Environmental and Technology Policy Options in the Electricity Sector: Interactions and Outcomes

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Policy background

- Economists generally advocate pricing emissions as the most efficient way to get greenhouse gas reductions.
- Yet we observe a great diversity of policies — many of which are aimed directly at technology:
  - Renewable production subsidies
  - Renewable portfolio standards
  - Clean energy standards
  - R&D subsidies
  - Energy efficiency programs
- Not clear to what extent intended as substitutes or complements — or how effective they are.
EU “20/20/20 by 2020” Goals

Reduce greenhouse gas levels by 20%
Increase share of renewables to 20%
Reduce energy consumption by 20%

Current trend to 2020:
-20%
20%
-10%

Source: European Commissions DG Energy
22 June 2011
Figure 3 | Regional Cap-and-Trade Programs

U.S. GHG Emissions in 2007 (excludes land use change)


U.S. Population in 2007

29 states + DC and PR have an RPS
(8 states have goals)
Combining Renewable Policies with a Cap-and-Trade System

- *With a binding cap, zero incremental emissions reductions are realized from supplementary policies.*
- Renewable energy subsidies cause allowance prices to fall
  - Tends to benefit dirtier emitters!
    - i.e., coal-fired save more than natural gas-fired
  - Less fossil energy generation overall
    - Displaced by RES-E
- Also cause electricity prices to fall
  - Lowers incentives for energy efficiency
Multiple Market Failures

- Emissions externality
- Knowledge market failure – inability of innovators to appropriate all the gains
  - R&D spillovers
  - LBD spillovers
- Energy efficiency demand failure
  - Apparent undervaluation of EE investments
Basic Model

• Partial equilibrium model of electricity supply and demand with representative sectors
  – Upward-sloping supply curves
• Mature technologies
  – Coal
  – Natural gas (conventional and combined cycle)
  – Nuclear (fixed in 1st stage)
  – Hydro (baseload)
• Innovating technologies
  – Conventional renewable (“wind”)
  – Advanced renewable (“solar”)
Two Stages

• Stage 1 (2015-2020)
  – Production
  – R&D and learning-by-doing for renewables
  – Short- and long-run EE improvements

• Stage 2 (2020-2035)
  – Production
  – Cost-reducing knowledge application for renewables
  – Short-run EE improvement
  – With discounting, 2nd stage ~ 10 years
Knowledge Accumulation

• Stock of knowledge lowers renewable costs

• A function of:
  – Cumulative R&D, requiring investment costs
  – Cumulative production (LBD)
  – Differs by technology

• Benefits are appropriated according to factor $\rho$
  – Spillovers present when $\rho < 1$
Electricity Demand

- A function of
  - Price
  - Rate of electricity consumption per unit of energy services, which is a function of
    - Short-run EE improvements
    - Long-run EE improvements
  - Very short-run elasticity
- Valuation rate for EE improvements, $\beta_j \leq 1$
- Increasing investment costs
Optimal Policy is a Combination

1. Carbon price
   - rising according to the discount factor

2. Subsidies for LBD in the first stage
   - to correct for learning spillovers for each technology

3. R&D subsidy
   - equal to the R&D spillover rate

4. Subsidy to EE investments
   - to offset the unvalued share of EE benefits, both in the short and long term
Numerical Application to U.S. Electricity Sector

- Simulations based on analytical model
- Linear supply curves
- Parameters and baseline values calibrated to EIA 2011 AEO
- Knowledge functions calibrated to literature on R&D and learning curves
- Targeted demand elasticities to very short, short, and long-run estimates from literature
Supply Curves in Baseline Scenario

