Market Power Rents and Climate Change Mitigation

A Rationale for Export Taxes on Coal?

Philipp M. Richter, Roman Mendelevitch, Frank Jotzo

Roman Mendelevitch
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Export Taxes as a Tool of Climate Change Mitigation

Problem:
- High and increasing global demand for coal → high CO₂ emissions
- No global climate regime that would impose a cap on CO₂ emissions

Question: how to reduce CO₂ from coal demand?
- Unilateral climate policy (e.g. EU-ETS) may lead to carbon leakage (↓ demand → ↓ world price → ↑ consumption in other regions)
- Supply side policies to tackle the source (Sinn 2008, Haftendorn 2012, Harstad 2012)

Here: Analysis of supply restrictions of coal (e.g., via an export tax)
- Generation of tax revenues, improvement of the terms-of-trade, and reduction of worldwide CO₂ emissions

Short-term and long-term reactions of interest !!!
Focus on Steam Coal and Major Exporters

World steam coal seaborne trade in 2012: 967 Mt

→ Australia 16.5% of exports

Australia: Major exporter with impact on world price + climate change awareness (?!)

Source: own illustration based on IEA, 2013. Coal Information
Agenda

1. Motivation
2. A Two-Level Game: Methodology and the Model
3. Results – Australian Export Tax vs. Coalition
4. Discussion of Limitations
5. Conclusions & Next Steps
Setting-Up a Two-Level Game as an Mathematical Program with Equilibrium Constraints (MPEC)

The Upper Level
- country $g$ that takes the market reaction into account (lower level)
- Decision variable: (starting value) of an (energy based) export tax
- Maximization of the NPV of tax revenues
Lower Level – Structure

P: Producers
E: Exporters
C: Consumption
\{\}: Capacity restriction

\$/t

Production costs

Q

Transport costs

\$/GJ

Port fees

Freight rates

\$/GJ

P: Producers
E: Exporters
C: Consumption
\{\}: Capacity restriction

Source: Haftendorn et al. 2012
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The Lower Level – Equilibrium in...
- Large-scale multi-period model of (competitive) steam coal market
  - CoalMod-World (Haftendorn et al. 2012 and Holz et al. 2015)
- Profit-maximizing players with specific constraints
  - Producers and Exporters
- Market clearing via inverse demand functions
- Model features:
  - Mine mortality effects on costs and production capacities
  - Endogenous investment in production and export capacities
  - Substitution between importing and domestic production
Example: A Producer’s Optimization Problem

Each producer $f$ maximizes its discounted profits ...

$$\max_{x_{a,f,c}, y_{a,f,e}} \Pi_f = \sum_c \left( \frac{1}{1 + r_f} \right)^{a-1} \left[ \sum_c p_{a,c} x_{a,f,c} + \sum_e p_{a,e} y_{a,f,e} \right]$$

$$- \left( m_{c}^{int} \kappa_f \left( \sum_c x_{a,f,c} + \sum_e y_{a,f,e} \right) + 0.5 m_{c}^{slp} (\kappa_f)^2 \left( \sum_c x_{a,f,c} + \sum_e y_{a,f,e} \right)^2 \right)$$

$$- \left[ \sum_c trans_{a,f,c} x_{a,f,c} - \sum_e trans_{a,f,e} y_{a,f,e} \right]$$

$$- P_{inv_{a,f}} C P_{inv_{a,f}} - \sum_c T_{inv_{a,f,c}} C T_{inv_{a,f,c}} - \sum_e T_{inv_{a,f,e}} C T_{inv_{a,f,e}} \right]$$

where marginal costs increase in accumulated extraction via:

$$m_{c}^{int} = m_{c}^{int} \kappa_f \left( \sum_c x_{a-1,f,c} + \sum_e y_{a-1,f,e} \right) \text{const}_f$$
Example: A Producer’s Optimization Problem (ctd.)

s.t. the following constraints:

• Production capacity constraint
• Maximum annual investment in production capacity constraint
• Reserve constraint
• Transport capacity constraint
  • To consumption node
  • To exporter
• Maximum annual investment in production capacity constraint
• Maximum annual investment in production capacity constraint
Example: An Exporter’s Optimization Problem

