Carbon Taxation if Liquefied Coal will (not) Substitute Oil

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Introduction

Intro: Background

- Leakage crucial for climate policy, widely studied
- Fuel channel dominant
- Often CGE
  - often static (fuel supply)
  - sectors use aggregage 'energy' inputs → sector specific leakage (and pricing)

Intro: Paper in a Nutshell

- Fuel depletion (and future developments and discounting) crucial
  - w/o future developments & discounting: leakage $\rightarrow 100\,\%$

$\rightarrow$ Here: dynamic model of fuel market with depletable fuels

- discounting $\rightarrow$ leakage oil $\approx +50\,\%$, coal $< 10\,\%$
- future CTL $\rightarrow$ leakage oil $\approx -75\,\%$, coal $\approx +10\,\%$

$\Rightarrow$ **optimal fuel emission tax** thus **fuel-specific**, **scenario dependent**

Efficient Climate Tax

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Reality: only *regional* policy
$\Rightarrow$ At least regionally *uniform* tax?

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NO!

Regional emissions affect emissions elsewhere

Taget is reduction of global (not regional) emissions

$$\Rightarrow \quad T_i^* = \mathrm{WTP}_{glob\,\mathrm{CO}_2} \quad \cdot \quad glob\,\mathrm{CO}_2 \text{ of } i$$

$$\Rightarrow \quad \tau_i^* = \mathrm{WTP}_{glob\,\mathrm{CO}_2} \quad \cdot \quad \underbrace{glob\,\mathrm{CO}_2 \text{ of } i \,/\, reg\,\mathrm{CO}_2}_{\equiv 1 - leakage_i}$$

Exhaustibility: oil vs. coal

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Loads of Coal – Limited Oil

Exhaustibility: oil vs. coal

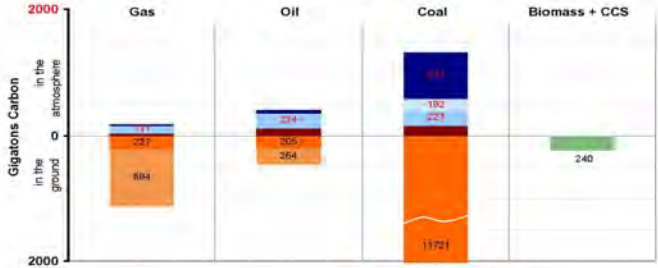
Loads of Coal – Limited Oil

E.g. van der Ploeg & Withagen 2011[1]

- "Oil [...] at most another half a century", "coal [...] another 3-4 centuries"
- "Coal relatively cheap to extract compared to oil"

→ they assume **oil exhaustible & coal limitless**

Figure 1: Coal Reserves dominate Gas and Oil Reserves



Exhaustibility: oil vs. coal

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E.g. International Energy Agency 2010[2]

	Reserves (incl. unconv)	Reserves/Production
Oil	1350 Gbbl	46 years
Coal	1000 Gt	210 years

Exhaustibility: oil vs. coal

Loads of Coal – Limited Oil

E.g. International Energy Agency 2010[2]

	Reserves (incl. unconv)	Reserves/Production	Resources
Oil	1350 Gbbl	46 years	×3
Coal	1000 Gt	210 years	×15

Dynamic Fuel Market Model

Model: Framework

Small dynamic equilibrium model for oil & coal.

Regions OECD and non-OECD (ROW), $r = \{o, n\}$

Fuels oil and coal, $i = \{1, 2\}$, Prices p_i, Emission intensities ε_i

Regional fuel consumption $x_r = \{x_{r,1}, x_{r,2}\}$

Regional Utility of fuel cons. $u_r(x_r)$: $2^n d$ order Taylor polynomial

Global Emissions $E = \sum_{r,i} x_{r,i}\varepsilon_i$

Emission tax in OECD.

Model: Fuel Consuming Regions

- Instantaneous regional welfare W_r
  $$W_r = \underbrace{u_r(x_r)}_{\text{fuel cons.util.}} \underbrace{-c_r(x_r)}_{\text{fuel cost}} \underbrace{-D_r(E)}_{\text{emiss.disutil.}}$$

- Present discounted total welfare
  $\mathbb{W}_r = \int_t W_{r,t}^{\delta \cdot t} \mathrm{d}t$, where δ discount factor $\delta = 1 - \rho_{\text{cons}}$

- Decentralized regional **fuel consumption decision - FOCs**:
  - No Tax: $\frac{\partial u_r(x_r)}{\partial x_{r,i}} \stackrel{!}{=} p_i \quad \underset{i}{\forall}$
  - Tax: $\frac{\partial u_r(x_r)}{\partial x_{r,i}} \stackrel{!}{=} p_i + \tau_i \varepsilon_i \quad \underset{i}{\forall}$

Model: Fuel Suppliers – Hoteling Framework

Rate of supply (=consumption) r_t

Inverse fuel demand $p_t(r_t)$

Cumulative extractions $A_t = \int_{s=0}^{t} r_s \mathrm{d}s$, and $A_0 = 0$

Extraction cost curve $e(A_t)$, $e'(A_t) > 0$

Maximize present discounted net profits

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$\rightarrow$Hamiltonian

$$\mathcal{H} = r_t \cdot (p_t(r_t) - e(A_t)) - \lambda_t r_t$$
$$\text{s.t.} \quad \dot{A} = r_t$$