- Coal 1
- Coal 2
- NGCC 1
- NGCC 2
- NG non-CC 1
- NG non-CC 2
- Wind 1
- Wind 2
- Solar 1
- Solar 2
- Nuc 1
- Nuc 2
Baseline Generation

kWh/year

Stage 1

Stage 2

Hydro
Solar
Wind
Nuclear
NGCC
NG
Coal
## No-Policy Baseline

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price of electricity ($P_t$) (¢/kWh)</td>
<td>8.8</td>
<td>9.0</td>
</tr>
<tr>
<td>Electricity demand ($D_t$) (kWh/yr)</td>
<td>$4.33 \times 10^{12}$</td>
<td>$4.81 \times 10^{12}$</td>
</tr>
<tr>
<td>Coal generation ($q_t^X$) (kWh/yr)</td>
<td>$1.83 \times 10^{12}$</td>
<td>$2.09 \times 10^{12}$</td>
</tr>
<tr>
<td>Natural gas generation from boilers and turbines ($q_t^{ng}$) (kWh/yr)</td>
<td>$3.34 \times 10^{11}$</td>
<td>$3.87 \times 10^{11}$</td>
</tr>
<tr>
<td>Combined cycle natural gas generation ($q_t^{cc}$) (kWh/yr)</td>
<td>$7.15 \times 10^{11}$</td>
<td>$7.53 \times 10^{11}$</td>
</tr>
<tr>
<td>Nuclear generation ($q_t^{nu}$) (kWh/yr)</td>
<td>$8.53 \times 10^{11}$</td>
<td>$8.77 \times 10^{11}$</td>
</tr>
<tr>
<td>Wind generation ($q_t^{w}$) (kWh/yr)</td>
<td>$2.57 \times 10^{11}$</td>
<td>$3.52 \times 10^{11}$</td>
</tr>
<tr>
<td>Solar generation ($q_t^{s}$) (kWh/yr)</td>
<td>$1.66 \times 10^{10}$</td>
<td>$1.89 \times 10^{10}$</td>
</tr>
<tr>
<td>Hydro generation ($q_t^{h2o}$) (kWh/yr)</td>
<td>$3.19 \times 10^{11}$</td>
<td>$3.26 \times 10^{11}$</td>
</tr>
<tr>
<td>Wind share of generation (%)</td>
<td>5.95</td>
<td>7.32</td>
</tr>
<tr>
<td>Solar share of generation (%)</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>CO$_2$ emissions ($E_t$) (billion metric tons CO$_2$/year)</td>
<td>2.29</td>
<td>2.59</td>
</tr>
<tr>
<td>Rate of wind cost reduction (%)</td>
<td>9%</td>
<td>—</td>
</tr>
<tr>
<td>Rate of solar cost reduction (%)</td>
<td>30%</td>
<td>—</td>
</tr>
<tr>
<td>Policy</td>
<td>Emissions price</td>
<td>Optimal policy combination</td>
</tr>
<tr>
<td>--------------------------------------------</td>
<td>----------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td></td>
<td>No EE failures</td>
<td>10% EE undervaluation</td>
</tr>
<tr>
<td></td>
<td>$\beta = 1$</td>
<td>$\beta = 0.9$</td>
</tr>
<tr>
<td>Emissions reduction target</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>Emissions price, 1 (t1) ($/ton CO$_2$)</td>
<td>11.2</td>
<td>10.3</td>
</tr>
<tr>
<td>Emissions price, 2 (t2) ($/ton CO$_2$)</td>
<td>24.8</td>
<td>22.8</td>
</tr>
<tr>
<td>Learning subsidy (wind) 1 (¢/kWh)</td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td>Learning subsidy (solar) 1 (¢/kWh)</td>
<td></td>
<td>0.63</td>
</tr>
<tr>
<td>R&amp;D subsidy (wind)</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>R&amp;D subsidy (solar)</td>
<td></td>
<td>50%</td>
</tr>
<tr>
<td>EE subsidy 1 ($b_{SL_1}, b_{L_1}$)</td>
<td>0%</td>
<td>10%</td>
</tr>
<tr>
<td>EE subsidy 2 ($b_{SL_2}, b_{L_1}$)</td>
<td>0%</td>
<td>10%</td>
</tr>
<tr>
<td>Price 1 (% change from baseline)</td>
<td>8.3%</td>
<td>7.4%</td>
</tr>
<tr>
<td>Price 2 (% change from baseline)</td>
<td>16.7%</td>
<td>14.8%</td>
</tr>
<tr>
<td>% Renewables 1</td>
<td>8.0%</td>
<td>8.4%</td>
</tr>
<tr>
<td>% Renewables 2</td>
<td>11.6%</td>
<td>12.8%</td>
</tr>
<tr>
<td>% EE red 1</td>
<td>2.3%</td>
<td>2.1%</td>
</tr>
<tr>
<td>% EE red 2</td>
<td>5.7%</td>
<td>5.1%</td>
</tr>
<tr>
<td>$\Delta$ Welfare</td>
<td>-4.37</td>
<td>-2.47</td>
</tr>
<tr>
<td>$\Delta W$ (relative to emissions price alone)</td>
<td></td>
<td>-12%</td>
</tr>
</tbody>
</table>
### Single Policy Levels to Achieve 20% Reduction

