

Non-renewable and intermittent renewable energy sources: Friends and foes?

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Introduction

Motivations

Non-renewable and intermittent renewable energy sources: Friends and foes?

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Theoretical model

Empirical model

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Conclusion

Starting point: Study the interactions which are both adversarial and cooperative between renewables and non-renewable (especially natural gas) energies :

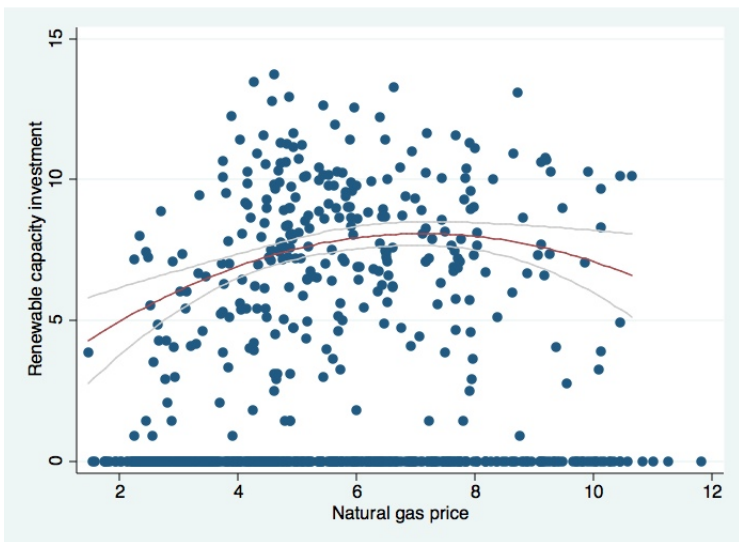
- Renewables (wind and solar): Free input (no need to go to the market) but not flexible intermittent and unstorable
- Natural gas: Very flexible (+ less CO₂ compared to other fossil fuels) but at a cost as you need to go to the market!

Main question: How does an increase in the price of natural gas (p_{ng}) influence renewable capacity investments (k)?

- $dk/dp_{ng} > 0$: (gross) substitutes ?
- $dk/dp_{ng} < 0$: (gross) complements ?
- ...or it depends \Rightarrow Non-linear relationship!
 \Rightarrow Empirical result with theoretical explanation!

Introduction

Suggestive evidences (49 U.S. States/years 1998-2012) : non-linear relationship?



Source: U.S. Energy Information Administration (2014)

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Main results

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Empirical results:

- Non-linear relationship: Before a threshold, they are substitutes and after they are complements!
- Using aggregate U.S. state-level data (from EIA(2014)) \Rightarrow robust to different approaches and specifications

Theoretical explanation:

- Trade-off between benefit derived from input price differential and opportunity cost due to intermittency of renewables

Policy implications:

- Indirect consequences of policy decisions (Ukrainian crisis, TTIP, shale gas, fall in oil prices, etc.) on the renewable sector
- Call for a comprehensive approach!

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Literature review

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Empirical literature:

- On determinants of investments/generation in renewable energies: which policies to implement?
- Few on the impact of natural gas price on renewable investments (only used as control variable and linearly):
 - Marques et al. (2010) \Rightarrow Substitutes
 - Shrimali and Kniefel (2011) \Rightarrow Complements
 - Economical, technical, environmental and political considerations (Lee et al. (2012))

Theoretical literature:

- Ambec and Crampes (2012), Bouckaert and De Borger (2013) or Garcia and Alzate (2010)
- Main focus: demand/supply uncertainty and decentralization

Theoretical model

Presentation

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Goal: Obtain and explain a non-linear relationship between renewable capacity investment k and natural gas price p_{ng}

Context:

- Model the decision to invest in k of a risk-averse state-level representative energy company
- Aggregate approach
- Need to secure the supply at all cost
- If there is no wind/sun, k produces nothing and we need to use gas turbines to supply the market
- Assume infinite natural gas production capacities

Theoretical model

Main theoretical results

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Trade-off faced by the state-level representative energy company when investing an additional unit of $k(p_{ng})$:

- marginal benefit of having capacity available to produce electricity for free (input price differential)
- marginal cost of having to buy natural gas on the market (opportunity cost of intermittency)

⇒ Non-linear relationship due to a convexity in the opportunity cost function with intermittence and risk-aversion for high natural gas prices.

