Optimal Unilateral Carbon Policy

David Weisbach, Samuel Kortum, and Michael Wang
Excellent research assistance by Bella Yao

NBER International Trade Policy and Institutions Conference
September 11, 2020
Policy Dilemma

- Emissions of CO$_2$ generate a global externality
Policy Dilemma

- Emissions of CO$_2$ generate a global externality

- The harm from emissions doesn’t depend on where the CO$_2$ originates
• Emissions of CO$_2$ generate a global externality
• The harm from emissions doesn’t depend on where the CO$_2$ originates
• Ideal policy = globally harmonized carbon price
Emissions of CO₂ generate a global externality

The harm from emissions doesn’t depend on where the CO₂ originates

Ideal policy = globally harmonized carbon price

But it’s been impossible to coordinate global carbon prices
Emissions of CO$_2$ generate a global externality

The harm from emissions doesn’t depend on where the CO$_2$ originates

Ideal policy = globally harmonized carbon price

But it’s been impossible to coordinate global carbon prices

- free-rider problems, different exposure to harms, different costs of climate policies, preferences, political capture ...
• Emissions of CO$_2$ generate a global externality

• The harm from emissions doesn’t depend on where the CO$_2$ originates

• Ideal policy = globally harmonized carbon price

• But it’s been impossible to coordinate global carbon prices
  
  • free-rider problems, different exposure to harms, different costs of climate policies, preferences, political capture …

• This paper: What’s the best that a smaller coalition can do on its own?
The Role of Trade
• Different carbon prices in different parts of the world can generate inefficiencies
  
  • distort the location of various activities
The Role of Trade

- Different carbon prices in different parts of the world can generate inefficiencies
  - distort the location of various activities
- Key effect known as *leakage*
  - increased emissions in a low-tax jurisdictions as carbon-intensive activities relocate
The Role of Trade

• Different carbon prices in different parts of the world can generate inefficiencies
  • distort the location of various activities

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

• Leakage potentially undermines the effectiveness of carbon policies
Border Adjustments
• Most common response to leakage is *border adjustments*
  
  • taxes on imports based on the energy used in production
  
  • rebates on export of prior taxes paid
Most common response to leakage is *border adjustments*

- taxes on imports based on the energy used in production
- rebates on export of prior taxes paid

Border adjustments shift the tax downstream

- from a tax on domestic extraction to domestic production
- from a tax on domestic production to domestic consumption
Border Adjustments

• Most common response to leakage is *border adjustments*
  • taxes on imports based on the energy used in production
  • rebates on export of prior taxes paid

• Border adjustments shift the tax downstream
  • from a tax on domestic extraction to domestic production
  • from a tax on domestic production to domestic consumption

• Huge literature estimating effects of border adjustments, mostly CGE models
Questions
Questions

- For a given coalition, what is the optimal unilateral carbon policy?
  - assume the rest of the world is passive
Questions

• For a given coalition, what is the optimal unilateral carbon policy?
  • assume the rest of the world is passive

• What role do border adjustments play in the optimal policy?
Questions

• For a given coalition, what is the optimal unilateral carbon policy?
  • assume the rest of the world is passive

• What role do border adjustments play in the optimal policy?

• What novel features are part of an optimal policy?
Questions

• For a given coalition, what is the optimal unilateral carbon policy?
  • assume the rest of the world is passive

• What role do border adjustments play in the optimal policy?

• What novel features are part of an optimal policy?

• What parameters matter most for the effectiveness of unilateral policy?
  • e.g. energy supply elasticity, the size of the coalition, etc.
Questions

• For a given coalition, what is the optimal unilateral carbon policy?
  • assume the rest of the world is passive

• What role do border adjustments play in the optimal policy?

• What novel features are part of an optimal policy?

• What parameters matter most for the effectiveness of unilateral policy?
  • e.g. energy supply elasticity, the size of the coalition, etc.

