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

Carolyn Fischer, *Resources for the Future*
Richard Newell, *Duke University & RFF*
Louis Preonas, *UC-Berkeley & RFF*

June, 2012

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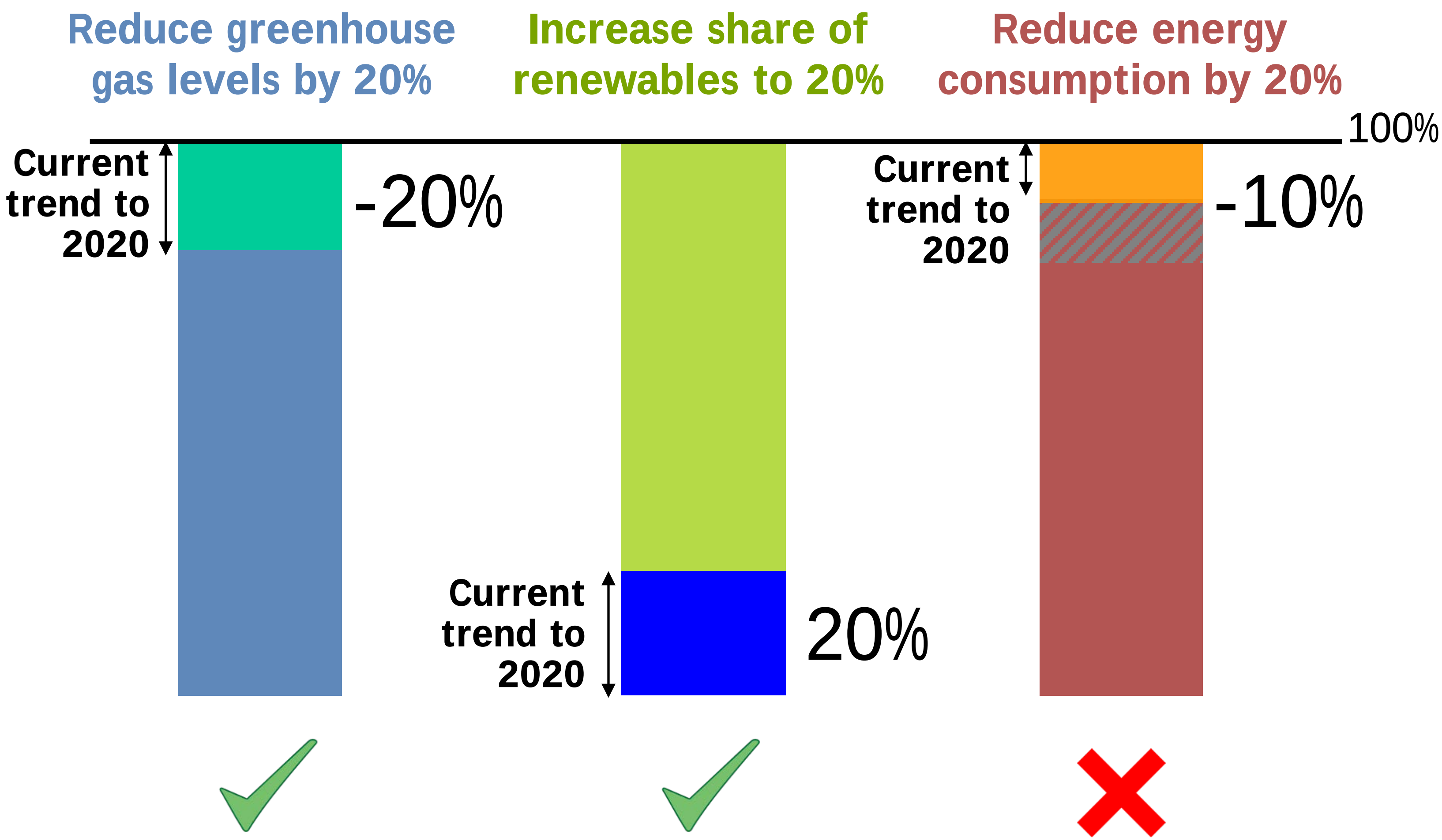
Policy background

