Transition to Renewable Energy: the Role of Taxation and Research Subsidies in Electricity Generation for US Industries

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Motivation

- Transitioning from fossil fuels to renewable energy is vital to addressing the climate change concerns.
- The U.S. electricity generation sector, responsible for substantial CO_2 emissions, remains relatively understudied.
- U.S. electricity's renewable share rose from 9% to 21% between 2000 and 2020.
- This trend offers key lessons for transitioning to green energy, notably within the Canadian context.
- It also highlights the sector's potential for a deeper transition to renewable energy.
- **Taxes & R&D subsidies:** Tools for renewable energy transition.

Research Questions

1. What is the impact of tax changes, including carbon taxes and green incentives, on the transition to renewable energy?
2. How effective are R&D subsidies in promoting the adoption of renewable energy?
3. What is the comparative impact of tax adjustments versus R&D subsidies on the transition to renewable energy?

Roadmap

1. Theoretical Framework
   - Theoretical predictions on taxation and R&D subsidies' effects on green transition.
2. Empirical Evaluation
   - Empirical assessment using data from the U.S. electricity generation sector.
3. Main Findings
   - Tax Reform: Critical role of carbon taxes and green incentives in renewable shift.
   - Green R&D Focus: Favoring green R&D subsidies compared to fossil fuel R&D.
   - Tax vs. R&D: Tax reforms lead to a faster green transition compared to R&D subsidies.

Key Drivers of Green Transition:

$$\underbrace{\frac{E_g}{E_d}}_{\text{Renew/Fossil Ratio}} = \underbrace{\left(\frac{p_g}{p_d}\right)^{\frac{-\epsilon\sigma(1-\alpha)+\alpha}{(1-\sigma)(1-\alpha)}}}_{\text{Price effect}} \times \underbrace{\left(\frac{1-\tau_g}{1+\tau_d}\right)^{\frac{-\epsilon\sigma}{1-\sigma}}}_{\text{Taxation Effect}} \times \underbrace{\left(\frac{1-R_g^s}{1-R_d^s}\right)^{-\frac{\sigma}{1-\sigma}}}_{\text{R\&D subsidy effect}} \times \underbrace{\left(\frac{A'_g}{A'_d}\right)}_{\text{Direct productivity effect}} \times \underbrace{\left(\frac{h_g}{h_d}\right)}_{\text{Market size effect}}$$

- Price Effect: stimulates production in the sector with a lower price.
- Productivity Effect: promotes the sector with initially greater productivity
- Market Size Effect: drives production in the sector with a larger market size
- The dirty sector dominates the green sector in market size and productivity.
- → The need for governmental intervention:
  - Taxation Effect (carbon tax, τ_d and green incentive τ_g)
  - R&D Subsidy Effect (green, R_g^s and dirty R_d^s)

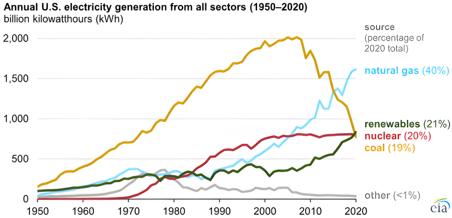
Empirical Methodology: System Generalized Method of Moments

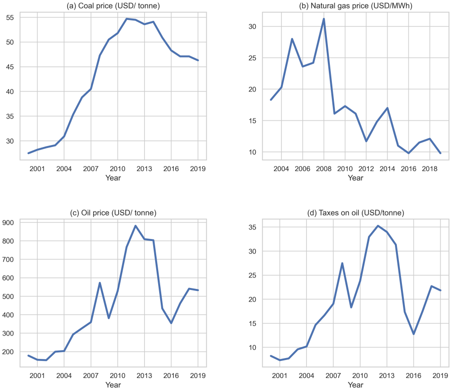
- **Dynamic Panel Equation:**

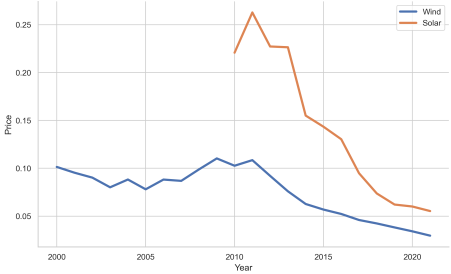
$$\widetilde{E}_{it} = \gamma_1 \widetilde{E}_{i,t-1} + \gamma_2 \widetilde{R}_{it} + \gamma_3 \widetilde{p}_{it} + \gamma_4 \widetilde{A}_{it} + \gamma_5 \widetilde{h}_{it} + \eta_i + \phi_t + \varepsilon_{it}, \quad (1)$$