• Show that trade can strengthen the coalition’s carbon policy by extending its reach
• Tax energy extraction: tax rate equals the marginal damages from global emissions
• Tax energy extraction: tax rate equals the marginal damages from global emissions

• Partial border adjustments on energy:
  - the BA tax rate is typically below the extraction tax rate; pushes only part of the tax burden downstream from extractors to producers
• Tax energy extraction: tax rate equals the marginal damages from global emissions

• Partial border adjustments on energy:
  • the BA tax rate is typically below the extraction tax rate; pushes only part of the tax burden downstream from extractors to producers

• Border adjustments for the energy content of imports of goods
  • leaves the import margin the same as without policy
• Tax energy extraction: tax rate equals the marginal damages from global emissions

• Partial border adjustments on energy:
  • the BA tax rate is typically below the extraction tax rate; pushes only part of the tax burden downstream from extractors to producers

• Border adjustments for the energy content of imports of goods
  • leaves the import margin the same as without policy

• No border adjustment for exports of goods
• Tax energy extraction: tax rate equals the marginal damages from global emissions

• Partial border adjustments on energy:
  • the BA tax rate is typically below the extraction tax rate; pushes only part of the tax burden downstream from extractors to producers

• Border adjustments for the energy content of imports of goods
  • leaves the import margin the same as without policy

• No border adjustment for exports of goods

• Instead, subsidize marginal exporters, per unit exported
  • expands the set of goods that the taxing region exports; expands carbon policy through trade
1. Model structure

2. Planner’s problem

3. Optimal unilateral policy

4. Quantitative illustration
• **Countries:** Home (imposing a carbon policy) and Foreign (*)
• **Countries:** Home (imposing a carbon policy) and Foreign (*)

• **Endowments:** labor $L$ and a distribution of energy deposits, $E$
Model Structure

- **Countries**: Home (imposing a carbon policy) and Foreign (*)
- **Endowments**: labor L and a distribution of energy deposits, E
- **Sectors**: energy, goods, and services
  - energy extracted from deposits with labor
  - differentiated goods produced with labor and energy
  - services provided by labor
Model Structure

- **Countries**: Home (imposing a carbon policy) and Foreign (*)
- **Endowments**: labor L and a distribution of energy deposits, E
- **Sectors**: energy, goods, and services
  - energy extracted from deposits with labor
  - differentiated goods produced with labor and energy
  - services provided by labor
- **Mobility**: labor freely mobile across sectors but immobile across countries
Model Structure

- **Countries**: Home (imposing a carbon policy) and Foreign (*)

- **Endowments**: labor $L$ and a distribution of energy deposits, $E$

- **Sectors**: energy, goods, and services
  - energy extracted from deposits with labor
  - differentiated goods produced with 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
• Build on Markusen (1975) in modeling energy extraction, externalities, and policy
• Build on Markusen (1975) in modeling energy extraction, externalities, and policy

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

• Build on Markusen (1975) in modeling energy extraction, externalities, and policy

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

• Follow Costinot, Donaldson, Vogel, and Werning (2015, henceforth CDVW), who use the primal method to derive optimal unilateral trade policy in DFS
• Build on Markusen (1975) in modeling energy extraction, externalities, and policy

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

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

• Stylized analysis, but mimics some features of a big CGE model
Carbon in the Model
1. Carbon is pulled from the earth by energy extractors
1. Carbon is pulled from the earth by energy extractors
2. It’s then embodied in energy trade
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
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
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 consumed
Carbon in the World

- Gigatonnes of CO\textsubscript{2} in 2015 (IEA and OECD TECO\textsubscript{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>
Preferences

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

\[ U = C_s + \eta^{1/\sigma} \frac{C_g^{(\sigma-1)/\sigma}}{(\sigma - 1)/\sigma} - \varphi(Q_e + Q_e^*) \]
Preferences

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

\[ U = C_s + \frac{C_g^{(\sigma-1)/\sigma}}{(\sigma - 1)/\sigma} - \varphi(Q_e + Q^*_e) \]

Social Cost of Carbon
Preferences

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

\[ U = C_s + \eta^{1/\sigma} \frac{C_g^{(\sigma-1)/\sigma}}{\sigma} - \varphi(Q_e + Q_e^*) \]

Social Cost of Carbon

\[ C_g = \left( \int_0^1 c_j^{(\sigma-1)/\sigma} \, dj \right)^{\sigma/(\sigma-1)} \]

• Note the linearity across goods
Preferences

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

\[ U = C_s + \eta^{1/\sigma} \frac{C_g^{(\sigma-1)/\sigma}}{(\sigma - 1)/\sigma} - \varphi(Q_e + Q^*_e) \]