- 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



Source: European Commissions DG Energy
22 June 2011

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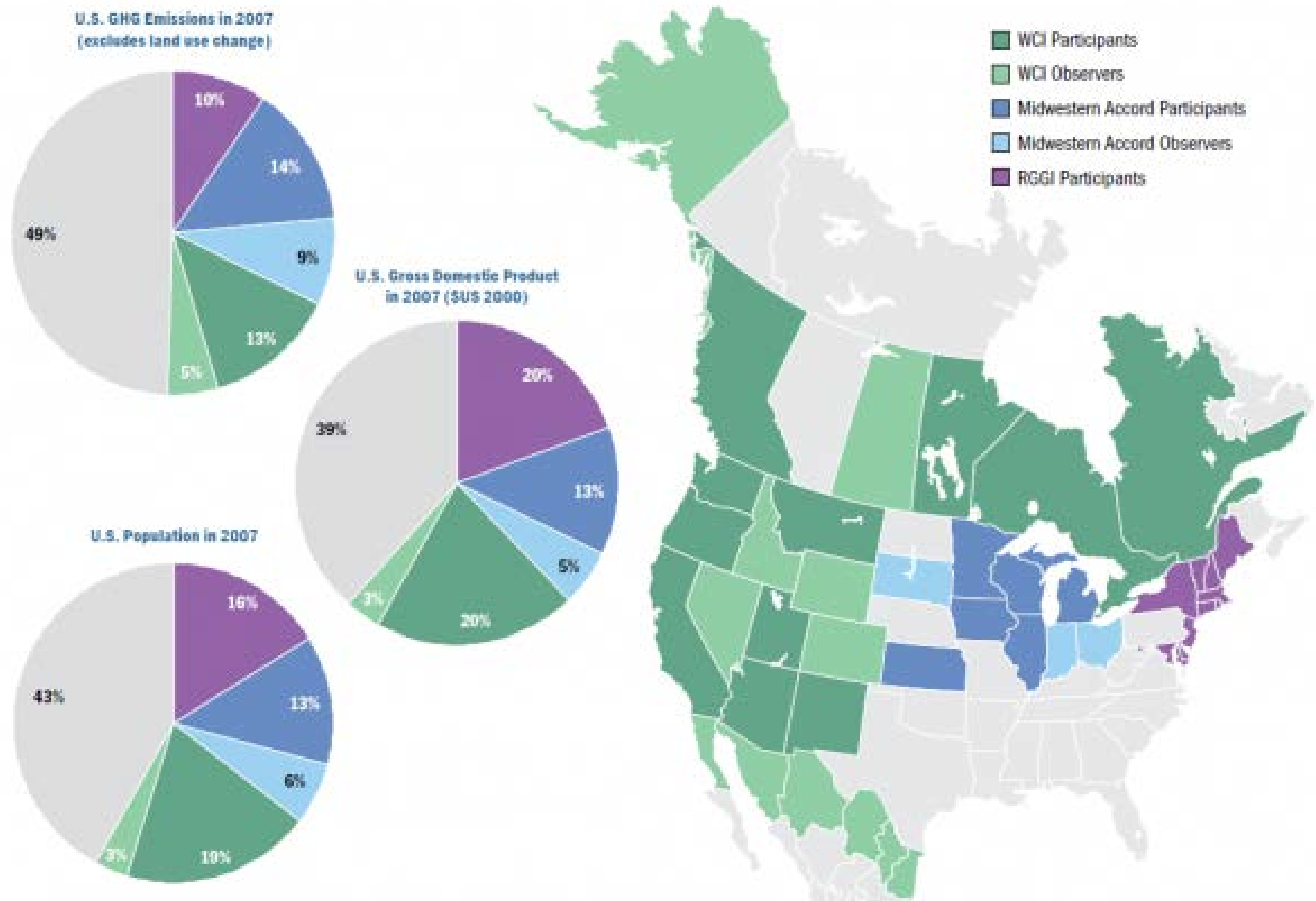
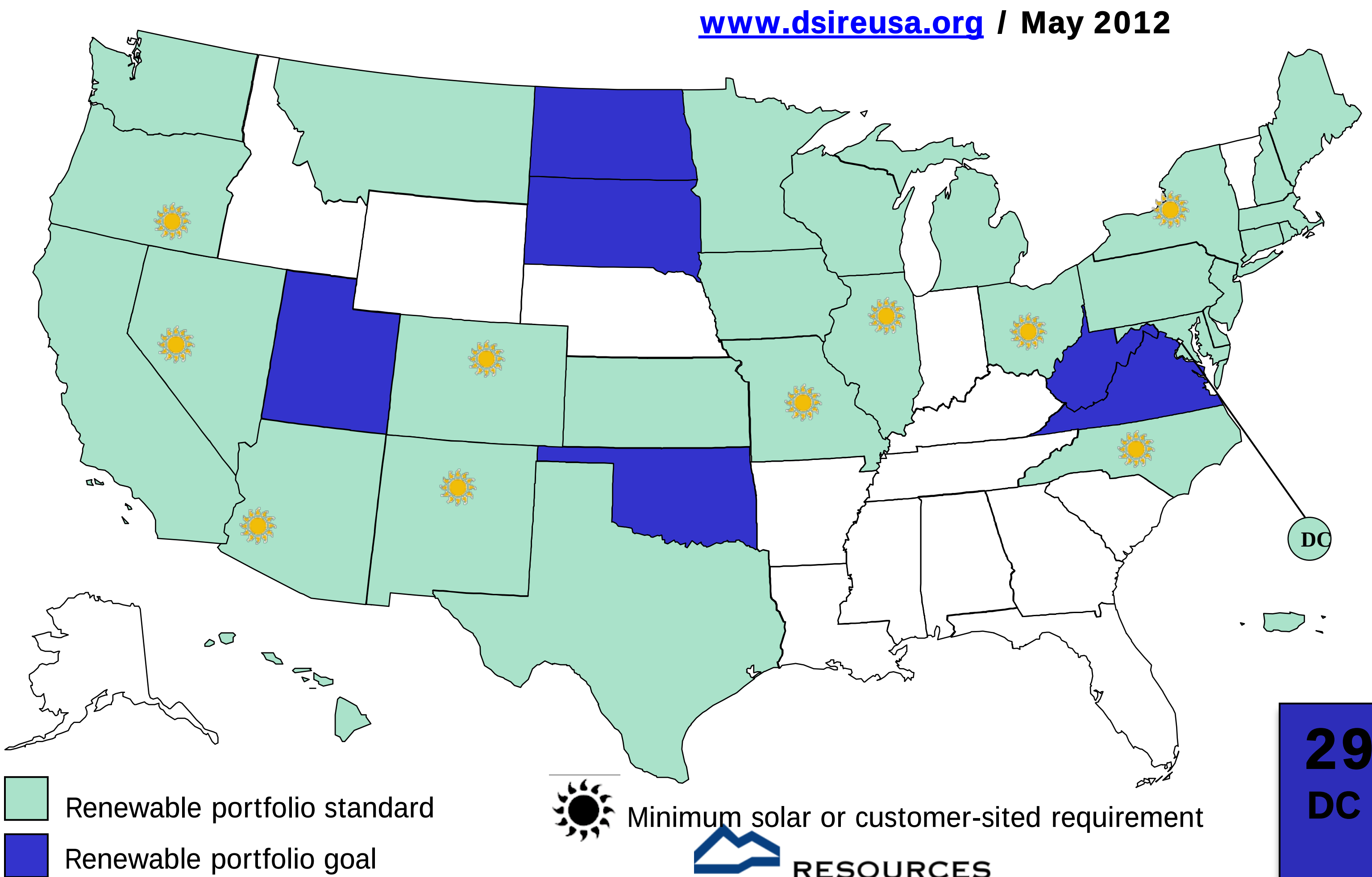
Figure 3 | Regional Cap-and-Trade Programs



