencies), where **no instrument** is **effective**
- *Second regime*: Medium-high competencies: dynamic incentives of MB and CC become powerful but for different reasons:
  - **CC** -- **stick** for **fossil-fuel innovation**
  - **MB** -- **carrot** for **renewable innovation**
- *Third regimes*: High competencies (top 15 percent): MB **consolidate** green comparative advantage

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Thank you

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Additional Slides

Policy implications: emerging economies

	K stock Ren/Foss			Mkt Based Policies			Command-Control Policies		
	Pre-Kyoto	Post-Kyot	Post-Crisis	Pre-Kyoto	Post-Kyot	Post-Crisis	Pre-Kyoto	Post-Kyot	Post-Crisis
Eastern European Countires: ***Policy Push EU > Successful Redirection***									
CZE	44.6	83.4	94.4	0.06	0.26	0.59	0.00	0.40	0.67
HUN	25.9	51.6	80.4	0.00	0.31	0.57	0.00	0.38	0.67
POL	49.0	31.7	66.4	0.09	0.27	0.56	0.11	0.30	0.67
SVK	12.9	49.0	63.6	0.05	0.18	0.45	0.00	0.13	0.17
SVN	12.7	21.0	29.2	0.01	0.07	0.35	0.17	0.32	0.67
Emerging Economies: ***No Yet Policy Push > Heterogenous Effect***									
BRA	82.3	73.4	82.6	0.00	0.00	0.00	0.11	0.11	0.11
CHN	11.9	49.9	95.8	0.05	0.13	0.29	0.15	0.17	0.29
IDN	2.0	3.1	29.4	0.00	0.00	0.22	0.13	0.17	0.17
IND	13.6	14.1	17.4	0.00	0.00	0.29	0.06	0.06	0.06
RUS	24.9	33.1	73.4	0.00	0.05	0.06	0.02	0.17	0.17
ZAF	9.0	16.2	52.8	0.00	0.00	0.34	0.00	0.00	0.10
Total	41.9	45.5	72.4	0.06	0.20	0.44	0.13	0.32	0.56

Empirical Framework: Hansen model

- How does the Hansen's (1999) threshold model work – in brief:

$$\hat{\mathbf{e}}(\gamma) = \mathbf{Y} - \hat{\mathbf{Y}}(\gamma)$$

- γ is chosen so to minimize the sum of squared errors

$$S_1(\gamma) = \hat{\mathbf{e}}(\gamma)'\hat{\mathbf{e}}(\gamma) \rightarrow \hat{\gamma} = \underset{\gamma}{\operatorname{argmin}} \; S_1(\gamma)$$

- Two additional steps
  - Significant difference in thresholds
  - Building the 95 percent CI around γ

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Data and Descriptives

Variable	Obs.	Mean	Median	SD	Min	Max
Renewable/Fossil patents $P_{R/F}$	782	1.319	1.298	1.043	-1.872	4.839
Renewable patents P_{REN}	782	42.720	7.000	111.7	0.0	969.6
Fossil patents P_{FFS}	782	4.753	0.515	11.89	0.0	132.3
Pre-Sample Mean	782	0.919	0.593	0.768	0.0	2.838
Renewable/Fossil stocks $K_{R/F}$	782	1.693	1.756	0.819	-0.613	3.995
Market-based policies	833	0.759	0.462	0.846	0.0	3.531
command-and-control policies	833	1.940	1.000	1.734	0.0	6.0
GDP per capita (2011 USD PPP)	850	9.964	10.17	0.733	7.177	11.34
Human Capital	850	2.971	3.113	0.536	1.487	3.734
Total Knowledge Stock	782	31,262	4,543	71,637	14.35	430,998
Coal Dependence	844	0.136	0.0	0.483	0.0	6.660
Electricity Exports	782	-0.065	-0.029	0.099	-0.573	0.0
Instrument $PM2.5_{i,t}$	850	23.31	23.22	9.002	7.677	46.61
Democracy longevity $t-2$	766	37.46	28.0	27.66	1.0	80.0

[a] Electricity Exports is the log of the ratio of electricity exports over production of electricity.

	$P_{R/F}$ [a] (5)	P_{REN} (6)	P_{FFS} (7)
Pre-Sample Mean	0.006	0.099	0.456***
	(0.128)	(0.114)	(0.125)
$K_{R/F}$	0.134*	0.416***	0.350***
	(0.066)	(0.103)	(0.065)
MB $\times \mathbf{I}(K \leq \hat{\gamma}_2)$	0.053	0.041	-0.047
	(-0.293)	(-0.362)	(-0.294)
MB $\times \mathbf{I}(\hat{\gamma}_2 < K \leq \hat{\gamma}_1)$	0.377	0.572**	0.255
	(-0.299)	(-0.252)	(-0.235)
MB $\times \mathbf{I}(K \leq \hat{\gamma}_1)$	2.276***	1.678***	-0.529
	(-0.592)	(-0.535)	(-0.327)
CC $\times \mathbf{I}(K \leq \hat{\gamma}_2)$	-0.207	0.258	-0.056
	(-0.214)	(-0.234)	(-0.238)
CC $\times \mathbf{I}(\hat{\gamma}_2 < K \leq \hat{\gamma}_1)$	0.361	-0.051	-0.412**
	(-0.247)	(-0.242)	(-0.164)
CC $\times \mathbf{I}(K \geq \hat{\gamma}_1)$	-0.2	-0.474	0.168
	(-0.384)	(-0.393)	(-0.255)
Observations	782	782	782
R-squared	0.631	0.881	0.802
LL	-752.1	-689.8	-558.6
RSS	313.4	267.3	191.1
LR-test	5.626		
P-value	0.060		

Instruments

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- Length of Democracy:
  - Extensive literature showing that environmental regulation is more stringent instable democracy
  - Nesta et al. (2014) use this instrument in a similar context
  - Hyp: long-lasting democracy are more willing to approve stringent env. policies

- Counterfactual PM2.5 emissions: initial PM2.5 concentration multiplied by pop. growth
  - Emissions of PM2.5 mostly transport and not utilities
  - High public concerns but less lobbying from oil companies and utilities
  - Hyp: PM2.5 concerns increase support for renewable energy

- Both instruments pass standard tests of strength (F well above 10)

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