**Social Cost of Carbon**

\[ C_g = \left( \int_0^1 c_i^{(\sigma-1)/\sigma} dj \right)^{\sigma/(\sigma-1)} \]

• Note the linearity across goods

• Same form for Foreign preferences, but may have different parameters
  
  • for now assuming \( \sigma^* \leq 1 \)
Energy Extraction

- Energy deposits in Home and Foreign represented as $E(a), E^*(a)$
  - quantity of energy that can be extracted at unit labor requirement $\leq a$
• Energy deposits in Home and Foreign represented as $E(a)$, $E^*(a)$

• quantity of energy that can be extracted at unit labor requirement $\leq a$

• Home extracts energy from deposits with $a \leq \bar{a}$

$$L_e = \int_{0}^{\bar{a}} adE(a) \quad Q_e = E(\bar{a})$$
Energy Extraction

- Energy deposits in Home and Foreign represented as $E(a), E^*(a)$
  - quantity of energy that can be extracted at unit labor requirement $\leq a$
- Home extracts energy from deposits with $a \leq \bar{a}$
  $$L_e = \int_0^{\bar{a}} adE(a) \quad Q_e = E(\bar{a})$$
- Foreign extraction is governed by the global energy price
  $$Q_{e^*} = E^*(p_e)$$
Energy Extraction

• Energy deposits in Home and Foreign represented as \( E(a), E^*(a) \)

• quantity of energy that can be extracted at unit labor requirement \( \leq a \)

• Home extracts energy from deposits with \( a \leq \bar{a} \)

\[
L_e = \int_0^{\bar{a}} a dE(a) \quad Q_e = E(\bar{a})
\]

• Foreign extraction is governed by the global energy price

\[
Q_e^* = E^*(p_e)
\]

• Normalize a unit of energy to be a unit of CO2 emissions
• Continuum of goods \( j \in [0,1] \)

• Cobb-Douglas production

\[
q_j = \frac{1}{\nu \Delta_j} L_j^a E_j^{1-\alpha} \quad \nu = \alpha^\alpha (1 - \alpha)^{1-\alpha}
\]
Goods Production

- Continuum of goods \( j \in [0,1] \)

- Cobb-Douglas production

\[
q_j = \frac{1}{\nu a_j} L_j^\alpha E_j^{1-\alpha} \quad \nu = \alpha^\alpha (1 - \alpha)^{1-\alpha}
\]

- Energy share parameter equal across all goods and for both countries
Goods Production

- Continuum of goods \( j \in [0,1] \)
- Cobb-Douglas production
  \[
  q_j = \frac{1}{\nu a_j} L_j^\alpha E_j^{1-\alpha} \quad \nu = \alpha^\alpha (1 - \alpha)^{1-\alpha}
  \]
- Energy share parameter equal across all goods and for both countries
- Relative productivity schedule
  \[
  \frac{q_j^*}{a_j} = F(j)
  \]
Goods Production

• Continuum of goods \( j \in [0,1] \)

• Cobb-Douglas production

\[
q_j = \frac{1}{\nu a_j} L_j^\alpha E_j^{1-\alpha} \quad \nu = \alpha^\alpha (1 - \alpha)^{1-\alpha}
\]

• Energy share parameter equal across all goods and for both countries

• Relative productivity schedule

\[
\frac{a_j^*}{a_j} = F(j)
\]

• Iceberg trade costs \( \tau, \tau^* \)
• Services provided with unit labor requirement in both countries
• Services provided with unit labor requirement in both countries
• Require conditions so that services sector is active in both countries
• Services provided with unit labor requirement in both countries

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

• When we consider a decentralized equilibrium services are numeraire
  • leading to a common wage = 1
Energy Flows

- Distinguish quantities by source and destination: \( y_j, y_j^*, m_j, x_j \)
• Distinguish quantities by source and destination
\[ y_j, y^*_j, m_j, x_j \]

• Energy intensity may vary for each, e.g.
\[ z^y_j, z^*_j, z^m_j, z^x_j = E^x_j / L^x_j \]
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 may vary for each, e.g. \( e_j(z_j^x) = \nu a_j(z_j^x)^\alpha \)
• 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 may vary for each, e.g. $e_j(z_j^x) = \nu a_j(z_j^x)^\alpha$

