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

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The diagram illustrates the structure of Renewable Energy Markets. At the center is a green oval labeled "Renewable Energy Markets". A red double-headed arrow connects this central oval to two blue boxes: "Compliance Market" on the left and "Voluntary Market" on the right.

Associated with the Compliance Market is a map of the United States titled "Renewable Portfolio Standards". The map shows various states with different colored regions, indicating different renewable energy standards. A legend below the map lists "Renewable" and "Non-Renewable" sources. Text at the bottom of the map states "RPS States in the U.S.".

Associated with the Voluntary Market is a bar chart titled "Compliance Voluntary Market Growth". The chart shows growth from 2005 to 2010 for "Compliance (MWh)" and "Voluntary (MWh)". The Y-axis represents "MWh" and ranges from 0 to 10. The X-axis represents "Year" and ranges from 2005 to 2010. The chart shows that both Compliance and Voluntary markets have grown significantly over the period, with Compliance reaching approximately 10 MWh and Voluntary reaching approximately 8 MWh by 2010.

Renewable Portfolio Standard	Voluntary Purchases by Consumers
❖ Mandate on retail electricity providers to include a certain percent of renewable in their electricity supplies	❖ Offered by utilities/marketers to residential and non-residential consumers in both regulated & deregulated states

- ❖ Design varies across states (coverage, existing renewable capacity, REC trading)
- ❖ Green utility programs (fixed-quantity or percent-of-use products)

- ❖ 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

- ❖ 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.

The diagram shows a box labeled "RPS Effects in the Compliance Market" with two arrows pointing to the right. The top arrow points to "Cost Effect: $\gamma = C_a^{RPS} - C_a$ ". The bottom arrow points to "Utility Effect: $\delta = a - a'$ ".

Regular Power Market

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

Green Power Market

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

X_{c0}, X_{c1} – Power Quantities
 P_1, P_2 – Power Prices
 a, b – WTP for Regular Grid on Power
 c_0, c_1 – Power Costs
 θ_1, θ_2 – Market Power Parameters
 α_1, α_2 –

Prices-Quantities

$$P_B = \frac{\alpha \theta_1 (\theta_2 (b-a) + c_2) + b(1+\theta_1) \alpha_2}{(1+\theta_1) \theta_2 \theta_3 + \theta_1 \theta_2 (b-a)}$$

$$c = \alpha (\theta_2 (b-a) + c_2) - (b + (b-a)\alpha_2)$$

$$a(t) = a[(1 + \theta_a + \theta_{a1}) + \theta_{a2}(\theta_a - a)]$$

$$\tau_{ij} = \frac{a[(1 + \theta_{\tau})][\theta_{\tau}(\theta_a - a) + \frac{c_{ij}}{a} + \theta_{\tau}c_{ij}]}{(1 + \theta_a + \theta_{a1}) + \theta_{a2}(\theta_a - a)}$$

$$l_{ij} = \frac{a[(1 + \theta_l) + \theta_{l1} + \theta_{l2}] - \theta_l + \theta_l - \theta_l}{(\theta_a - a)[(1 + \theta_a + \theta_{a1}) + \theta_{a2}(\theta_a - a)]}$$

Market Equilibrium Conditions Under Pro-REPS Scenario

Y_{it} - $\ln y_t + \beta_2 X_{it} + \gamma_i X_i + \varepsilon_{it}$

$\ln y_t$ - the logarithmic transformation of the response variable - levels of regular/green power sales

X_{it} - a vector of fixed effects (variables: utility & state characteristics, RE policies, resource potential)

X_i - a vector of random effects (variables: interaction term of region*resource cost)

ε_{it} - 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 2003–2010.

