Leakage in Regional Cap-and-Trade Markets for CO2

James Bushnell and Yishu Chen

Iowa State University and UC Merced

May, 2010
Outline

- Introduction: CO2 regulation and Cap and Trade
- Allocation of Emissions Credits
- Model of Western Climate Initiative
- Results
Emissions of CO2 from US Power Plants

Electric Generating Sector GHG Footprint

The Western Climate Initiative

- Seven US states and 3 CA provinces
- Goal of reducing to 15% below 2005 levels by 2020
- Initial phase covers large stationary sources only
  - Dominated by electricity production
- Second phase to expand to include other sources, including transportation fuels
Goals of this Paper

- Examine the western electricity market under carbon regulation
- Measure potential leakage under various geographic caps
- Gain rough insight into potential permit costs
- Assess the impacts of allocation policies
  - On leakage
  - On product prices
  - On permit prices
- General Approach
  - Use detailed unit-level and market data to reproduce target year (2007)
  - Generate counter-factual market outcomes under various C&T scenarios
Allocation and Policy Goals

- Allocation is one of the most disputed elements cap-and-trade markets
- It is awarding (potentially) valuable property rights
- Distinctive approaches
  - Exogenous
    - Allocations are completely set before C&T market starts
    - Grandfathering, Auctioning
  - Endogenous or *Updated* allocations
    - Allocations are changed (updated) in response to market outcomes
    - Output-based, input-based, fuel-based, benchmarking
Permit Allocation

- **Output-based** updating allocates permits according to *current* rather than historical output of products (e.g. electricity).
  - Plays a prominent role in both WCI and HR 2454 (Waxman-Markey) proposals
- It is attractive to policy-makers for several reasons
  - Can minimize pass-through of carbon costs in product prices (Burtraw, et al., 2001)
    - Can therefore lead to inefficient over-consumption of products
    - Can also lead to inefficient allocation of production as cleaner sources get a larger proportional subsidy
- **Can mitigate leakage**
Fuel-based Updating

- Fuel-based (or benchmarked) updating scales allocations proportionately to emissions rates
  - For example coal-fired output would receive 2x more permits than gas-fired output
  - This is because coal generation is roughly twice as carbon intensive
- Fuel-based updating and its equivalents appeals because it better matches allocations to emissions and therefore to the cost burdens of regulations
  - Apparently combines attractive features of both grandfathering and output-based
  - This view overlooks the endogeneity of permit prices
  - Allocating proportional to emissions can inflate permit prices (Bohringer & Lange (2005))
    - In “closed” market, can reverse most effects of updating
An Example

- 2 Technologies, Coal and Gas
  - Coal - MC of $25/MWh and emissions rate of 1 ton/MWh
  - Gas - MC of $50/MWh and emissions rate of 1/2 ton/MWh
  - Inelastic demand of 10 MW
  - Perfectly competitive price would be $25/MWh with 10 tons of CO2
- To reduce emissions by 1 ton, must substitute 2 MWh of gas for coal
**Example: Exogenous Allocation**

\[ p_{\text{elec.}} = MC_{\text{coal}} + p_{\text{carbon}} \times e_{\text{coal}} \]
\[ = MC_{\text{gas}} + p_{\text{carbon}} \times e_{\text{gas}} \]

\[ 25 + p_{\text{carbon}} \times 1 = 75 \]
\[ 50 + p_{\text{carbon}} \times .5 = 75 \]

\[ p_{\text{carbon}} = \frac{50 - 25}{1 - .5} = 50 \]

\[ p_{\text{elec.}} = 25 + 50 \times 1 = 75 \]
Example: Fuel-based Allocation

- Now allocate half of all permits via fuel-based allocation
- Coal gets twice as many permits *per MWh* as gas
- Must raise costs of coal generation sufficiently to at least equal cost of gas
  - Or else there is no carbon reduction
Result with Fuel-based (benchmarked) Allocation

\[ p_{elec.} = MC_{coal} + p_{carbon} \times (e_{coal} - allocation_{coal}) \]
\[ = MC_{coal} + p_{carbon} \times \frac{1}{2}(e_{coal}) \]
\[ p_{elec.} = MC_{gas} + p_{carbon} \times (e_{gas} - allocation_{gas}) \]
\[ = MC_{gas} + p_{carbon} \times \frac{1}{2}(e_{gas}) \]

\[ p_{carbon} = \frac{50 - 25}{0.5 - 0.25} = 100 \]

\[ p_{elec} = 25 + (1 - 0.5) \times 100 = 75 \]
• (partial) Equilibrium Model
• Calculate 8760 hourly equilibrium (dispatch) solutions
• Focus is on short-run - abatement is through fuel-switching
• Perfect competition (in product and permits)
• Model a source-based C&T system (no taxing of imports)
• Utilize EPA and EIA data on costs, production, and transmission
• Simultaneously solve for
  • Firm level problem (MC = price by location)
  • Transmission Flows (arbitrage conditions)
  • Environmental constraint (emissions ≤ cap)
The Model: Firm Level Problem

