Market and Welfare Effects of Renewable Portfolio Standard in the Vertically Differentiated U.S. Energy Markets

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Selected Poster prepared for presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4-6, 2013.

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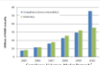
INTRODUCTION


RPS States in the U.S.[1]

Renewable Energy Markets


Compliance-Voluntary Market Demands[7]

Compliance Market — Voluntary Market

Renewable Portfolio Standard

- ❖ Mandate on retail electricity providers to include a certain percent of renewable in their electricity supplies
- ❖ Design varies across states (coverage, existing renewable capacity, REC trading)

Voluntary Purchases by Consumers

- ❖ Offered by utilities/marketers to residential and non-residential consumers in both regulated & deregulated states
- ❖ Green utility programs (fixed-quantity or percent-of-use products)

RESEARCH OBJECTIVES

Previous Studies[2,3,4,6,8]:

- ❖ Focus only on supply effects of state RPS
- ❖ Focus on economic effects of federal RPS but do not
  - a) consider market power among suppliers
  - b) heterogeneous consumer preference

Present Study:

- ❖ Builds an applied-theoretic RPS model that considers:
  - a) Supply-demand effects of RPS
  - b) Interaction of compliance with voluntary markets
  - c) Imperfect competition among electricity suppliers
  - d) Consumer heterogeneity
- ❖ Estimates theoretical model using mixed effect approach
- ❖ Simulates on key parameter values to analyze the economic effects of the introduction of RPS across 8 NERC regions in the U.S.

MODEL FRAMEWORK

Theoretical VPD Model[5]

RPS Effects in the Compliance Market

- **Cost Effect:** $\gamma = C_R^{RPS} - C_R$
- **Utility Effect:** $\delta = a_1 - a$

Inverse Demand Curves

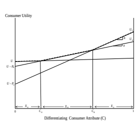
Regular Power Market

$$P_R(X_R, X_G) = \frac{a}{b}P_G - \frac{a(b-a)}{b}X_R$$

Green Power Market

$$P_G(X_R, X_G) = P_R + (b-a) - (b-a)$$

- X_R, X_G – Power Quantities
- P_R, P_G – Power Prices
- a, b – WTP for Regular/Green Power
- c_R, c_G – Power Costs
- θ_R, θ_G – Market Power Parameters
- $b > a, \frac{P_G}{P_R} > \frac{b}{a}, P_G - P_R < b - a$


Consumption Decisions and Welfare Under Pre-RPS Scenario

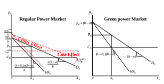
Prices-Quantities

$$P_R = \frac{a\theta_R(\theta_G(b-a)+c_G) + b(1+\theta_G)c_R}{(1+\theta_R+\theta_G)b + \theta_G\theta_R(b-a)}$$

$$X_R = \frac{b(a[\theta_G(b-a)+c_G] - [b+(b-a)\theta_G]c_R)}{a(b-a)((1+\theta_R+\theta_G)b + \theta_R\theta_G(b-a))}$$

$$P_G = \frac{b[(1+\theta_R)(\theta_G(b-a)+c_G)+\theta_G c_R]}{(1+\theta_R+\theta_G)b + \theta_G\theta_R(b-a)}$$

$$X_G = \frac{b[(b-a)(1+\theta_R)+c_G] - (b+(b-a)\theta_R)c_G}{(b-a)((1+\theta_R+\theta_G)b + \theta_R\theta_G(b-a))}$$



Market Equilibrium Conditions Under Pre-RPS Scenario

Empirical Mixed-Effects Model

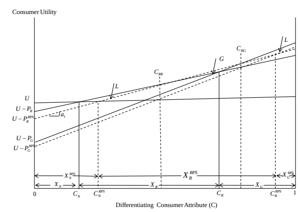
$$Y_{k_{it}} = \alpha_0 + \beta_k X_f + \gamma_k Z_r + \varepsilon_{it}$$

- Y_{it} - the logarithmic transformation of the response variable - levels of regular/green power sales
- X_f - a vector of fixed effects (variables: utility & state characteristics, RE policies, resource potential)
- Z_r - a vector of random effects (variables: interaction term of region*resource cost)
- ε_{it} - idiosyncratic error term

Data – Panel data comprising of 757 utilities selling regular/green power in 48 U.S. states nested in 8 NERC regions during the period 2007-2010

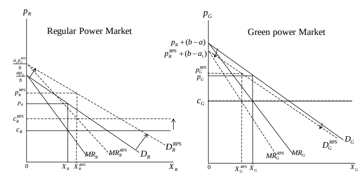
SIMULATION RESULTS

$$P_R^{RPS} \uparrow P_G^{RPS} \uparrow Q_R^{RPS} \uparrow Q_G^{RPS} \downarrow \Pi_R^{RPS} \uparrow \Pi_G^{RPS} \uparrow CW^{RPS} \uparrow CW_R^{RPS} \uparrow CW_G^{RPS} \downarrow$$



$$L = \int_{C_N}^{C_N^{RPS}} (U_R - U_N)dC + \int_{C_N^{RPS}}^{C_{RR}} (U_R - U_R^{RPS})dC + \int_{C_{RG}}^{C_R^{RPS}} (U_G - U_R^{RPS})dC + \int_{C_R^{RPS}}^{1} (U_G - U_G^{RPS})dC, \quad G = \int_{C_{RR}}^{C_R} (U_R^{RPS} - U_R)dC + \int_{C_R}^{C_{RG}} (U_R^{RPS} - U_G)dC$$

