Ron Jones Lecture

Optimal Unilateral Carbon Policy

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Emissions of CO$_2$ generate a *global externality*

- harm doesn’t depend on where the emissions originate

Ideal policy is a globally harmonized carbon price

- little progress toward that ideal

- free riding, different exposure to harms, costs of climate policies, political capture …

**This paper:** What’s the best a coalition (Home) can do on its own?
The Role of Trade

• With trade, different carbon prices distort economic activity

• Key effect known as *carbon leakage*
  
  • increased emissions in low-tax regions as carbon-intensive activities relocate

• Leakage undermines carbon policies that aren’t implemented globally
  
  • with leakage, it matters at what stage you tax carbon:
    
    • upstream: extraction (fossil fuels containing C)
    
    • middle: production of goods (releasing CO$_2$)
    
    • downstream: consumption (embodied CO$_2$)
• Common response to leakage is *border adjustments (BAs)*
  • taxes on imports based on the energy used in production
  • rebates on exports of prior taxes paid

• BAs shift the tax downstream
  • from a tax on domestic *extraction* to domestic *production*
  • from a tax on domestic *production* to domestic *consumption*

• Example “Energy Innovation and Carbon Dividend Act” (*EICDA*), T. Deutch of Florida

• Questions: What’s the best combination? What’s the economic logic? Are there better options?
• **Tax energy extraction**: tax rate equals marginal damages from global emissions

• **Partial border adjustments** on energy:
  
  • tax energy imports or rebate tax on exports < extraction tax rate
  
  • pushes part of the tax downstream from extractors to producers

• Same partial BAs on carbon content of goods imports
  
  • import margin unchanged relative to no policy

• No BAs for exports of goods; instead a subsidy per unit for marginal exporters
  
  • export margin expands relative to no policy
Economic Rationale

- Extraction tax raises **global energy price**; production or consumption tax lowers it
  - partial BAs optimize the mix, given Foreign’s extraction and demand elasticities

- BAs on goods imports mimics a consumption tax
  - avoids distorting consumption and incentivizes correct **energy intensity** in Foreign

- No BAs for goods exports mimics a production tax
  - incentivizes correct energy intensity in Home

- Subsidy per unit exported expands the reach of Home’s policy
  - crowds out Foreign’s production of goods for itself
1. Model structure

2. Planner’s problem

3. Implementing optimal policy

4. Quantitative illustration
• Build on Markusen (1975) in modeling energy extraction, externalities, and policy

• Combine with Dornbusch, Fischer, and Samuelson (DFS, 1977) to get trade in differentiated goods produced with energy

• Follow Costinot, Donaldson, Vogel, and Werning (CDVW, 2015), who use the primal method to derive optimal unilateral trade policy in DFS

• Follow Böhringer, Lange, and Rutherford (2014) by replacing trade balance with requirement that Home’s policy doesn’t reduce Foreign’s welfare
Model Structure

• **Countries:** Home (planner imposes a carbon policy) and Foreign* (competitive)

• **Endowments:** labor L and a distribution of energy fields E

• **Sectors:** energy, goods, and services (it’s a mini CGE)
  - energy extracted from fields using labor
  - differentiated goods produced using labor and energy
  - services provided by labor

• **Mobility:** labor freely mobile across sectors but immobile across countries

• **Trade:** energy and services costlessly traded; goods traded subject to iceberg costs
Carbon in the Model