• Energy embodied in Home’s exports, e.g. $C_e^{FH} = \int_0^1 e_j(z_j^x)x_jdj$
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 may vary for each, e.g. \( e_j(z_j^x) = \nu a_j(z_j^x)^\alpha \)

• Energy embodied in Home’s exports, e.g. \( C_{eFH} = \int_0^1 e_j(z_j^x)x_jdj \)

• Recall the flow matrix

\[
\begin{array}{ccc|c}
C_{eHH} & C_{eHF} & C_{e} & C_{e} \\
C_{eFH} & C_{eFF} & C_{e}^* & C_{e}^* \\
G_{e} & G_{e}^* & C_{e}^W & C_{e} \\
\end{array}
\]
1. Model structure

2. Planner’s problem

3. Optimal unilateral policy

4. Quantitative illustration
Home’s Planning Problem

- The planner seeks to maximize welfare in Home, by choosing

\[ Q_e, X_e, p_e, Q_s, C_s, \{y_j\}, \{x_j\}, \{m_j\}, \{z_j^y\}, \{z_j^x\}, \{y_j^m\} \]
Home’s Planning Problem

• The planner seeks to maximize welfare in Home, by choosing

\[ Q_e, X_e, p_e, Q_s, C_s, \{y_j\}, \{x_j\}, \{m_j\}, \{z_j^y\}, \{z_j^x\}, \{y_j^m\} \]

• **Energy**: Home’s extraction, exports of energy, and the global price of energy
Home’s Planning Problem

• The planner seeks to maximize welfare in Home, by choosing

\[ Q_e, X_e, p_e, Q_s, C_s, \{y_j\}, \{x_j\}, \{m_j\}, \{z^y_j\}, \{z^x_j\}, \{y^m_j\} \]

• **Energy**: Home’s extraction, exports of energy, and the global price of energy

• **Services**: quantity of services provided and consumed
Home’s Planning Problem

• The planner seeks to maximize welfare in Home, by choosing

\[ Q_e, X_e, p_e, Q_s, C_s, \{y_j\}, \{x_j\}, \{m_j\}, \{z_j^y\}, \{z_j^x\}, \{y_j^m\} \]

• **Energy**: Home’s extraction, exports of energy, and the global price of energy

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

• **Goods**:
  
  • quantity of goods produced in Home, for domestic consumption and for export
  
  • quantity of goods consumed in Home and imported
  
  • energy intensity of production for each of those three
Foreign
Foreign

- Foreign responds to price signals; it has no climate policy
Foreign

- Foreign responds to price signals; it has no climate policy
  - chooses how much to extract based on the global energy price
Foreign

- Foreign responds to price signals; it has no climate policy
  - chooses how much to extract based on the global energy price
  - chooses how much to produce for itself and how much to consume
Foreign

- Foreign responds to price signals; it has no climate policy
  - chooses how much to extract based on the global energy price
  - chooses how much to produce for itself and how much to consume
  - Home chooses exports, but can’t price them above Foreign’s cost
Foreign

• Foreign responds to price signals; it has no climate policy
  • chooses how much to extract based on the global energy price
  • chooses how much to produce for itself and how much to consume
  • Home chooses exports, but can’t price them above Foreign’s cost
  • Home chooses imports, but can’t buy them for less than Foreign’s cost
Foreign

• Foreign responds to price signals; it has no climate policy
  • chooses how much to extract based on the global energy price
  • chooses how much to produce for itself and how much to consume
• Home chooses exports, but can’t price them above Foreign’s cost
• Home chooses imports, but can’t buy them for less than Foreign’s cost

• Energy supply and demand elasticities in Foreign

\[ \epsilon^*_S = \frac{dE^*(p_e)}{dp_e} \frac{p_e}{E^*} \quad \epsilon^*_D = \alpha + (1 - \alpha)\sigma^* \]
Constraints

• Labor in Home

\[ Q_s = L - \int_0^{E^{-1}(Q_e)} adE(a) - \int_0^1 \left( l_j(z_j^y)y_j + \tau l_j(z_j^x)x_j \right) dj \]
Constraints