- Each firm sets output to equalize marginal costs of its generation with the local market price
  - Alternative implementation (market power) equalizes marginal revenues to marginal cost
- MC includes emissions costs for capped locations
  - output × emission rate × price of permits
  - emissions costs may be adjusted by allocation policy
- Marginal cost for a given generation technology includes a shadow price on capacity constraint for that technology.
Transmission and Emissions

- Transmission market clearing conditions
  - Locational prices differ only by “cost” of transport
  - Cost of transport defined by shadow value on transmission capacity
  - Electric trades mapped to flows via a simple DC load flow model

- Emissions market clearing conditions
  - Total emissions must be $\leq$ the cap
  - Permit price is shadow value on cap constraint
Aggregated Western Grid

WECC Topology
Aggregated Western Grid
Stylized Network Flows
Market Clearing: Graphical Example
Market Clearing in Market Model

Model Formulation

Bushnell and Chen (ISU and UCM)
Leakage in Regional Markets
May, 2010
Adjusting Costs for Carbon Permit Costs
Carbon Costs Reorients Supply Curve

- Residual Demand
- MC with CO2 permits
- MC_sim
- p_sim
- p_actual
- q_imports
- q_cems
- q Others
- q_sim
- q_tot

Bushnell and Chen (ISU and UCM)
Market Clearing with Carbon Costs

Model Formulation
Computation of Solution

- Solve Firm, Grid, and Emissions market equilibrium conditions
  - linear marginal cost and emissions rates by firm, location, technology
  - Capacity constraints on generation transmission and emissions (the cap)
  - Dual values associated with capacity constraints
- Forms a Linear Complementarity Problem
  - Implemented in AMPL, solved with PATH algorithm
  - With larger problem size, iterative solution for permit price
A Guide to the Results

- Geographic scope of cap
  - Assuming a 15% reduction from 2007 levels
  - No cap, Cal only, WCI cap, all WECC

- Allocation policies for WCI cap
  - Exogenous allocation (auctioning or grandfathering)
  - Output-based allocation - 80% of permits allocated
  - Fuel-based allocation -
    - 80% of permits allocated
    - Allocation rate twice as high (per MWh) for coal as gas
### Table: Regulatory Scope: Emissions by Region (mmTons)

<table>
<thead>
<tr>
<th>Regulation</th>
<th>CA</th>
<th>NWPP</th>
<th>SW</th>
<th>non-WCI</th>
<th>Total</th>
<th>Carbon Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cap</td>
<td>34.4</td>
<td>84.4</td>
<td>59.0</td>
<td>140.2</td>
<td>318.0</td>
<td>NA</td>
</tr>
<tr>
<td>Cal only</td>
<td>28.4</td>
<td>85.5</td>
<td>61.6</td>
<td>142.0</td>
<td>317.4</td>
<td>11</td>
</tr>
<tr>
<td>WCI cap</td>
<td>30.9</td>
<td>72.0</td>
<td>48.2</td>
<td>148.8</td>
<td>299.9</td>
<td>39.15</td>
</tr>
<tr>
<td>WCI updating</td>
<td>38.4</td>
<td>65.5</td>
<td>47.2</td>
<td>141.9</td>
<td>293.0</td>
<td>51.55</td>
</tr>
<tr>
<td>Fuel-based</td>
<td>33.8</td>
<td>67.1</td>
<td>50.2</td>
<td>145.7</td>
<td>296.8</td>
<td>89.85</td>
</tr>
</tbody>
</table>

Bushnell and Chen (ISU and UCM)
Table: Effect of Updating: Emissions by Region (mmTons)

<table>
<thead>
<tr>
<th>Regulation</th>
<th>CA</th>
<th>NWPP</th>
<th>SW</th>
<th>non-WCI</th>
<th>Total</th>
<th>Carbon Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cap</td>
<td>34.4</td>
<td>84.4</td>
<td>59.0</td>
<td>140.2</td>
<td>318.0</td>
<td>NA</td>
</tr>
<tr>
<td>Cal only</td>
<td>28.4</td>
<td>85.5</td>
<td>61.6</td>
<td>142.0</td>
<td>317.4</td>
<td>11</td>
</tr>
<tr>
<td>WCI cap</td>
<td>30.9</td>
<td>72.0</td>
<td>48.2</td>
<td>148.8</td>
<td>299.9</td>
<td>39.15</td>
</tr>
<tr>
<td>WCI updating</td>
<td>38.4</td>
<td>65.5</td>
<td>47.2</td>
<td>141.9</td>
<td>293.0</td>
<td>51.55</td>
</tr>
<tr>
<td>Fuel-based</td>
<td>33.8</td>
<td>67.1</td>
<td>50.2</td>
<td>145.7</td>
<td>296.8</td>
<td>89.85</td>
</tr>
</tbody>
</table>
### Table: Effect of Output-Based Updating: Emissions by Region (mmTons)