1. Carbon is pulled from the earth by energy extractors

2. It’s then embodied in energy trade

3. Released into the atmosphere through combustion by goods producer, or utilities generating electricity for them

4. Carbon is embodied in these goods, which are traded prior to being consumed

5. Carbon can be tracked all the way from its extraction to where the goods embodying the carbon are ultimately consumed

Convenient to measure it, at each stage, in units of CO₂
Carbon in the World

- Gigatonnes of CO$_2$ in 2015 (IEA and OECD TECO$_2$) with Home as the OECD

<table>
<thead>
<tr>
<th></th>
<th>Home</th>
<th>Foreign</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home</td>
<td>$C_e^{HH} = 11.3$</td>
<td>$C_e^{HF} = 2.5$</td>
<td>$C_e = 13.8$</td>
</tr>
<tr>
<td>Foreign</td>
<td>$C_e^{FH} = 0.9$</td>
<td>$C_e^{FF} = 17.6$</td>
<td>$C_e^* = 18.5$</td>
</tr>
<tr>
<td>Total</td>
<td>$G_e = 12.2$</td>
<td>$G_e^* = 20.1$</td>
<td>$C_e^W = 32.3$</td>
</tr>
<tr>
<td>Extraction</td>
<td>$Q_e = 8.6$</td>
<td>$Q_e^* = 23.7$</td>
<td>$Q_e^W = 32.3$</td>
</tr>
</tbody>
</table>
Welfare and Preferences

• Home’s welfare: quasi-linear to eliminate income effects

\[ U = C_s + u(C_g) - \varphi(Q_e + Q_e^*) \]

Social Cost of Carbon

\[
\begin{align*}
    u(c) &= \eta^{1/\sigma} \frac{c^{(\sigma-1)/\sigma} - 1}{(\sigma - 1)/\sigma} \\
    C_g &= \left( \int_0^1 c_j^{(\sigma-1)/\sigma} \, dj \right)^{\sigma/(\sigma-1)} \\
    u(C_g) &= \int_0^1 u(c_j) \, dj
\end{align*}
\]

• note the linear separability across goods

• Same form for Foreign welfare, but may have different parameters

• global marginal harm (globally optimal carbon tax rate)

\[ \varphi^W = \varphi + \varphi^* \]
• Services provided with unit labor requirement in both countries

• Assume conditions so that services sector is active in both countries

  • and that services are consumed in both countries

• When we consider a decentralized equilibrium services are numeraire

  • leading to a common wage = 1
Energy Extraction

- Energy deposits in Home and Foreign \( E(a), E^*(a) \)
  - quantity of energy extracted at unit labor requirement \( \leq a \)
- Home extracts energy from all deposits with \( a \leq \bar{a} \)
  \[
  L_e = \int_{0}^{\bar{a}} aE'(a)da \\
  Q_e = E(\bar{a})
  \]
- Foreign extraction is governed by the energy price \( Q^*_e = E^*(p_e) \)
- Normalize a unit of energy to be a unit of CO2 emissions
Goods Production

- Continuum of goods \( j \in [0,1] \)
- Cobb-Douglas production (energy intensity \( z \))
  \[
  q_j = \frac{1}{\nu a_j} L_j^\alpha E_j^{1-\alpha} = \frac{z_j^{1-\alpha}}{\nu a_j} L_j \quad \nu = \alpha^\alpha (1 - \alpha)^{1-\alpha}
  \]
- Energy share parameter is equal across all goods and for both countries
- Relative productivity schedule
  \[
  \frac{a_j^*}{a_j} = F(j)
  \]
- Iceberg trade costs \( \tau, \tau^* \)
Energy Flows

• Distinguish quantities by source and destination \( y_j, y_j^*, m_j, x_j \)

• Energy intensity may vary for each, e.g. \( z_j^y, z_j^*, z_j^m, z_j^x = E_j^x / L_j^x \)

• Unit energy requirement \( e_j(z_j^x) = \nu a_j(z_j^x)^\alpha \)

• Energy embodied in Home’s exports, e.g. \( C_{e}^{FH} = \int_{0}^{1} e_j(z_j^x)x_jdj \)

• Recall the flow matrix

\[
\begin{array}{ccc|c}
C_{e}^{HH} & C_{e}^{HF} & C_e & C_e \\
C_{e}^{FH} & C_{e}^{FF} & C_{e}^* & C_e^* \\
C_{e} & C_{e}^* & C_{e} & C_{e} \\
G_{e} & G_{e}^* & C_{e} & C_{e}^W
\end{array}
\]
1. Model structure

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Home’s Planning Problem

The planner seeks to maximize Home’s welfare by choosing:

- **Energy**: Home’s extraction and the price of energy in Foreign

- **Services**: quantity of services provided and consumed

- **Goods**:
  - quantity produced in Home for domestic consumption and for export
  - quantity imported for consumption in Home
  - energy intensity of production for all three
Foreign

- Foreign responds to price signals with no climate policy
  - chooses extraction, production for itself, and consumption based on energy price
- Foreign’s marginal utility is bounded above by \( p_j^* = a_j^* p_e^{1-\alpha} \)
  - since it can always supply itself at this price
- Key Foreign elasticities: energy supply and energy demand
  \[
  \epsilon^*_S = E^*(p_e)p_e/E^* > 0 \\
  \epsilon^*_D = \alpha + (1 - \alpha)\sigma^* > 0
  \]
Planner’s Constraints

- **Labor in Home**
  
  \[ Q_s = L - L_e - L_g \]

- **Foreign Welfare**
  
  \[ C_s^* + u^*(C_g^*) - \varphi^*Q_e^W = U_0^* \]

- **Energy**
  
  \[ C_e^W \leq Q_e^W \]
Objective Function Simplified

- Start with Home’s Welfare
  \[ U = C_s + u(C_g) - \phi Q_e^W \]

- Substitute in services constraint, labor constraints, and Foreign welfare constraint

- Combine and drop constants
  \[ U = u(C_g) + u^*(C^*_g) - \phi W Q_e^W - L_e^W - L_g^W \]

- Now it looks like a global planner’s objective!
Massive Maximization Problem

- Lagrangian for Home’s planning problem

\[ \mathcal{L} = u(C_g) + u^*(C_g^*) - \varphi^W Q_e^W - L_e^W - L_g^W - \lambda_e (C_e^W - Q_e^W) \]

- choosing \( Q_e, p_e, \{y_j\}, \{x_j\}, \{m_j\}, \{z_{jy}\}, \{z_{jx}\}, \{z_{jm}\} \)

- with \( C_e^W = \int_0^1 e_j(z_{jy})y_jdj + \tau \int_0^1 e_j(z_{jx})x_jdj + \int_0^1 e_j^*(z_{jy})y_j^*dj + \tau^* \int_0^1 e_j^*(z_{jm})m_jdj \)

- Solve by exploiting CDVW’s idea

- \textit{inner problem}, for a particular good \( j \); \textit{outer problem}, for aggregates

- Simple case: if \( \varphi^W = 0 \) then solution mimics BAU competitive equilibrium, \( \lambda_e = p_e \)
Solution: Inner Problem

- Energy intensity
  \[ z_j^y = z_j^m = z_j^x = z = \frac{1 - \alpha}{\alpha \lambda_e} \]
  \[ z_j^* = z^* = \frac{1 - \alpha}{\alpha p_e} \]

- Home consumption
  \[ u'(y_j) = a_j \lambda_e^{1-\alpha} \]
  \[ j < \bar{j}_m \]
  \[ u'(m_j) = \tau^* a_j^* \lambda_e^{1-\alpha} \]
  \[ \bar{j}_m < j \]

- Foreign consumption
  \[ u^*(x_j) = \tau a_j \lambda_e^{1-\alpha} \]
  \[ j < j_0 \]
  \[ u^*(x_j) = a_j^* p_e^{1-\alpha} \]
  \[ j_0 < j < \bar{j}_x \]
  \[ u^*(y^*) = a_j^* p_e^{1-\alpha} \]
  \[ \bar{j}_x < j \]

- Extensive margins of trade
  \[ F(\bar{j}_m) = 1/\tau^* \]
  \[ F(j_0) = \tau (\lambda_e/p_e)^{1-\alpha} \]
  \[ F(\bar{j}_x) = \frac{F(j_0)}{\alpha + (1 - \alpha)\lambda_e/p_e} \]
Solution: Outer Problem

- Home's energy extraction

\[ \phi^W + \frac{\partial L_e}{\partial Q_e} = \lambda_e \quad \Rightarrow \quad Q_e = E(\lambda_e - \phi^W) \]