⇒ Inverted U-shape curve if CARA and DARA utility function!

Empirical model

Methodology

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U.S. state level data from 1998 to 2012 \Rightarrow 732 observations

- Dependent variable: Annual renewable capacity investment
- Explanatory variables: Natural gas price (linear+ quadratic term)
- Control variables:
 - Electricity market: State size, wind/sun availability, growth in electricity sales, electricity price, production % renew. energy/nuclear energy/natural gas and experience with ISO/RTO
 - Socioeconomic context: Population, GDP per capita, democrat governor and LofCV indicator
 - Policy/tax factors: Policy and tax

Sources: EIA, DSIRE, U.S. census and BEA (2014)

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Three issues with the data generating process:

- ① High degree of censorship (445/732 are zero's)
- ② Not normally distributed (right-skewed and non-normal kurtosis)
- ③ Timing of investment

Main econometric approach:

- ① Panel tobit model
- ② Inverse hyperbolic sine transformation
- ③ Consider one-year lag

Robustness checks:

- ① Tobit with (unconditional) fixed effect, probit, fixed effect, (production) tobit and piece-wise linear model
- ② $\log(1 + x)$
- ③ Robust without lag and with 2/3 lags

Empirical model

Renewable capacity investments: Panel tobit model

	(1)	(2)	(3)	(4)	(5)	(6)
Natural gas price	5.908*** (0.623)	1.758*** (0.569)	1.339** (0.629)	1.326** (0.625)	2.161** (0.888)	-0.014 (0.284)
Natural gas price (squared)	-0.422*** (0.053)	-0.148*** (0.046)	-0.123** (0.048)	-0.115** (0.048)	-0.171*** (0.066)	- -
Electricity market factors	No	Yes	Yes	Yes	Yes	Yes
Socioeconomic factors	No	No	Yes	Yes	Yes	Yes
Policy/tax factors factors	No	No	No	Yes	Yes	Yes
Year fixed effects	No	No	No	No	Yes	Yes
Log likelihood	-1150.952	-1038.216	-1033.531	-1018.926	-978.084	-982.644

Robust standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Sample: 732 observations - 49 states - period 1998-2012 (including 441 left-censored observations)

Robustness Checks

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- (Unconditional) state fixed effects (biased and inconsistent due to incidental parameter problem)
- Dichotomous renewable capacity investment (probit)
- Additional renewable generation
- Average petroleum price
- Panel fixed effect with $\log(a + k)$ as dependent variable ($a=\text{constant}$)
- Semi-parametric piecewise linear approach (spline)

Robustness checks

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Dependent variable	(6)	(7)	(8)	(9)	(10)	(11)
Renewable Capacity Investment	Capacity Tobit	Capacity Probit	Production Tobit	Capacity Tobit	Capacity FE	Capacity Spline
Natural gas price	1.790** (0.720)	0.488* (0.281)	2.173* (1.188)		1.249*** (0.354)	
Natural gas price (squared)	-0.142*** (0.055)	-0.045** (0.020)	-0.157* (0.085)		-0.112*** (0.027)	
Average petroleum price				0.188** (0.085)		
Natural gas price spline 1						0.626** (0.293)
Natural gas price spline 2						-0.848** (0.342)
Electricity market factors	Yes	Yes	Yes	Yes	Yes	yes
Socioeconomic factors	Yes	Yes	Yes	Yes	Yes	yes
Policy/tax factors factors	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	No	Yes	Yes	Yes
State fixed effects	Yes	No	No	No	Yes	No
Log likelihood	-883.912	-272.866	-1318.176	-978.593	/	-977.868

Robust standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Robustness checks

Endogeneity

Reverse causality:

- One year lag between dependent and independent variables
- Use yearly (marginal) investment \Rightarrow very small share of the production in total (average = 1%)
- Not short run dispatch data but long-run investment data

Omitted variable bias:

- Control for time-invariant unobserved factors in tobit with (unconditional) fixed effect

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Our main results:

- Renewable energies and natural gas: friends and foes!
- Non-linear relationship between the price of natural gas and renewable capacity investments
- Economic (no input price) and technological (intermittent) trade-off
- Need for comprehensive policy approach

Next on the research agenda:

- Use another (complementary) approach to treat zeros: Heckman's self selection model
- Impact on the imperfect possibility to store electricity