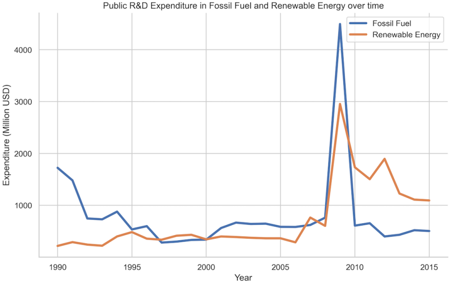
  - i represents the industry, and $t \in (1990 - 2015)$ represents the time.
  - $\widetilde{E}_{i,t}$ is the Ren/Fossil Ratio $= \frac{\textit{Green Energy utilization}}{\textit{Fossil Fuel Energy utilization}}$
  - $\widetilde{R}_{it}$: R&D Subsidy Ratio $= \frac{\textit{Green R\&D Subsidy}}{\textit{Fossil Fuel R\&D Subsidy}}$
  - $\widetilde{p}_{it}$: Tax-inclusive Price Ratio $= \frac{\textit{GreenTax inc. price}}{\textit{Fossil Fuel Tax inc. Price}}$
  - $\widetilde{A}_{it}$: Knowledge Stock Ratio $= \frac{\textit{Green Knowledge Stock}}{\textit{Fossil Fuel Knowledge Stock}}$
  - $\widetilde{h}_{it}$: Market Size ratio $= \frac{\textit{Green Market Size}}{\textit{Fossil Fuel Market Size}}$
  - η_i : Cross-industry effects; time dummies (ϕ_t); ε_{it}: Error across industries i and time t.

Data Visualization






Wind
Solar
Price
Year
0.25
0.20
0.15
0.10
0.05
2000
2005
2010
2015
2020


Public R&D Expenditure in Fossil Fuel and Renewable Energy over time
Fossil Fuel
Renewable Energy
Expenditure (Million USD)
Year
4000
3000
2000
1000
1990
1995
2000
2005
2010
2015

Results: System GMM Estimates -Industry Level Panel (2000-2015)

VARIABLES	(1) Ren/Fossil Ratio	(2) Ren/Fossil Ratio	(3) Ren/Fossil Ratio
Ren/Fossil Ratio (-1)‡	0.732***	0.738***	0.422***
	(0.009)	(0.010)	(0.006)
Tax-inc. Price Ratio		-0.261***	-0.561***
		(0.022)	(0.056)
R&D Subsidy Ratio (d)°			0.062***
			(0.015)
Market Size Ratio			0.198***
			(0.016)
Constant	0.802***	0.334***	0.132
	(0.043)	(0.064)	(0.096)
Observations	2,119	2,119	1,464
Instruments/Groups	92/134	93/134	78/130
Year Dummies	YES	YES	YES
Hansen	72.72	74.74	71.58
p-value	0.388	0.327	0.145
AR(2)	1.17	1.20	0.37
p-value	0.241	0.229	0.715

Robust SE in parentheses. *** p<0.01, ** p<0.05, * p<0.1. ‡ Lagged values. ° First difference.

Theoretical vs Empirical Effects: Taxation and R&D

Theoretical Predictions		
Range of Scenarios	**Taxation Coef.** ($\frac{-\epsilon\sigma}{1-\sigma}$)	**R&D Coef.** ($\frac{\sigma}{1-\sigma}$)
$\epsilon = 1.8, \sigma = 0.020$	-0.037	0.020
$\epsilon = 3.9, \sigma = 0.098$	-0.428	0.109
$\epsilon = 6.5, \sigma = 0.200$	-1.615	0.250
Empirical Analysis		
Model	**Taxation Coef.**	**R&D Coef.**
System GMM	-0.561	0.062
System GMM (Spec.2)	-0.608	0.085
Fixed Effects	-0.385	0.126

Key Insights:

- Taxation effect is always **negative**.
- R&D subsidy effect is always **positive**.
- Taxation effect is **stronger** than R&D effect.
- Empirical estimates **align** within the range of theoretical predictions.

Effects of Taxation and R&D Subsidies on Renewable Transition

- **Taxation's Role:**
  - Tax ratio change (-0.561 coefficient) significantly impacts the green transition.
  - A 10% tax ratio decrease (i.e., ↑ carbon tax and/or ↑ green tax incentive) leads to a 5.61% increase in renewable transition.
- **R&D Subsidies Impact:**
  - R&D subsidy ratio increase (i.e., ↑ green R&D and/or ↓ dirty R&D) positively affects the transition.
  - A 10% R&D subsidy increase results in a 0.62% increase in renewable transition.
- **Relative Strength:**
  - Taxation ($|-0.561|$) facilitates a quicker green transition compared to R&D subsidies (0.062).
  - R&D subsidies influence green transition over a longer period, whereas taxation affects it in the short- and medium-term.

Policy Implications

- **Tax Over R&D Subsidies for timely Impact**: Target for faster emission reductions within specific timeframes.
- **Tie Subsidies to Outcomes:** Ensure R&D subsidies result in measurable innovation and productivity gains in the green sector.
- **Budgetary Neutrality:** If green incentives burden the budget, use revenues from fossil fuel taxes to fund them, ensuring fiscal balance.

Conclusion

- Increasing carbon taxes and/or green tax incentives promote renewable adoption.
- These taxes increase the relative cost of fossil fuels, encouraging the shift to greener alternatives.
- Redirecting R&D to green energy drives innovation and facilitates the renewable shift.
- Tax policies stimulate a faster renewable energy transition than R&D subsidies.
  - Taxes directly stimulate demand-side participants to shift from fossil fuels to green energy, creating a faster effect.
  - In contrast, green R&D subsidies lead to gradual market shifts as innovation takes time to evolve and make an impact.

Thank You!

Questions?