Climate Analysis Indicators Tool (CAIT US) Version 4.0. (Washington, DC: World Resources Institute, 2011).

State RPS Programs



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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

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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, 2^{nd} 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 ρ
  - Spillovers present when $\rho < 1$

Electricity Demand

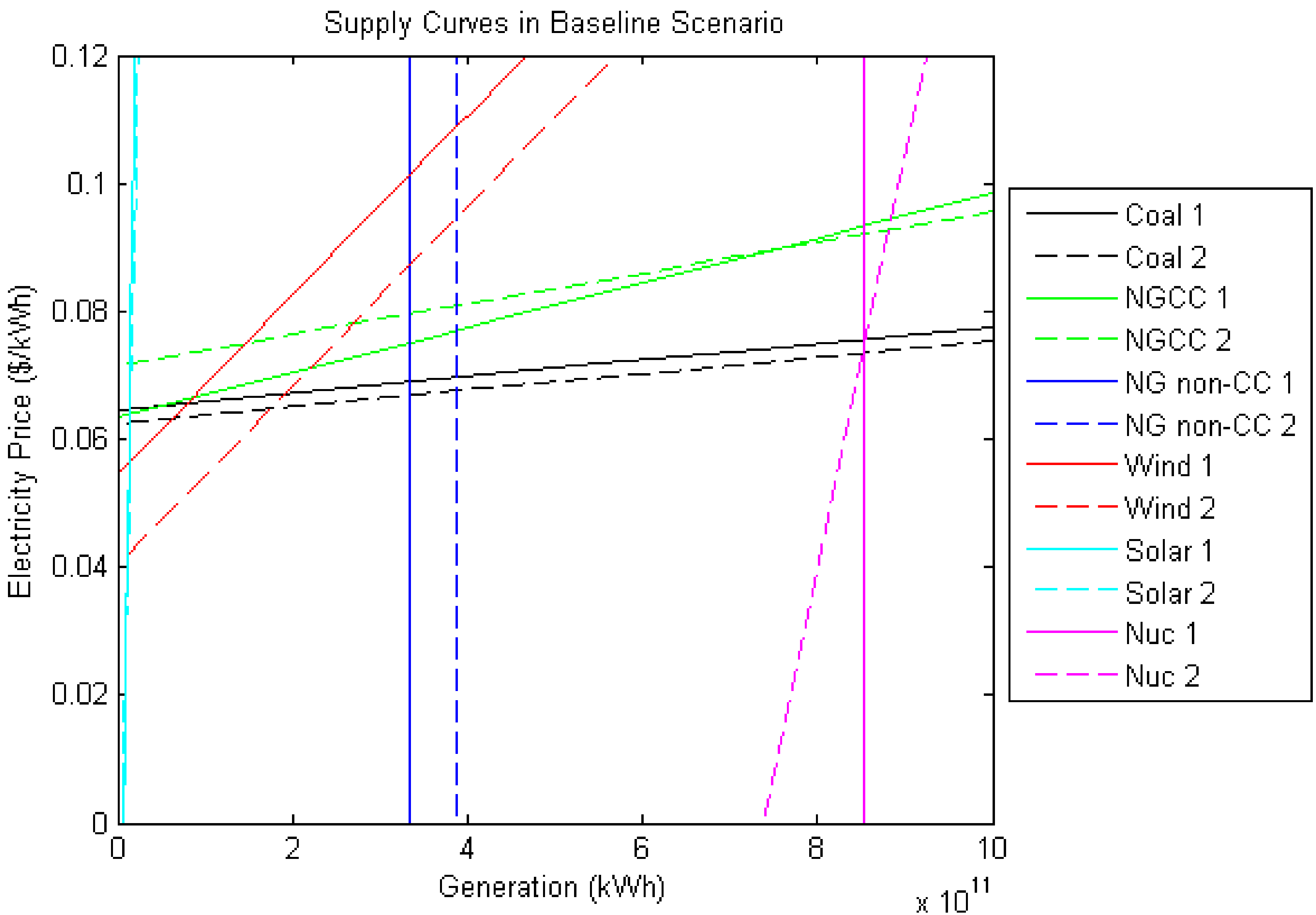
- A function of
  - Price
  - Rate of electricity consumption per unit of energy services, which is a function of
    - Short-run EE improvements
    - Long-run EE improvements
  - Very short-run elasticity
- Valuation rate for EE improvements, $\beta_j \leq 1$
- Increasing investment costs

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



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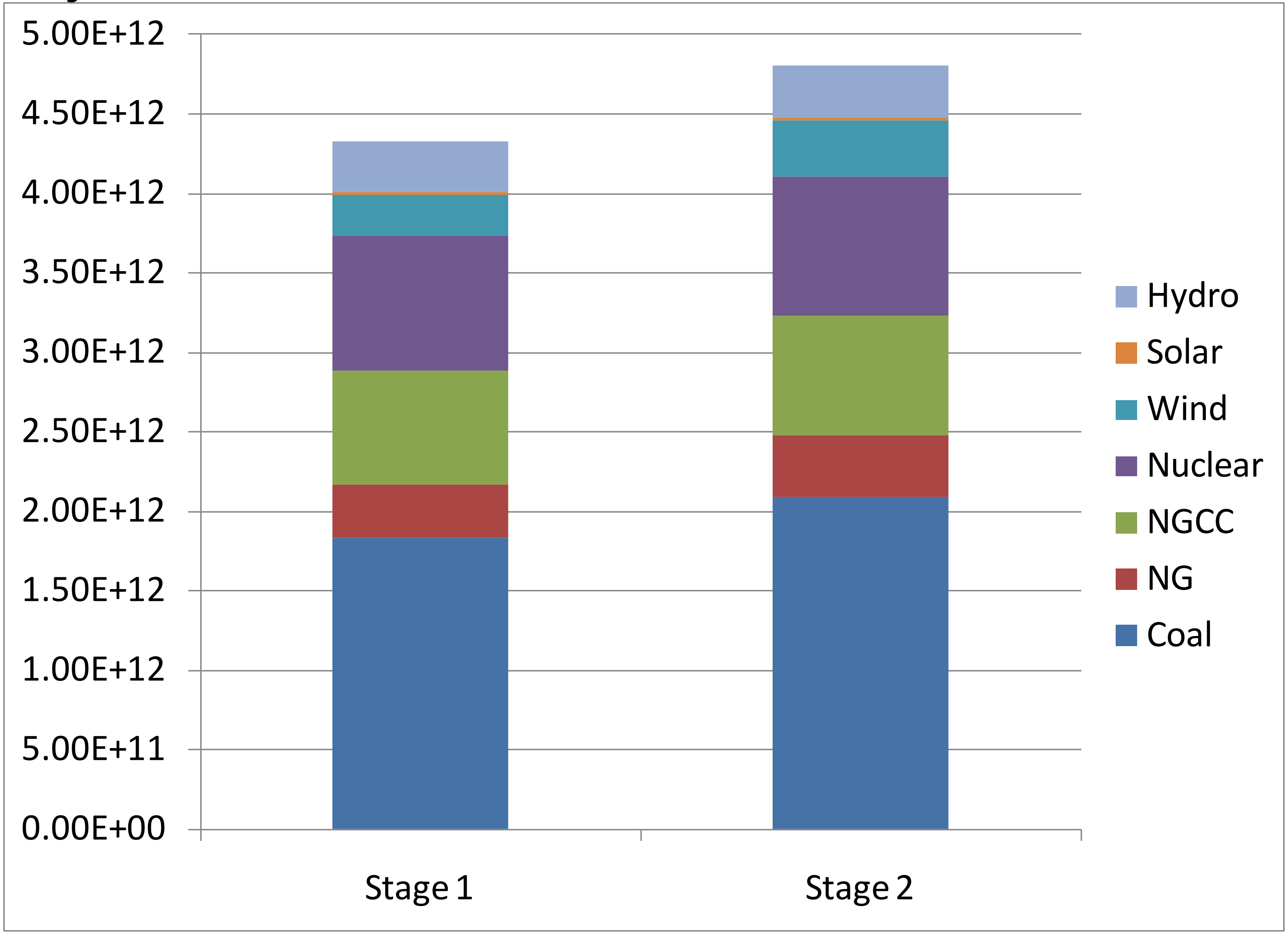
Baseline Generation