• Labor in Home

\[ Q_s = L - \int_0^{E^{-1}(Q_e)} adE(a) - \int_0^1 \left( l_j(z_j^y)y_j + \tau l_j(z_j^x)x_j \right) dj \]

• Trade balance

\[ C_s = Q_s + p_eX_e + \int_0^1 p_j^x x_j dj - \int_0^1 p_j^m m_j dj \]
Constraints

- Labor in Home

\[ Q_s = L - \int_0^{E^{-1}(Q_e)} adE(a) - \int_0^1 \left( l_j(z_j^y)y_j + \tau l_j(z_j^x)x_j \right) dj \]

- Trade balance

\[ C_s = Q_s + p_eX_e + \int_0^1 p_j^x x_j dj - \int_0^1 p_j^m m_j dj \]

- Energy in Home

\[ \int_0^1 e_j(z_j^y)y_j dj + \tau \int_0^1 e_j(z_j^x)x_j dj \leq Q_e - X_e \]
Constraints

- Labor in Home

\[ Q_s = L - \int_0^{E^{-1}(Q_e)} adE(a) - \int_0^1 \left( l_j(z_j^y)y_j + \tau l_j(z_j^x)x_j \right) dj \]

- Trade balance

\[ C_s = Q_s + p_e X_e + \int_0^1 p_j^x x_j dj - \int_0^1 p_j^m m_j dj \]

- Energy in Home

\[ \int_0^1 e_j(z_j^y)y_j dj + \tau \int_0^1 e_j(z_j^x)x_j dj \leq Q_e - X_e \]

- Energy in Foreign

\[ \int_0^1 e_j^*(z_j^y)y_j^* dj + \tau^* \int_0^1 e_j^*(z_j^m)m_j dj \leq Q_e^* + X_e \]
Solution Strategy

- Use labor and trade balance constraint to substitute out Home’s provision and consumption of services

- Apply Lagrange multipliers $\lambda_e$, $\lambda_e^*$ to the two energy constraints

- Solve by exploiting CDVW’s idea
  - inner problem, for a particular good j
  - outer problem, for aggregates
1. Model structure

2. Planner’s problem

3. Optimal unilateral policy

4. Quantitative illustration
Properties of Optimal Policy
Properties of Optimal Policy

• Home typically extracts less than would be dictated by the global energy price
Properties of Optimal Policy

• Home typically extracts less than would be dictated by the global energy price

• Home equates all energy intensities that it controls
  • goods produced in Home and imports produced in Foreign
Properties of Optimal Policy

• Home typically extracts less than would be dictated by the global energy price

• Home equates all energy intensities that it controls
  • goods produced in Home and imports produced in Foreign

• Extensive margin of imports remains fixed, invariant to the policy
Properties of Optimal Policy

- Home typically extracts less than would be dictated by the global energy price
- Home equates all energy intensities that it controls
  - goods produced in Home and imports produced in Foreign
- Extensive margin of imports remains fixed, invariant to the policy
- Home sets export prices at Foreign’s cost, ignoring its own cost of production
Properties of Optimal Policy

• Home typically extracts less than would be dictated by the global energy price

• Home equates all energy intensities that it controls
  • goods produced in Home and imports produced in Foreign

• Extensive margin of imports remains fixed, invariant to the policy

• Home sets export prices at Foreign’s cost, ignoring its own cost of production

• Home expands its export margin
  • effectively expands its control of energy use in production
  • can even lead to cross-hauling if iceberg costs are low
Extensive Margin of Trade: No Policy

\[ F(j) \]

\[ \frac{1}{\tau^*} \]

\[ \tau \]

0 \hspace{1cm} \bar{j}_x \hspace{1cm} \bar{j}_m \hspace{1cm} 1

Home exports \hspace{2cm} \text{endogenously non-traded goods} \hspace{2cm} \text{Home imports}
Weisbach, Kortum, and Wang
Extensive Margin of Trade: Optimal Policy

$F(j) = \frac{(1 + \lambda^* / p_e)^{1-\alpha}}{1 + (1 - \alpha)\lambda^* / p_e}$

