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

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Introduction
Motivations

Starting point: Study the interactions which are both adverserial 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!

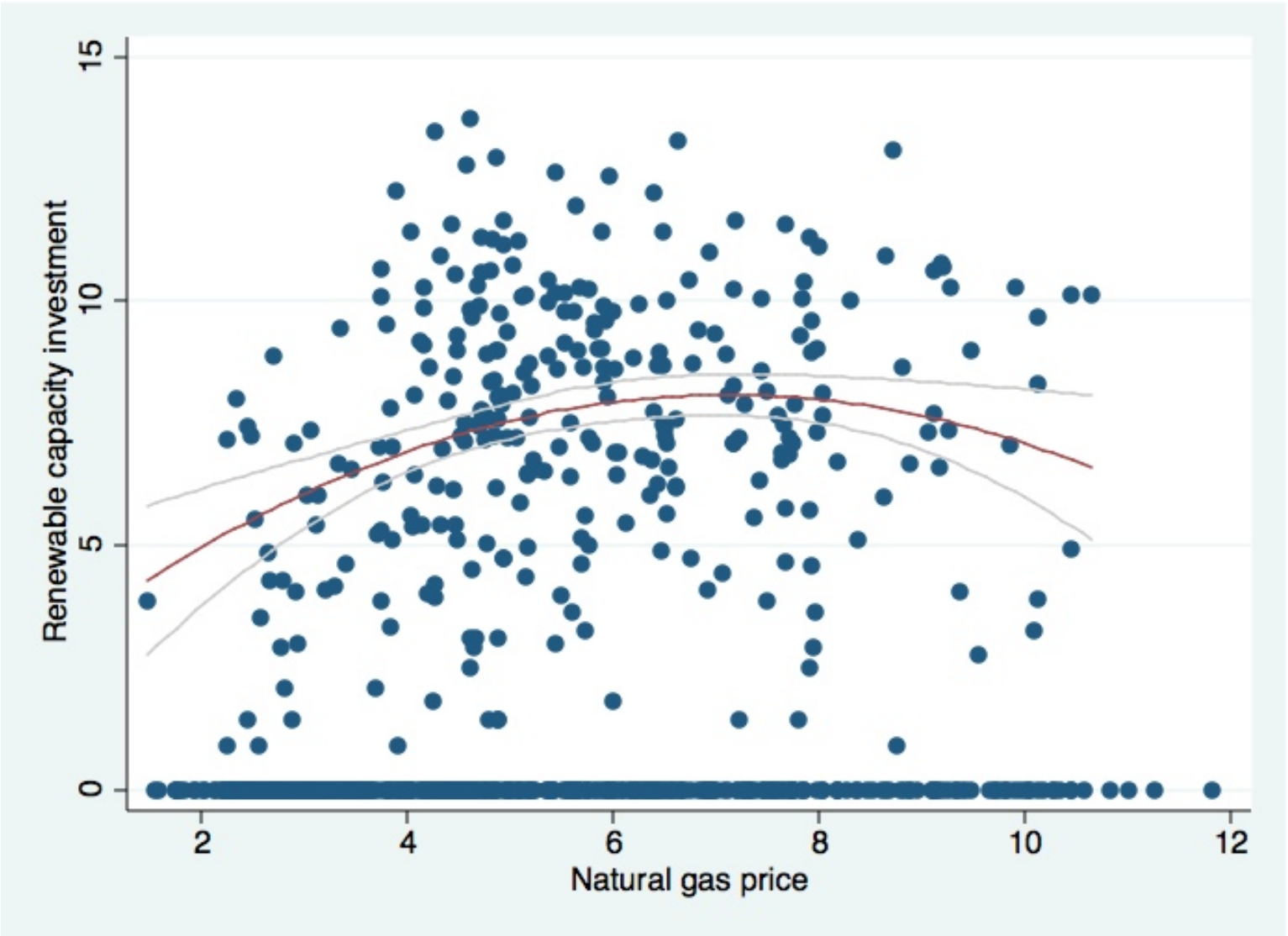
Main question: How does an increase in the price of natural gas (p_{ng}) influence renewable capacity investments (k)?

- $dk/dp_{ng} > 0$: (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)

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 (Ukranian crisis, TTIP, shale gas, fall in oil prices, etc.) on the renewable sector
- Call for a comprehensive approach!

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

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

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)

$\Rightarrow$ Non-linear relationship due to a convexity in the opportunity cost function with intermittence and risk-aversion for high natural gas prices.
$\Rightarrow$ Inverted U-shape curve if CARA and DARA utility function!

Empirical model
Methodology

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)

Empirical model
Methodology

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***	1.758***	1.339**	1.326**	2.161**	-0.014
	(0.623)	(0.569)	(0.629)	(0.625)	(0.888)	(0.284)
Natural gas price (squared)	-0.422***	-0.148***	-0.123**	-0.115**	-0.171***	-
	(0.053)	(0.046)	(0.048)	(0.048)	(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)

Robusteness Checks

- (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=constant)
- Semi-parametric piecewise linear approach (spline)

Robustness checks

Dependent variable Renewable Capacity Investment	(6) Capacity Tobit	(7) Capacity Probit	(8) Production Tobit	(9) Capacity Tobit	(10) Capacity FE	(11) Capacity Spline
Natural gas price	1.790**	0.488*	2.173*		1.249***	
	(0.720)	(0.281)	(1.188)		(0.354)	
Natural gas price (squared)	-0.142***	-0.045**	-0.157*		-0.112***	
	(0.055)	(0.020)	(0.085)		(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

Conclusion

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