- Energy price

\[ \left((\lambda_e - \phi^W) - p_e\right) \frac{\partial Q^*_e}{\partial p_e} = \left(\lambda_e - p_e\right) \frac{\partial C_e^{FF}}{\partial p_e} + \int_{j_0}^{j_x} \left(\tau a_{j_e}^{1-\alpha} - p^*_j\right) \frac{\partial x_j}{\partial p_e} dj \]

- Extraction wedge

\[ (\lambda_e - \phi^W) - p_e \]

- Consumption wedge

\[ \lambda_e - p_e \]

- Export wedges

\[ \tau a_{j_e}^{1-\alpha} - p^*_j \]

- Pigouvian wedge (consumption wedge - extraction wedge)

\[ \phi^W \]
Summary: Outer Problem

- Energy price condition becomes

\[
\lambda_e - p_e = \frac{\phi^W e^*_S Q^*_e - \sigma^*(1 - \alpha)S}{\epsilon^*_S Q^*_e + \epsilon^*_D C^F e^*}
\]

- where aggregating export wedges

\[
S = \int_{j_0}^{\tilde{j}_x} (\tau a_j \lambda_e^{1-\alpha} - p^*_j) x_j dj
\]

- Key result:

\[
\lambda_e - p_e \in [0, \phi^W)
\]
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Implementation in a Market Economy

- **Global energy price**
  \[ p_e \]

- **Nominal extraction tax**
  \[ t_e^N = \varphi^W \]

- **Border adjustment**
  \[ t_b = \lambda_e - p_e \quad 0 \leq t_b < \varphi^W \]

- **Effective extraction tax**
  \[ p_e - (\lambda_e - \varphi^W) = \varphi^W - (\lambda_e - p_e) \]
Interpretation

• **Border adjustment**
  - applies to imports and exports of energy; to imports of goods but not to exports of goods

• **Markusen reasoning**: higher border adjustment lowers global energy price
  - border adjustment moves up or down with ratio of Foreign supply to demand elasticity

• **Export policy**:
  - expand export margin through subsidies as needed
  - subsidy is *not the same* as removing the tax on exporters
• **Fischer and Fox reasoning:** keep tax on the energy content of exports
  - incentive for them to be produced with low energy intensity
  - a per-unit subsidy for marginal exporters doesn’t remove that incentive

• **CDVW reasoning:** don’t mess with the import margin
  - by taking account of Foreign Welfare, we lose their policy of taxing exporters

• **New reasoning:** export subsidy applies to goods Home wouldn’t otherwise export
  - in theory the optimal policy can involve cross hauling!
Extensive Margins: No Policy

\[ F(j) \]

\[ \tau \]

\[ 1/\tau^* \]

0 \[ \tilde{j}_x \]

endogenously non-traded goods

\[ \tilde{j}_m \]

Home imports

Home exports
Extensive Margins: Optimal Policy

\[
F(j) = \frac{(\lambda_e/p_e)^{1-\alpha}}{\alpha + (1 - \alpha)\lambda_e/p_e}
\]

0 \quad j_0 \quad j_m \quad j_x \quad 1

Home exports \quad cross hauling \quad Home imports

\frac{1}{\tau^*} \quad \tau
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Calibration Strategy

• Impose functional forms for extraction and comparative advantage
  
  • constant supply elasticities, $\epsilon_S$, $\epsilon^*_S$ and constant trade elasticity $\theta$

• Calibrate to BAU using data above on carbon flows, for Home = OECD
  
  • can change the taxing coalition by simply plugging in new carbon flows matrix

• All results are relative to BAU competitive equilibrium, applying “hat algebra”
  
  • we normalize BAU energy price = 1
Calibrated Parameters

- Energy share in production
  - source: value of energy use and value added of production
  \[1 - \alpha = 0.15\]

- Elasticity of energy supply
  \[\epsilon_S = \epsilon_S^* = 0.5\]

- Elasticity of substitution in consumption
  - source: interim values
  \[\sigma = \sigma^* = 1\]

- Trade elasticity
  - source: Simonovska and Waugh (2014)
  \[\theta = 4\]
We show (i) the emissions reductions, (ii) the change in welfare ($W^*$), (iii) the change in $p_e$, (iv) the rate under the optimal policy, (v) the change in Home’s export margin, $\bar{\mu}^x$, and (vi) the export subsidy, $S$.