kWh/year



No-Policy Baseline

	Stage 1	Stage 2
Price of electricity (P_t) (¢/kWh)	8.8	9.0
Electricity demand (D_t) (kWh/yr)	4.33×10^{12}	4.81×10^{12}
Coal generation (q_t^x) (kWh/yr)	1.83×10^{12}	2.09×10^{12}
Natural gas generation from boilers and turbines (q_t^{ng}) (kWh/yr)	3.34×10^{11}	3.87×10^{11}
Combined cycle natural gas generation (q_t^{cc}) (kWh/yr)	7.15×10^{11}	7.53×10^{11}
Nuclear generation (q_t^{nu}) (kWh/yr)	8.53×10^{11}	8.77×10^{11}
Wind generation (q_t^w) (kWh/yr)	2.57×10^{11}	3.52×10^{11}
Solar generation (q_t^s) (kWh/yr)	1.66×10^{10}	1.89×10^{10}
Hydro generation (q_t^{h20}) (kWh/yr)	3.19×10^{11}	3.26×10^{11}
Wind share of generation (%)	5.95	7.32
Solar share of generation (%)	0.38	0.39
CO_2 emissions (E_t) (billion metric tons CO_2/year)	2.29	2.59
Rate of wind cost reduction (%)	9%	—
Rate of solar cost reduction (%)	30%	—

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<table>
<tr><th>Policy</th><th colspan="2">Emissions price</th><th colspan="2">Optimal policy combination</th></tr>
<tr><th></th><th>No EE failures $\beta = 1$</th><th>10% EE undervaluation $\beta = 0.9$</th><th>No EE failures $\beta = 1$</th><th>10% EE undervaluation $\beta = 0.9$</th></tr>
<tr><td>Emissions reduction target</td><td colspan="2">20%</td><td>20%</td><td>20%</td></tr>
<tr><td>Emissions price, 1 (t1) ($/ton CO_2)</td><td colspan="2">11.2</td><td>10.3</td><td>8.0</td></tr>
<tr><td>Emissions price, 2 (t2) ($/ton CO_2)</td><td colspan="2">24.8</td><td>22.8</td><td>17.8</td></tr>
<tr><td>Learning subsidy (wind) 1 (¢/kWh)</td><td colspan="2"></td><td>.33</td><td>0.30</td></tr>
<tr><td>Learning subsidy (solar) 1 (¢/kWh)</td><td colspan="2"></td><td>0.63</td><td>0.57</td></tr>
<tr><td>R&D subsidy (wind)</td><td colspan="2"></td><td>50%</td><td>50%</td></tr>
<tr><td>R&D subsidy (solar)</td><td colspan="2"></td><td>50%</td><td>50%</td></tr>
<tr><td>EE subsidy 1 (b_{S1}, b_{L1})</td><td colspan="2"></td><td>0%</td><td>10%</td></tr>
<tr><td>EE subsidy 2 (b_{S2}, b_{L1})</td><td colspan="2"></td><td>0%</td><td>10%</td></tr>
<tr><td>Price 1 (% change from baseline)</td><td colspan="2">8.3%</td><td>7.4%</td><td>4.9%</td></tr>
<tr><td>Price 2 (% change from baseline)</td><td colspan="2">16.7%</td><td>14.8%</td><td>9.9%</td></tr>
<tr><td>% Renewables 1</td><td colspan="2">8.0%</td><td>8.4%</td><td>8.0%</td></tr>
<tr><td>% Renewables 2</td><td colspan="2">11.6%</td><td>12.8%</td><td>12.0%</td></tr>
<tr><td>% EE red 1</td><td colspan="2">2.3%</td><td>2.1%</td><td>3.9%</td></tr>
<tr><td>% EE red 2</td><td colspan="2">5.7%</td><td>5.1%</td><td>8.3%</td></tr>
<tr><td>Δ Welfare</td><td>-4.37</td><td>-2.47</td><td>-3.84</td><td>-1.57</td></tr>
<tr><td>Δ W (relative to emissions price alone)</td><td colspan="2">—</td><td>-12%</td><td>-36%</td></tr>
</table>