<table>
<thead>
<tr>
<th>Stage</th>
<th>Emissions Price ($/ton CO₂)</th>
<th>Emissions Performance Standard (ton CO₂/GWh)</th>
<th>Fossil Fuel Tax (¢/kWh)</th>
<th>Clean Energy Standard (%)</th>
<th>Renewable Portfolio Standard (%)</th>
<th>Renewable Production Tax Credit (¢/kWh)</th>
<th>EE Subsidy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>11.2</td>
<td>485</td>
<td>1.40</td>
<td>46.8</td>
<td>11.2</td>
<td>4.08</td>
<td>30% short run</td>
</tr>
<tr>
<td>Stage 2</td>
<td>24.8</td>
<td>430</td>
<td>3.10</td>
<td>52.4</td>
<td>21.6</td>
<td>9.05</td>
<td>30% long run</td>
</tr>
</tbody>
</table>

Like emission price + generation subsidy

Like subsidy to qualifying sources + generation tax
Welfare Effects of Single Policies Relative to Emissions Price Alone
Second-Best Combination Policies: RPS

- RPS that maximizes welfare with an emissions cap is only 0.4 – 0.5% above reference scenario
  - Learning externality relatively small
- Exacerbates EE undervaluation, since modest RPS lowers electricity prices
  - With 10% undervaluation, no RPS improves cost-effectiveness
Second-Best Combination Policies: EE Standards

• With no undervaluation, welfare decreasing
  – Also because it lowers electricity prices, exacerbating the knowledge market failure

• With 10% undervaluation, second-best EE standards close to the optimal improvements
  – But the required subsidies are lower, due to the absence of the renewable energy technology policies, which would otherwise keep electricity prices lower.
More Ambitious Combinations

- EU 20/20/20 policy
  - 20% emissions reduction
  - 20% RPS
  - 20% improvement in EE
Sensitivity of Cost of Cap versus 20/20/20 Targets to EE Undervaluation

-25
-20
-15
-10
-5
0
5
10

Welfare Costs ($billion)

Percentage Undervaluation

Cap Alone
20/20/20
Cap+EE Std
Sensitivity of Cost of Cap versus 20/20/20 Targets to Knowledge Spillovers
Variations

- Optimal R&D policy cuts costs in half
- Double credits for solar lowers costs somewhat but not substantially.
- More stringent emissions target increases optimal renewable subsidies but still small
Conclusions

- Some technology policies can complement emissions pricing for reducing GHGs when additional market failures are present.
- However, these justifiable policies are likely to be much more modest than the suite of renewable energy policies being proposed.
  - Even with high rates of knowledge spillovers from learning by doing, ambitious RPSs seem unlikely to be welfare enhancing.
  - Correcting R&D market failures has greater potential for reducing costs.
Conclusions (2)

- The desirability of stringent EE policies very sensitive to the degree of undervaluation.
  - Priority for empirical work
- Even with more refined representations of electricity markets & failures, emissions pricing still the single most cost-effective option
- Technology policies are very poor substitutes, and when they overreach, they can be poor complements too.
Thanks!

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About RFF

- Independent, nonpartisan, nonprofit research institute in Washington, DC
- Founded in 1952
- Our mission: To improve environmental and natural resource policymaking worldwide through objective social science research of the highest caliber.