Focusing on our baseline calibration, global emissions go down by about $\frac{1}{3}$ when $W^* = 2$, a substantial reduction given that emissions in the OECD are only about $\frac{1}{3}$ of global emissions (as reflected in the value of $G_e$ in Table 5). Note that the substantial reduction from the OECD policy does not mean that the OECD’s emissions are near zero. Some of the reductions arise in other parts of the world because of how the optimal policy expands the carbon price to trading partners.

Notably, the OECD would choose to impose a significant carbon policy even when the rest of the world does not. For $W^* = 2$, the optimal carbon policy reduces global emissions by $7.6$ Gt CO$_2$. That the OECD would choose...
The Taxing Coalition

Figure 2: Choice of Pricing Coalition

Table 8: Calibration for the EU and the United States

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<tr>
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<tbody>
<tr>
<td>$C$</td>
<td>$H^H_e$</td>
<td>7.7</td>
</tr>
<tr>
<td>$C$</td>
<td>$H^F_e$</td>
<td>2.0</td>
</tr>
<tr>
<td>$C$</td>
<td>$H^W_e$</td>
<td>9.8</td>
</tr>
</tbody>
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<tr>
<td>$C$</td>
<td>$F^F_e$</td>
<td>2.1</td>
</tr>
<tr>
<td>$C$</td>
<td>$F^W_e$</td>
<td>2.2</td>
</tr>
</tbody>
</table>

| Extraction | $Q^H_e$ | 5.4   |
| $Q^W_e$ | 3.2   |

Looking at the calibration tables, we can see that the size of the extraction base is the key difference between the EU and the coalition of the EU and the United States. Production and consumption roughly double, reflecting the relative size of the two economies, but extraction goes up by a factor of more than 5. With almost no extraction, the EU on its own is unable to take advantage of the extraction tax portion of the optimal policy, which means...
Simple Policies

- If the planner chooses only $Q_e, p_e$ outcome is an optimal pure extraction tax

$$t_e = \varphi^W \frac{\epsilon_D C_e + \epsilon^*_D C^*_e}{\epsilon^*_S Q^*_e + \epsilon_D C_e + \epsilon^*_D C^*_e}$$

- If chooses $Q_e, p_e, \{y_j\}, \{m_j\}, \{z^y_j\}, \{z^m_j\}$ get extraction-consumption hybrid
  - get back the optimal extraction tax
    $$t_e = \varphi^W$$
  - border adjustment both on energy and on carbon embodied in goods

$$t_b = \varphi^W \frac{\epsilon^*_S Q^*_e}{\epsilon^*_S Q^*_e + \epsilon^*_D C^*_e}$$

- If the planner can choose everything then get global optimum of simply
  $$t_e = \varphi^W$$
When $\xi = 2.0$, extraction taxes are no longer desirable. Increasing $p$ would cause a substantial increase in Foreign extraction, offsetting the effectiveness of the tax. Demand-side taxes are correspondingly more effective because lowering $p$ causes a significant reduction in Foreign extraction. For example, the pure production tax goes from an optimal emissions reduction of 4.8% when $\xi = 0.5$ to reductions of 10.6% when $\xi = 2.0$.

Looking at the bottom right panel, we can see that Home is less willing to allow $p$ to change when $\xi$ is high.
Conclusions

• Theory reveals basic logic of optimal unilateral carbon policy
  • the combination of BAs matters, and trade expands the policy’s reach

• **Practical policy**: mix of extraction and production tax (simple to administer)
  • reduce the BA relative to the carbon tax in EICDA
    • so that there’s a positive effective tax on extraction (no BA on goods!)

• Readily accommodates extensions, such as renewable energy

• Directions to explore
  • many countries as in EK (2002) or recently Farid and Lashkaripour (2020)
  • dynamics as in Golosov, Hassler, Krusell, and Tsyvinsky (2014)