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Single Policy Levels
to Achieve 20% Reduction

	Emissions Price ($/ton CO_2)	Emissions Performance Standard (ton CO_2/GWh)	Fossil Fuel Tax (¢/kWh)	Clean Energy Standard (%)	Renewable Portfolio Standard (%)	Renewable Production Tax Credit (¢/kWh)	EE Subsidy (%)
Stage1	11.2	485	1.40	46.8	11.2	4.08	30% short run 48% long run
Stage2	24.8	430	3.10	52.4	21.6	9.05	30%

Like
emission price
+ generation
subsidy

Like
subsidy to
qualifying sources
+ generation tax

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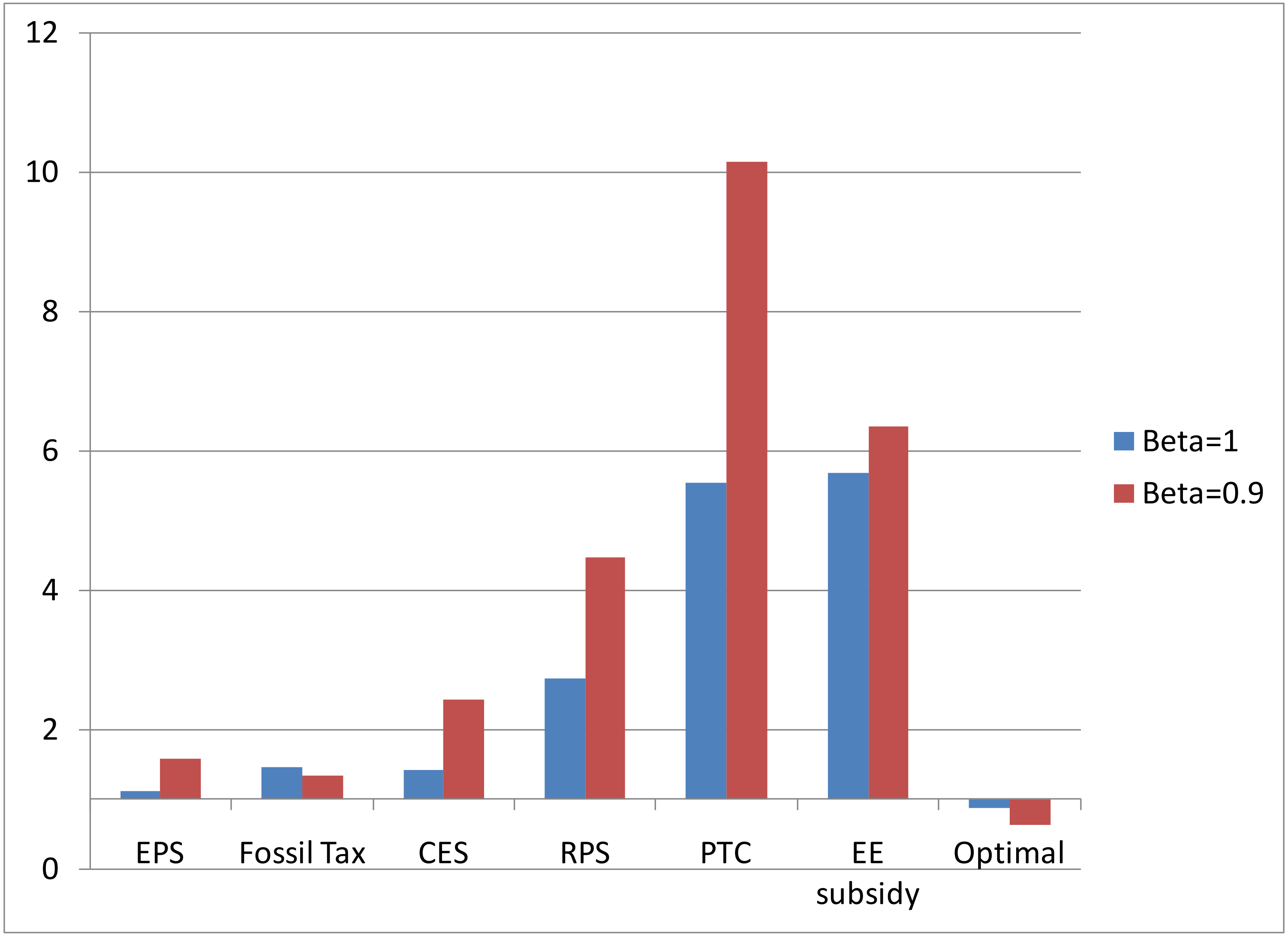
Welfare Effects of Single Policies Relative to Emissions Price Alone