Each exporter $e$ maximizes its discounted profits ...

$$\max_{z_{aec} Einv_{a,e}} \Pi_e = \left( \frac{1}{1 + r_e} \right)^{a-1} \left[ \sum_c z_{a,e,c}P_{ac} \right]$$

$$- \sum_c \left( z_{a,e,c}p_{ae} + \kappa_e^s z_{a,e,c}f_{ee}^p + \kappa_e^s z_{a,e,c}e \text{,separate}_{a,e,c} + \tau^e_0 \cdot (1 + r_t)^{a-1} z_{a,e,c} \right)$$

$$- Einv_{a,e} CE_{inv_{a,e}}$$

s.t. to constraints:

- Maximum export capacity constraint
- Maximum annual investment in export capacity constraint
Solution Techniques for MPECs in GAMS

There exist different solution techniques for MPECs (with pros and cons)

- NLPEC (commercial) GAMS solver
  - Lower level formulated by means of Karush-Kuhn-Tucker conditions as a Mixed Complementarity Problem (MCP)
  - Pro: fast solve
  - Con: opaque, only local optima
Example: complementarity conditions for exporters’ optimization problem with respect to $z_{a,e,c}$

I. \[ z_{aec} \geq 0 \]

II. \[
\left( \frac{1}{1 + r_e} \right)^{a-1} \left[ -p_{ac} + p_{ae} + \kappa^s_e \text{searate}_{a,e,c} + \kappa^s_e \text{free}_{e} + \tau^e_0 \cdot (1 + r_t)^{a-1} \right] \\
+ \text{duals} \geq 0
\]

III. \[
\left( \frac{1}{1 + r_e} \right)^{a-1} \left[ -p_{ac} + p_{ae} + \kappa^s_e \text{searate}_{a,e,c} + \kappa^s_e \text{free}_{e} + \tau^e_0 \cdot (1 + r_t)^{a-1} \right] \\
+ \text{duals} \right) \cdot z_{aec} = 0
\]
There exist different solution techniques for MPECs (with pros and cons)

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- **Disjunctive Constraints in MIP formulation (based on Gabriel and Leuthold, 2010)**
  - Conversion of complementarity conditions to disjunctive constraints (binary variables plus large numbers)
  - Discretized tax rate to avoid bilinear term (tax*quantity)
  - Pro: global optimum
  - Con: choice of large numbers, discretized tax
Rewrite the objective function:

- Define a set \( d \) of exogenous tax rates
- Relate them to binary variables

\[
obj = \max \sum_{d} r_{e}(d)
\]

\[
r_{e}(d) \leq \sum_{a,e',e''} \left( \frac{1}{1 + r_{g}} \right)^{a-1} \left[ \tau_{0,d}^{e} \cdot (1 + r_{-})^{a-1} \cdot EXP_{a,e',e''} \right]
\]

\[
\sum_{d} bin_{\tau}(d) = 1
\]

\[
r_{e}(d) \leq K_{\tau}(d) \cdot bin_{\tau}(d)
\]

- The optimal tax rate (of given ones) is chosen by setting the value of one binary variable to unity
MIP Lower Level – Disjunctive Constraints

Rewrite the lower level:

• Replace complementarity conditions by disjunctive constraints

Continued Example complementarity conditions for exporters’ optimization problem with respect to $z_{a,e,c}$

$$0 \leq \left( \frac{1}{1+r_e} \right)^{a-1} \left[ -p_{ac} + p_{ae} + \kappa_{es} \text{searate}_{a,e,c} + \kappa_{es} \text{fee}_{e,\text{port}} + r_0^e \cdot (1 + r_t)^{a-1} \right]$$

$$+ \text{duals} \leq bin_{z}(a, e, c) \cdot K_z(a, e, c)$$

$$0 \leq z_{a,e,c} \leq (1 - bin_{z}(a, e, c)) \cdot K_z(a, e, c)$$

Where $K_z$ is a sufficiently large number to ensure the complementarity
Represented countries by type:

- 40 consumption nodes (C), 25 producers (P), and 14 exporters (E)
- Multi-period model with yearly equilibria in 5-years-steps from 2010 to 2035

**Base Case**: New Policies Scenario of World Energy Outlook 2012 (IEA, 2012)
- Increasing coal consumption over time (20% until 2035);
- Dominant consumers: China and India; increasing exports of the USA
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Four partial effects on the mass balances relative to the *Base Case*:

1. Australian exports are reduced

2. Australian domestic consumption is increased

3. RoW production is increased
   - Exporting competitors increase their supply
   - Importing countries increase domestic production

4. RoW consumption is reduced
Case – Australian Export Tax

**Tax Setter:** Australia  
**Tax Type:** Export Tax  
**Discount Rate:** 5%  
**Annual growth rate of tax:** 2.5%

**Initial Tax Rate:** 0.66 USD/GJ  
(18 USD/ton of Australian coal, 6.7 USD/tCO₂)

**NPV Tax Revenues:** 16 bn. USD

![Graph](image-url)  
*Figure 2: Time paths of the export tax rate and resulting tax revenues*
Case – Australian Export Tax - Global Impact

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• Unilaterally reduced Australian production is largely compensated for (leakage of 70%)
• USA, Russia and Indonesia substitute Australian exports
• Domestic production increases esp. in China and India
• Volumes of seaborne trade are reduced by 40-50 Mt per year
• Price effect only in 2015

Figure: Change in exports and production for domestic consumption relative to the base case, in Mt.
Case - Export Tax Coalition

**Tax Setter:** Australia, Colombia, Indonesia and South Africa

**Discount Rate:** 5%

**Annual growth rate of tax:** 2.5%

**Tax Type:** Export Tax

**Initial Tax Rate:** 0.99 USD/GJ (10.1 USD/tCO₂)

**NPV Tax Revenues:** 125 bn. USD

**AUS NPV Tax Revenues:** 16 bn. USD

**Optimal tax level**

**Figure 2:** Time paths of the export tax rate and resulting tax revenues

- **Tax revenue AUS**
- **Tax revenue COL**
- **Tax revenue IDN**
- **Tax revenue ZAF**
- **Change in global consumption**
- **Change in exports from coalition**
- **Change in total exports**

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Case – Export Tax Set by Coalition Global Impact

- Smaller leakage effect, larger reduction in global consumption
- Emissions reduced by on average 200 Mt CO₂ per year
- Significant price increase due to export tax

Figure: Change in exports, production for domestic consumption and weighted consumer price, relative to the base case, in Mt.
Some Considerations on Sensitivity

Export tax vs. Production tax

- Production tax consistently yields higher optimal tax rates and higher tax revenue, but ...
- exploits domestic consumers 100% dependent on domestic production

Include additional coalition member: USA

- Optimal tax rate increases by 20%, but ...
- US share of coalition tax revenue is very small compared to others
- → collusion incentives and stability of coalition needs to be further examined

Optimal tax rate is robust to different levels of the discount rate

Optimal tax rate and NPV is sensitive to annual growth rate of tax

- Highest NPV is achieved with growth rates between 0 and 2.5% per year
Short Discussion of Approach

What we do take into account:
• Production increases of exporting competitors
• Substitution between domestic production and imports
• Endogenous capacity expansions

What we do not / cannot take into account:
• Fuel substitution in partial coal model
  • Only indirectly in demand function
  • Hence, upper level of emissions reductions
• Retaliation of other exporters or importers
• Endogenous paths of tax rate
• Stability of coalition or distribution mechanism
Conclusions

Two motives which might justify an export tax on coal
• Rent extraction (and terms-of-trade improvement)
• Climate change mitigation

Non-negligible Australian export tax based on tax revenue maximization
• Large leakage effects, small climate effect
• Short-term and long-term reactions via investments
• Coalition policy may lead to welfare increases for exporters
• Production tax consistently show higher tax level and high NPV, but...

Outlook & next steps
• Focus on rent distribution
• More elaborate upper level at the costs of solution techniques?
Thank you for your attention.