- $1 / \tau^*$
- $\bar{j}_m$
- $\bar{j}_x$
- Home exports
- Cross hauling
- Home imports
Implementation in a Decentralized Equilibrium
• Extraction tax: \( t_e = \varphi \)
• Extraction tax: \( t_e = \varphi \)
• Border adjustment: \( t_b = \lambda_e^* \)
  • on imports and exports of energy and imports of goods
  • but not on exports of goods
Implementation in a Decentralized Equilibrium

• Extraction tax: \( t_e = \varphi \)

• Border adjustment: \( t_b = \lambda_e^* \)
  - on imports and exports of energy and imports of goods
  - but not on exports of goods

• Export policy:
  - expand export margin through subsidies (not the same as removing the tax on exporters)
  - exert market power by taxing exporters with strong comparative advantage
  - net cost of policy is \( \Pi_g \)
Border Adjustment
Border Adjustment

- **Incomplete**: does not apply to exports of goods
Border Adjustment

- **Incomplete:** does not apply to exports of goods
- **Partial:** often below extraction tax rate (as in Markusen), so extractors pay

\[
t_b = \frac{\varphi \epsilon_S^* Q_e^* + p_e (Q_e^* - C_e^{FF}) - p_e \partial \Pi_g / \partial p_e}{\epsilon_S^* Q_e^* + \epsilon_D^* C_e^{FF}}
\]
Border Adjustment

- **Incomplete**: does not apply to exports of goods
- **Partial**: often below extraction tax rate (as in Markusen), so extractors pay

\[ t_b = \frac{\varphi \epsilon^*_S Q^*_e + p_e (Q^*_e - C^F_F) - p_e \partial \Pi_g / \partial p_e}{\epsilon^*_S Q^*_e + \epsilon^*_D C^F_F} \]

- emissions externality
Border Adjustment

- **Incomplete**: does not apply to exports of goods

- **Partial**: often below extraction tax rate (as in Markusen), so extractors pay

\[
    t_b = \frac{\varphi e^*_S Q^*_e + p_e (Q^*_e - C_e^{FF}) - p_e \partial \Pi_g / \partial p_e}{\epsilon^*_S Q^*_e + \epsilon^*_D C_e^{FF}}
\]

- emissions externality

- terms of trade manipulation
Border Adjustment

• **Incomplete**: does not apply to exports of goods

• **Partial**: often below extraction tax rate (as in Markusen), so extractors pay

\[ t_b = \frac{\varphi \epsilon^* S Q^*_e + p_e (Q^*_e - C^F e) - p_e \partial \Pi_g / \partial p_e}{\epsilon^*_S Q^*_e + \epsilon^*_D C^F e} \]

• emissions externality

• terms of trade manipulation

• export policy
Export Policy
Export Policy

- 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 doesn’t remove that incentive
• **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 doesn’t remove that incentive

• **CDVW reasoning**: tax the better exporters to exploit market power
  
  • but don’t mess with the import margin
Export Policy

• **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 doesn’t remove that incentive

• **CDVW reasoning:** tax the better exporters to exploit market power
  - but don’t mess with the import margin

• **New reasoning:** subsidy applies to goods Home wouldn’t export with no policy
1. Model structure

2. Planner’s problem

3. Optimal unilateral policy

4. Quantitative illustration
• Impose functional forms for extraction and comparative advantage

  • constant supply elasticities, $\epsilon_S$, $\epsilon_S^*$ and constant trade elasticity $\theta$
Calibration Strategy

- Impose functional forms for extraction and comparative advantage
  - constant supply elasticities, $\epsilon_S$, $\epsilon^{*}_S$ and constant trade elasticity $\Theta$
- Calibrate to world with no carbon policy, using data on carbon flows, shown above
Calibration Strategy

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

• Calibrate to world with no carbon policy, using data on carbon flows, shown above

• All results are relative to this business as usual (BAU) competitive equilibrium
  
  • in which we normalize energy price = 1
Calibration Strategy

- Impose functional forms for extraction and comparative advantage
  - constant supply elasticities, $e_s$, $e_s^*$ and constant trade elasticity $\Theta$
- Calibrate to world with no carbon policy, using data on carbon flows, shown above
- All results are relative to this business as usual (BAU) competitive equilibrium
  - in which we normalize energy price = 1
- Compute outcomes for a range of marginal damages, $\varphi \in [0,2]$
  - i.e. consider Home’s marginal damages of up to twice the BAU energy price
Calibration of Energy Supply Elasticity