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

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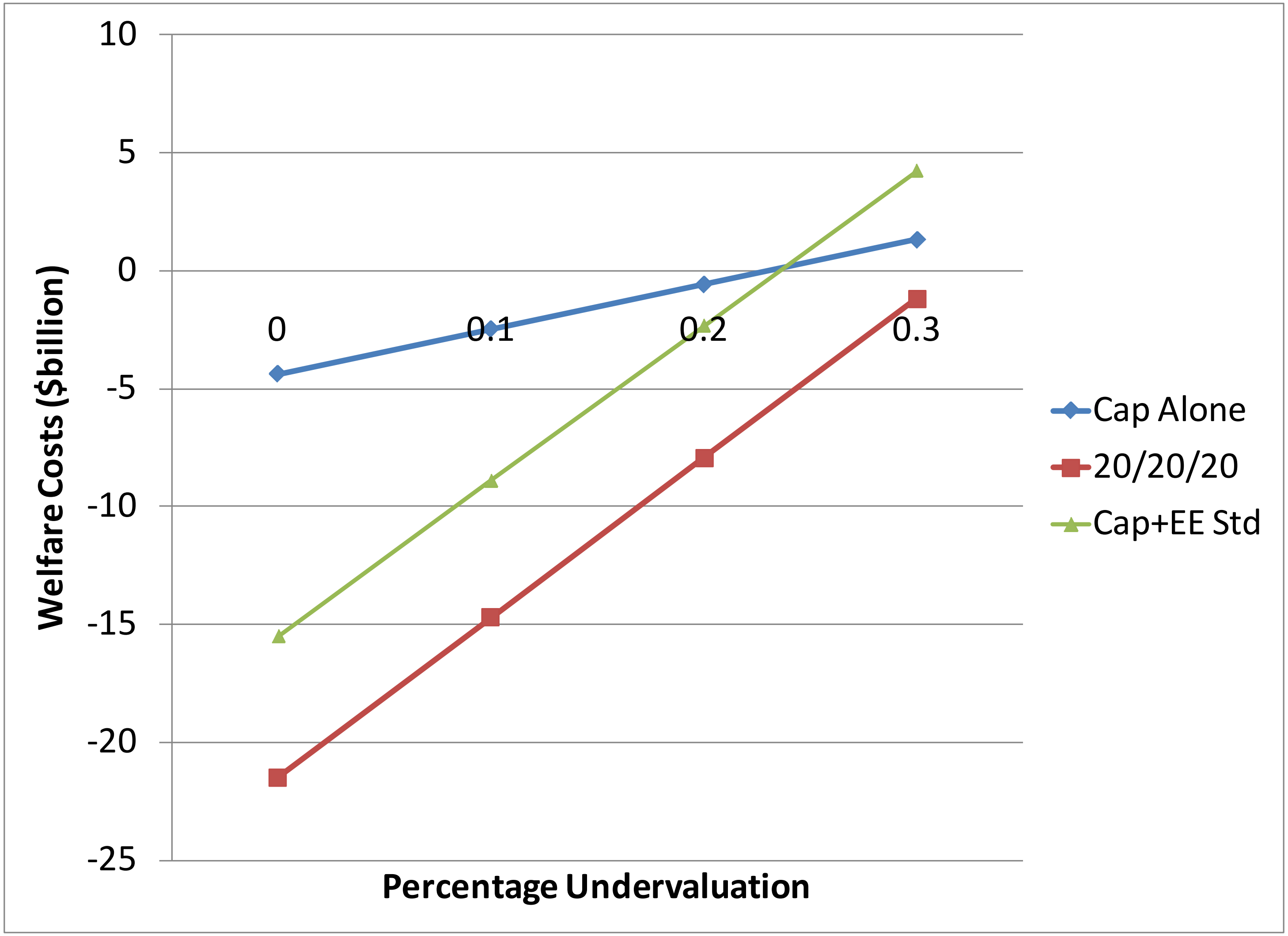
Sensitivity of Cost of Cap versus 20/20/20 Targets to EE Undervaluation