<table>
<thead>
<tr>
<th>Regulation</th>
<th>CA</th>
<th>NWPP</th>
<th>SW</th>
<th>non-WCI</th>
<th>Total</th>
<th>Carbon Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cap</td>
<td>34.4</td>
<td>84.4</td>
<td>59.0</td>
<td>140.2</td>
<td>318.0</td>
<td>NA</td>
</tr>
<tr>
<td>WCI cap</td>
<td>30.9</td>
<td>72.0</td>
<td>48.2</td>
<td>148.8</td>
<td>299.9</td>
<td>39.15</td>
</tr>
<tr>
<td>WCI updating</td>
<td>38.4</td>
<td>65.5</td>
<td>47.2</td>
<td>141.9</td>
<td>293.0</td>
<td>51.55</td>
</tr>
<tr>
<td>Fuel-based</td>
<td>33.8</td>
<td>67.1</td>
<td>50.2</td>
<td>145.7</td>
<td>296.8</td>
<td>89.85</td>
</tr>
</tbody>
</table>
## Table: Effect of Fuel-Based Updating: Emissions by Region (mmTons)

<table>
<thead>
<tr>
<th>Regulation</th>
<th>CA</th>
<th>NWPP</th>
<th>SW</th>
<th>non-WCI</th>
<th>Total</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cap</td>
<td>34.4</td>
<td>84.4</td>
<td>59.0</td>
<td>140.2</td>
<td>318.0</td>
<td>NA</td>
</tr>
<tr>
<td>WCI cap</td>
<td>30.9</td>
<td>72.0</td>
<td>48.2</td>
<td>148.8</td>
<td>299.9</td>
<td>39.15</td>
</tr>
<tr>
<td>WCI updating</td>
<td>38.4</td>
<td>65.5</td>
<td>47.2</td>
<td>141.9</td>
<td>293.0</td>
<td>51.55</td>
</tr>
<tr>
<td>Fuel-based</td>
<td>33.8</td>
<td>67.1</td>
<td>50.2</td>
<td>145.7</td>
<td>296.8</td>
<td>89.85</td>
</tr>
</tbody>
</table>
Emissions and Allocation Policy

CO2 Emissions by Region and Regulation

Graphs by regulation

Results
## Table: Effect of Updating: Electricity Prices (Average $/MWh)

<table>
<thead>
<tr>
<th>Regulation</th>
<th>Cal</th>
<th>NWPP</th>
<th>AZNMMNV</th>
<th>RMPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>No cap</td>
<td>57.22</td>
<td>57.91</td>
<td>58.37</td>
<td>62.24</td>
</tr>
<tr>
<td>WCI cap</td>
<td>74.78</td>
<td>74.93</td>
<td>75.03</td>
<td>73.74</td>
</tr>
<tr>
<td>WCI updating</td>
<td>60.36</td>
<td>61.14</td>
<td>61.67</td>
<td>64.68</td>
</tr>
<tr>
<td>Fuel-based</td>
<td>67.41</td>
<td>68.05</td>
<td>68.48</td>
<td>68.81</td>
</tr>
</tbody>
</table>

Bushnell and Chen (ISU and UCM)
# Emissions Cost Impacts of Allocating 80% of permits

## Table: Net Emissions Costs by Firm ( Millions $ )

<table>
<thead>
<tr>
<th>Firm</th>
<th>No Allocation</th>
<th>Fuel-based</th>
<th>Output-based</th>
<th>Grandfathering</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRKA</td>
<td>892.3</td>
<td>582.2</td>
<td>550.5</td>
<td>321.9</td>
</tr>
<tr>
<td>CPN</td>
<td>373.9</td>
<td>57.8</td>
<td>-93.6</td>
<td>137.5</td>
</tr>
<tr>
<td>DYN</td>
<td>250.7</td>
<td>-0.2</td>
<td>-78.9</td>
<td>104.8</td>
</tr>
<tr>
<td>EIX</td>
<td>153.5</td>
<td>8.3</td>
<td>-43.8</td>
<td>49.2</td>
</tr>
<tr>
<td>LADWP</td>
<td>639.7</td>
<td>341.1</td>
<td>325.9</td>
<td>244.3</td>
</tr>
<tr>
<td>PW</td>
<td>281.8</td>
<td>154.7</td>
<td>92.0</td>
<td>108.2</td>
</tr>
<tr>
<td>SALTRP</td>
<td>339.7</td>
<td>184.5</td>
<td>129.1</td>
<td>124.3</td>
</tr>
<tr>
<td>SEMPRA</td>
<td>193.9</td>
<td>-0.7</td>
<td>-68.1</td>
<td>64.2</td>
</tr>
<tr>
<td>XCEL</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Others</td>
<td>2789.2</td>
<td>1444.1</td>
<td>892.0</td>
<td>1364.3</td>
</tr>
</tbody>
</table>
Conclusions

- Leakage is substantial with a California-only cap
- Leakage still significant (1/3) with a WCI cap
  - Under a *source-based* scheme
  - *First deliverer* approach will mitigate this
  - This is what we are working on now
- Output-based updating substantially reduces leakage
  - It also lowers electricity prices
- Fuel-based updating tends to reverse the effects of updating
  - Leakage, Elect. Prices closer to Grandfathering
  - Permit prices much higher than any other allocation scheme
Thanks for your attention!

Leakage in Regional Cap-and-Trade Markets for CO2

James Bushnell and Yishu Chen

Iowa State University and UC Merced

May, 2010