Consumption Decisions and Welfare Under Post-RPS Scenario

Market Equilibrium Conditions Under Post-RPS Scenario

Regions	Consumer Valuation for Regular Power				
MRO		Wind	Solar	Biomass	
	Low Cost	$a_b/b > 0.62$	$a_b/b > 0.38$	$a_b/b > 0.35$	
	High Cost	$a_b/b > 0.82$	$a_b/b > 0.58$	$a_b/b > 0.56$	
SERC		Wind	Solar	Biomass	
	Low Cost	$a_b/b > 0.67$	$a_b/b > 0.38$	$a_b/b > 0.52$	
	High Cost	$c_a > c_u$	$a_b/b > 0.78$	$a_b/b > 0.73$	
FRCC		Wind	Solar	Biomass	
	Low Cost	$a_b/b > 0.67$	$a_b/b > 0.38$	$a_b/b > 0.52$	
	High Cost	$c_a > c_u$	$a_b/b > 0.67$	$a_b/b > 0.58$	
NPCC		Wind	Solar	Biomass	
	Low Cost	$a_b < c_u$	$a_b/b > 0.88$	$a_b > c_u$	
	High Cost	$a_b < c_u$	$c_a > c_u$	$c_a > c_u$	
RFC		Wind	Solar	Biomass	
	Low Cost	$a_b/b > 0.67$	$a_b/b > 0.35$	$a_b/b > 0.58$	
	High Cost	$c_a > c_u$	$a_b/b > 0.73$	$a_b/b > 0.75$	
SPP		Wind	Solar	Biomass	
	Low Cost	$a_b/b > 0.62$	$a_b/b > 0.35$	$a_b/b > 0.29$	
	High Cost	$a_b/b > 0.97$	$a_b/b > 0.58$	$a_b/b > 0.58$	
WECC		Wind	Solar	Biomass	Geothermal
	Low Cost	$a_b/b > 0.55$	$a_b/b > 0.50$	$a_b/b > 0.35$	$a_b/b > 0.20$
	High Cost	$a_b/b > 0.73$	$a_b/b > 0.61$	$a_b/b > 0.53$	$a_b/b > 0.44$

$c_G > c_R$
 c_G = generation costs from wind, solar, biomass, & geothermal resource
 c_R = generation costs from natural gas and coal
 High Cost: $c_r + 6$ cents/KWh, Low Cost: $c_r + 1$ cents/KWh

- ◆ This research provides a new framework of analysis of the economic effects of RPS in the U.S. electricity market that consists of:
 - ◆ the interaction of compliance with voluntary markets
 - ◆ heterogeneous consumer preferences
 - ◆ suppliers' market power
- ◆ Market and welfare effects of RPS depend on
 - ◆ region- and resource- specific renewable cost increase associated with the mandate
 - ◆ consumer valuation of mandated-regular power (i.e., regular power containing more renewables)
 - ◆ relative costs of the power products
 - ◆ 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 and non-IOUs) likely beneficiaries of RPS, while consumers of green power lose
- ◆ Unlikely to exercise market power, POUs selling regular power supply to IOUs
- ◆ Threshold values of (a/b) that cause prices, quantities and welfare to increase after RPS:
 - ◆ increase in net income in the compliance costs of RPS: $c_g > c_r$
 - ◆ increase in net income in the compliance costs of RPS: $c_g > c_r$ 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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Low Cost Scenario

The figure consists of four sub-graphs illustrating the impact of a Low Cost Scenario on the supply chain. The x-axis for all graphs represents time from 2008 to 2012.

- Player Prices:** Shows the price paid by the retailer (Retailer Price, orange line) and the price received by the supplier (Supplier Price, blue line). Both prices show a significant peak in 2010, with the Retailer Price reaching approximately 1.8 and the Supplier Price reaching approximately 1.2.
- Power Sales:** Shows the sales volume for the retailer (Retailer Sales, orange line) and the supplier (Supplier Sales, blue line). Both sales volumes show a significant peak in 2010, with the Retailer Sales reaching approximately 0.8 and the Supplier Sales reaching approximately 0.6.
- Suppliers' profits:** Shows the profit for the retailer (Retailer Profit, orange line) and the supplier (Supplier Profit, blue line). Both profits show a significant peak in 2010, with the Retailer Profit reaching approximately 0.4 and the Supplier Profit reaching approximately 0.2.
- Consumer Welfare:** Shows the welfare for the retailer (Retailer Welfare, orange line) and the supplier (Supplier Welfare, blue line). Both welfares show a significant peak in 2010, with the Retailer Welfare reaching approximately 0.4 and the Supplier Welfare reaching approximately 0.2.

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