Motivation

- Energy-intensive industries such as steel, aluminum, chemicals, paper and cement most likely to be affected by unilateral climate policy (Houser et al., 2008)

- If oligopolistic rent-shifting matters in these sectors, issues of carbon leakage and competitiveness best analyzed in tradition of, *inter alia*, Conrad (1993) and Barrett (1994)

- Use simple linear oligopoly model to trace out potential effects of US and Québec climate policies in US aluminum industry where border measures (BTAs) are assumed WTO-legal
Aluminum Production

- Primary aluminum produced in vertical process initially requiring bauxite and alumina
- Aluminum extracted from alumina by electrolytic reduction method using carbon anodes
- Production process energy-intensive, energy accounting for 25% of production costs (USITC, 2010)
- Two key sources of GHG emissions (Carbon Trust, 2011):
  - production process (2-3 tCO₂/t of aluminum)
  - upstream electricity generation (3-20 tCO₂/t aluminum)
Aluminum Industry: Market Structure

Table 1: Market Structure of North American Aluminum Industry

<table>
<thead>
<tr>
<th>US Producers</th>
<th>Market Share (%)</th>
<th>Canadian Producers</th>
<th>Market Share (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcoa</td>
<td>50.8</td>
<td>Rio Tinto Alcan</td>
<td>51</td>
</tr>
<tr>
<td>Century Aluminum</td>
<td>21.2</td>
<td>Alcoa</td>
<td>31</td>
</tr>
<tr>
<td>Rio Tinto Alcan</td>
<td>5.3</td>
<td>Alouette</td>
<td>18</td>
</tr>
<tr>
<td>Columbia Falls Aluminum</td>
<td>5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>17.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/H</td>
<td>2.94</td>
<td></td>
<td>2.57</td>
</tr>
</tbody>
</table>
North American Aluminum Industry

▪ Reasonable to treat US and Canada as segmented markets where Canadian producers compete in US

▪ 50% of US consumption via imports predominantly from Canada, and US is most important export market for Canada

▪ Key difference between US and Canadian aluminum production is that latter exclusively sources hydro-electric power

▪ Estimated GHG emissions: 2.5 tCO$_2$/t of aluminum in Canada (CIEEDAC, 2013) compared to 7.4 tCO2/t of aluminum in US (Carbon Trust, 2011)
Model

- Specific version of McCorriston and Sheldon (2005): conjectural variations with linear demand that can easily be calibrated to industry and used for policy simulation

- Inverse derived demand functions:

  \[ p_1 = a_1 - b_1 Q_1 - kQ_2 \]  
  \[ p_2 = a_2 - b_2 Q_2 - kQ_1 \]

  where \( a_i, b_i \) and \( k > 0 \), and \( b_1 b_2 - k_2 \geq 0 \)
Model

- Aggregate first-order conditions:
  \[ p_1 - c_1 - Q_1 V_1 = 0 \]  \hspace{2cm} (3)
  \[ p_2 - c_2 - Q_2 V_2 = 0 \]  \hspace{2cm} (4)

where \( V_i \) are aggregate conjectural variations parameters

- Using (1)-(4), comparative statics can be derived from:

\[
\begin{bmatrix}
  dQ_1 \\
  dQ_2
\end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix}
  (b_2 + V_2) & -k \\
  -k & (b_1 + V_1)
\end{bmatrix} \begin{bmatrix}
  -dc_1 \\
  -dc_2
\end{bmatrix}
\]  \hspace{2cm} (5)
Leakage

Leakage $l$ defined as:

$$l = \frac{de_2}{-de_1} \equiv \left[ f'(Q_2) \frac{dQ_2}{f'(Q_1) - dQ_1} \right] \equiv \left[ \frac{f'(Q_2)}{f'(Q_1)} \cdot \frac{\Delta^{-1} k dc_1}{f'(Q_1) \cdot \{-\Delta^{-1}(b_2 + V_2)dc_1\}} \right]$$ (6)