Consumption Decisions and Welfare Under Post-RPS Scenario



Market Equilibrium Conditions Under Post-RPS Scenario

Four Possible Market Scenarios:

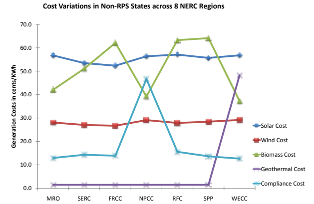
Scenario I - $\Delta X_R < 0, \Delta X_G > 0, \Delta P_R > 0, \Delta P_G > 0$

Scenario II - $\Delta X_R < 0, \Delta X_G < 0, \Delta P_R > 0, \Delta P_G > 0$

Scenario III - $\Delta X_R > 0, \Delta X_G < 0, \Delta P_R > 0, \Delta P_G > 0$

Scenario IV - $\Delta X_R > 0, \Delta X_G < 0, \Delta P_R > 0, \Delta P_G < 0$

Cost Variations in Non-RPS States across 8 NERC Regions



Regions	Consumer Valuation for Regular Power				
		Wind	Solar	Biomass	
MRO	Low Cost	$a_1/b > 0.62$	$a_1/b > 0.38$	$a_1/b > 0.35$	
	High Cost	$a_1/b > 0.82$	$a_1/b > 0.58$	$a_1/b > 0.56$	
		Wind	Solar	Biomass	
SERC	Low Cost	$a_1/b > 0.67$	$a_1/b > 0.38$	$a_1/b > 0.52$	
	High Cost	$c_R > c_G$	$a_1/b > 0.78$	$a_1/b > 0.73$	
		Wind	Solar	Biomass	
FRCC	Low Cost	$a_1/b > 0.67$	$a_1/b > 0.38$	$a_1/b > 0.32$	
	High Cost	$c_R > c_G$	$a_1/b > 0.67$	$a_1/b > 0.58$	
		Wind	Solar	Biomass	
NPCC	Low Cost	$c_R > c_G$	$a_1/b > 0.88$	$c_R > c_G$	
	High Cost	$c_R > c_G$	$c_R > c_G$	$c_R > c_G$	
		Wind	Solar	Biomass	
RFC	Low Cost	$a_1/b > 0.67$	$a_1/b > 0.35$	$a_1/b > 0.58$	
	High Cost	$c_R > c_G$	$a_1/b > 0.73$	$a_1/b > 0.75$	
		Wind	Solar	Biomass	
SPP	Low Cost	$a_1/b > 0.62$	$a_1/b > 0.35$	$a_1/b > 0.29$	
	High Cost	$a_1/b > 0.97$	$a_1/b > 0.58$	$a_1/b > 0.58$	
		Wind	Solar	Biomass	Geothermal
WECC	Low Cost	$a_1/b > 0.55$	$a_1/b > 0.50$	$a_1/b > 0.35$	$a_1/b > 0.29$
	High Cost	$a_1/b > 0.73$	$a_1/b > 0.61$	$a_1/b > 0.53$	$a_1/b > 0.44$

$c_G > c_R$

c_G = generation costs from wind, solar, biomass, & geothermal resources

c_R = generation costs from natural gas and coal

High Cost: $c_R + 6$ cents/KWh, Low Cost: $c_R + 1$ cents/KWh

CONCLUSIONS

- ❖ This research provides a new framework of analysis of the economic effects of RPS in the U.S. electricity market that considers:
  - a) the interaction of compliance with voluntary markets
  - b) heterogeneous consumer preferences
  - c) suppliers' market power
- ❖ Market and welfare effects of RPS depend on
  - a) region- and resource- specific renewable cost increase associated with the mandate
  - b) consumer valuation for mandated-regular power (i.e. regular power containing more renewables)
  - c) relative costs of the power products
  - d) suppliers' market power
- ❖ Regular and green power prices increase
- ❖ Regular (green) power sales increase (decrease)
- ❖ Consumers of regular power and both regular and green power suppliers (IOUs) are most likely beneficiaries of RPS, while consumers of green power lose
- ❖ Being unable to exercise market power, POUs selling regular power will always lose if RPS entails fixed costs
- ❖ Threshold values of (a_1/b) that cause prices, quantities and welfare to increase after RPS:
  - a) increase with an increase in the compliance costs of RPS
  - b) are relatively lower when $c_G = Solar\ cost$ in most regions, thus, indicating that consumer support for solar power through voluntary purchases is more likely to decline with RPS

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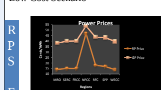
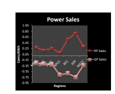
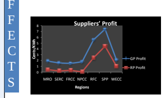
GRAPHS

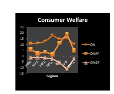
Low Cost Scenario

RPS EFFECTS









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