Home

![Graph showing fractions of energy extracted vs extraction cost for Home]

Foreign

![Graph showing fractions of energy extracted vs extraction cost for Foreign]

Upper 50th Percentile: $\varepsilon_s = 0.47$

Data

Upper 50th Percentile: $\varepsilon_s = 0.48$

Data
Calibrated Parameters

- Energy share in production
  - source: value of energy use and value added of production

\[ 1 - \alpha = 0.15 \]
Calibrated Parameters

• Energy share in production
  
  \[ 1 - \alpha = 0.15 \]

  • source: value of energy use and value added of production

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

  • source: oil fields from Asker, Collard-Wexler, and De Loecker (2018)
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
  \[ \sigma = \sigma^* = 1 \]
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)
  \[\theta = 4\]
Optimal Policy for the OECD
Simpler Policies

• If the planner chooses only $Q_e, X_e, p_e$

• with the rest determined competitively, outcome is an optimal pure extraction tax
Simpler Policies

• If the planner chooses only $Q_e, X_e, p_e$
  • with the rest determined competitively, outcome is an optimal pure extraction tax

• If the planner chooses only $X_e, p_e, \{y_j\}, \{m_j\}, \{z_j^y\}, \{y_j^m\}$
  • with the rest determined competitively, outcome is an optimal pure consumption tax
Simpler Policies

• If the planner chooses only \( Q_e, X_e, p_e \)
  • with the rest determined competitively, outcome is an optimal pure extraction tax

• If the planner chooses only \( X_e, p_e, \{y_j\}, \{m_j\}, \{z_j^y\}, \{y_j^m\} \)
  • with the rest determined competitively, outcome is an optimal pure consumption tax

• If the planner chooses over the union of these two
  • the outcome is an optimal hybrid of consumption and extraction tax
• If the planner chooses only $Q_e$, $X_e$, $p_e$
  • with the rest determined competitively, outcome is an optimal pure extraction tax

• If the planner chooses only $X_e$, $p_e$, $\{y_j\}$, $\{m_j\}$, $\{z^y_j\}$, $\{y^m_j\}$
  • with the rest determined competitively, outcome is an optimal pure consumption tax

• If the planner chooses over the union of these two
  • the outcome is an optimal hybrid of consumption and extraction tax

• We can also solve numerically for an optimal pure production tax as well as an optimal hybrid of consumption and production tax
Production and Consumption Taxes

- Marginal Damages
- Welfare Change (as % of initial goods consumption)

Graphs showing the relationship between Marginal Damages and World Emissions, with different elasticity scenarios.

Legend:
- BAU
- Optimal
- pure $t_c$
- pure $t_p$
- hybrid of consumption and production tax
Extraction and Consumption Taxes

Foreign Energy Supply Elasticity 0.5

Foreign Energy Supply Elasticity 1

World Emissions (gigatonnes of CO2)

Marginal Damages

Welfare Change (% of initial goods consumption)

Marginal Damages

BAU --- optimal --- pure $t_c$ --- pure $t_c$ --- hybrid of consumption and extraction tax
Leakage with Different Taxes

![Graphs showing marginal damages for different tax cases.]

(Due: 

0 0.5 1 1.5 2
0 0.5 1 1.5 2

Marginal Damages

Marginal Damages

Pure Extraction Tax Case

Pure Production Tax Case

Pure Consumption Tax Case

Unilateral Optimal Tax Case

Change in World Emissions

Change in Foreign Production

Change in Foreign Extraction

Change in Foreign Consumption

(Unit: gigatonnes of CO2)
Conclusions

• Theory reveals basic logic of optimal unilateral carbon policy
  • trade expands the reach of the policy
  • right mix of border adjustments makes a big difference
  • simpler hybrids can come close to the optimal
Conclusions

• Theory reveals basic logic of optimal unilateral carbon policy

  • trade expands the reach of the policy

  • right mix of border adjustments makes a big difference

  • simpler hybrids can come close to the optimal

• Readily accommodates extensions, such as renewable energy
Conclusions

• Theory reveals basic logic of optimal unilateral carbon policy
  • trade expands the reach of the policy
  • right mix of border adjustments makes a big difference
  • simpler hybrids can come close to the optimal

• 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)