Given $\Delta^{-1} k dc_1 > 0$, and $\{-\Delta^{-1}(b_2 + V_2)dc_1\} < 0$, leakage is determined by GHG emissions rates in US and Canada and extent of output change in both countries in response to US carbon tax, given cap-and-trade policy already implemented in Quebec.
BTAs and Neutrality

- Under WTO rules, BTAs have to be *neutral* in their effect on trade, two potential definitions satisfying criterion:

\[(i) \text{ Import-volume} - \quad t^b = \frac{(dQ_2 / dc_1) g^e}{-(dQ_2 / dc_2)} = \frac{\Delta^{-1}(k)g^e}{\Delta^{-1}(b_1 + V_1)} \quad (7)\]

\[(ii) \text{ Import-share} - \quad t^b = \frac{[(dQ_2 / dc_1) + (dQ_1 / dc_1)]g^e}{[(dQ_1 / dc_2) + (dQ_2 / dc_2)]} = \frac{[\Delta^{-1} \{ k + (b_2 + V_2) \}]g^e}{[\Delta^{-1} \{ k + (b_1 + V_1) \}]} \quad (8)\]
Policy Simulation

- Based on calibration of model with 2008 data for aluminum industry, evaluate $25/\text{t CO}_2$ US carbon tax, given Québec carbon price of $10/\text{t CO}_2$, and allow for BTAs.

- Assume US social welfare function:

\[
W = \pi_1 + \Gamma + g^e \{ f'(Q_1) \}Q_1 + t^b Q_2 - d(e_1 + e_2) \quad (9)
\]

- Tradeoff between targeting global public bad, retaining rents for domestic producers, and minimizing deadweight loss to users of aluminum – but only two instruments, $g^e$ and $t^e$.
Simulation Results

Table 2: Welfare Effects of US and Québec Carbon Policies ($ billion)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre-policy</th>
<th>US carbon tax</th>
<th>Volume BTA</th>
<th>Share BTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Producer profits</td>
<td>2.29</td>
<td>1.97</td>
<td>2.03</td>
<td>2.17</td>
</tr>
<tr>
<td>User surplus</td>
<td>11.72</td>
<td>10.96</td>
<td>10.73</td>
<td>10.26</td>
</tr>
<tr>
<td>Tax revenue</td>
<td>0.00</td>
<td>0.46</td>
<td>0.73</td>
<td>1.26</td>
</tr>
<tr>
<td>Social cost</td>
<td>0.52</td>
<td>0.49</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>Social welfare</td>
<td>13.49</td>
<td>12.89</td>
<td>13.00</td>
<td>13.20</td>
</tr>
<tr>
<td>Net deadweight loss</td>
<td>-</td>
<td>-0.28</td>
<td>-0.23</td>
<td>-0.18</td>
</tr>
<tr>
<td>Effective carbon price ($/tCO₂)</td>
<td>-</td>
<td>282, 84</td>
<td>282, 84</td>
<td>282, 84</td>
</tr>
<tr>
<td>BTA ($/t)</td>
<td>-</td>
<td>-</td>
<td>138</td>
<td>441</td>
</tr>
<tr>
<td>Market share (%)</td>
<td>57</td>
<td>55</td>
<td>56</td>
<td>59</td>
</tr>
<tr>
<td>Emissions (CO₂ t - millions)</td>
<td>24.67</td>
<td>23.32</td>
<td>23.41</td>
<td>23.61</td>
</tr>
<tr>
<td>Leakage</td>
<td>-</td>
<td>0.06</td>
<td>-0.11</td>
<td>-1.22</td>
</tr>
</tbody>
</table>
Conclusion

- Once oligopoly is allowed for in aluminum production, competitiveness can be defined in terms of rent-shifting.
- Extent of both leakage and reduction in competitiveness dependent on interaction between US and Canadian producers.
- WTO-legal application of BTAs needs to account for way in which oligopolistic firms respond to changes in costs.
- Net deadweight losses due to second-best structure of problem.