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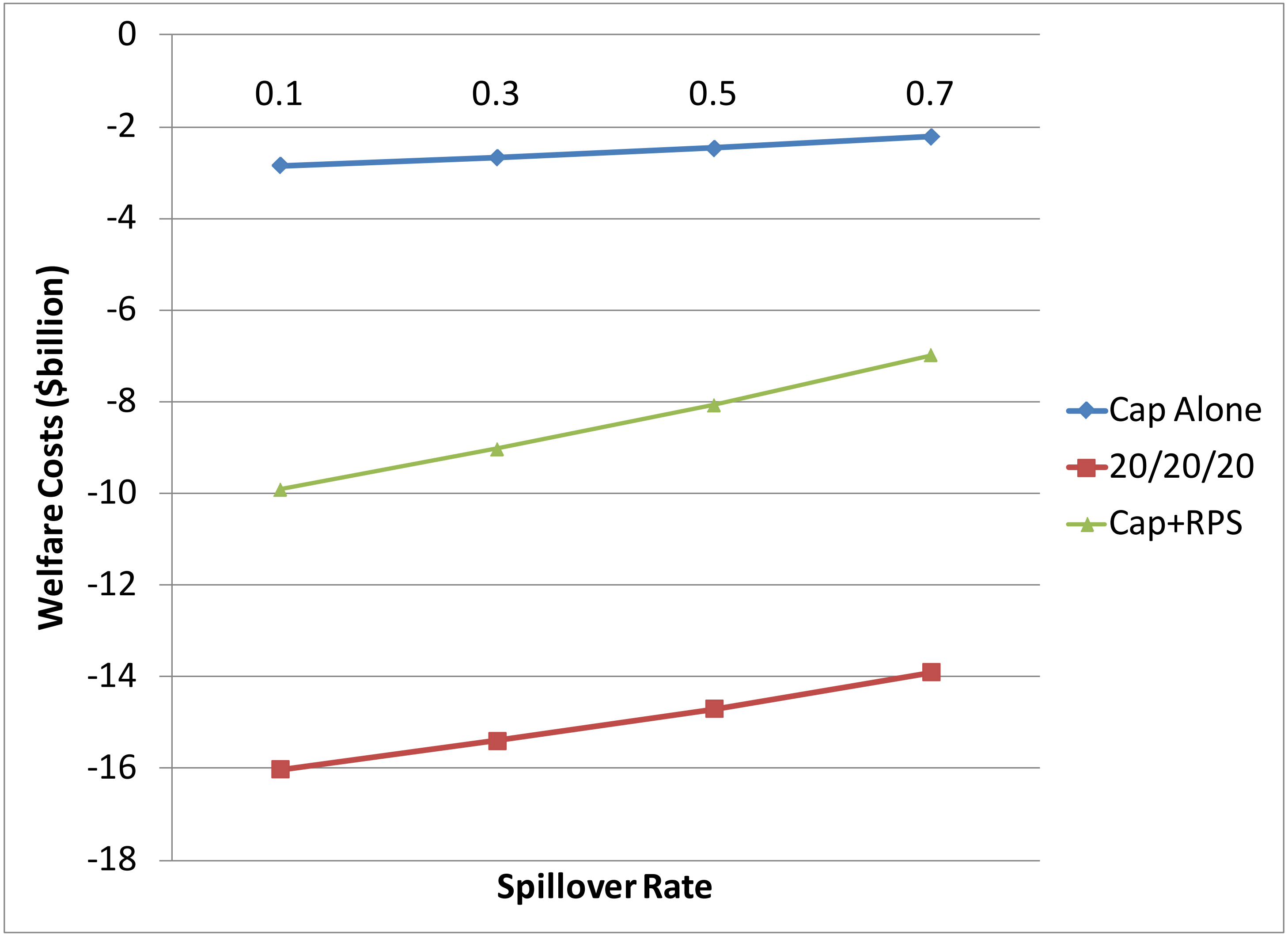
Sensitivity of Cost of Cap versus 20/20/20 Targets to Knowledge Spillovers



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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!

- Funding from US EPA-STAR and the Mistra Foundation Indigo program is gratefully acknowledged.

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  To improve environmental and natural resource policymaking worldwide through objective social science research of the highest caliber.

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