FOCs

$$\frac{\partial \mathcal{H}}{\partial r_t} = 0 : \quad p_t(r_t) \stackrel{!}{=} e(A_t) + \lambda_t$$
$$\dot{\lambda}_t = \rho_{\mathrm{res}} \lambda_t + \frac{\partial \mathcal{H}}{\partial A_t} : \quad \dot{\lambda}_t \stackrel{!}{=} \lambda_t \rho_{\mathrm{res}} - \dot{e}_t$$

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Model: Specification

CONSUMERS

- Fuel Demand
  Benchmark *q* & *p*

	Consumption[2]		Price[8]
	OECD	ROW	
Oil	16.4 Gbbl	14.3 Gbbl	76 $/bbl
Coal	1.61 Gt	3.12 Gt	83 $/t

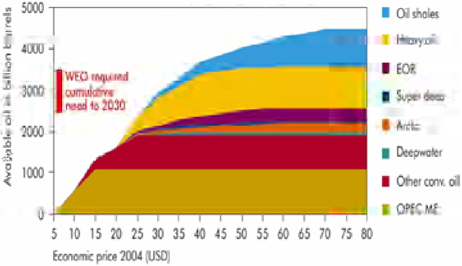
- Elasticities: Direct: -0.9, Cross-price: avg. 0.2 (close to Golombek&al.'95[3])
- Policy: Emission discount rate 0.5 %
- OECD: WTP $= 40\,\$/\mathrm{tCO}_{2,\mathrm{glob}}$

Model: Specification

SUPPLIERS

- **Extraction cost curve**

Oil (International Energy Agency):



Coal:

Exponential increase

$c(A) = c_0 \cdot 2^{A/A_d}$,

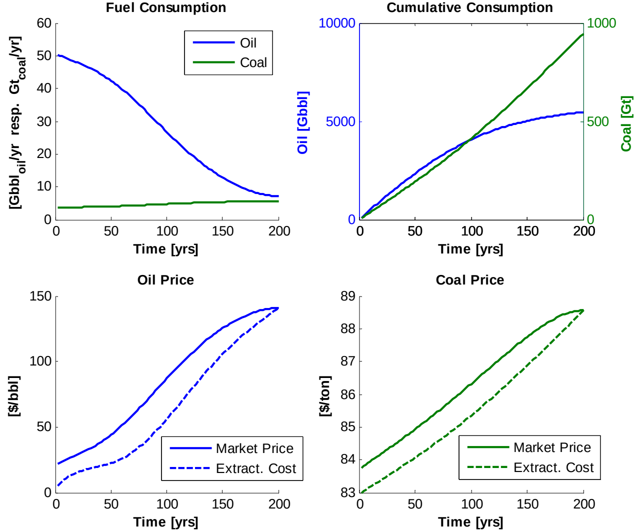
$A_d = 10\,000\,\mathrm{Gt}$ (slow)

$A_d = 1000 \text{ or } 2000\,\mathrm{Gt}$ (rapid)

- Time-discount rate for profit: $\rho_{\mathrm{res}} = 3\,\%$

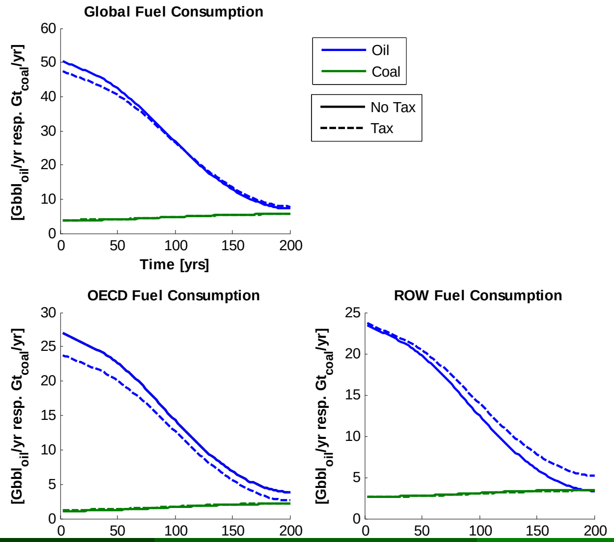
Model: Results

Time path, no tax (BAU)



Model: Results

Tax effect, e.g. oil (Tax vs. BAU)



Model: Results - Definition τ^*

'Definition' Optimal OECD *Climate* Tax

$$\tau^* \equiv \underbrace{\tau^*_{\text{tot}|\text{WTP}=40}}_{\text{climate + terms-of-trade}} - \underbrace{\tau^*_{\text{tot}|\text{WTP}=0}}_{\text{terms-of-trade}}$$

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$$\tau^* \equiv \underbrace{\tau^*_{\text{tot|WTP=40}}}_{\text{climate + terms-of-trade}} - \underbrace{\tau^*_{\text{tot|WTP=0}}}_{\text{terms-of-trade}}$$

Will correspond to discounting-adjusted **WTP·'1-leakage rate'**

Model: Results

Optimal tax rates (Tax vs. BAU)

	Tax [$\$/\,\mathrm{tCO_2}$]
Oil	20
Coal	38

for WTP 40 $\$/\,\mathrm{tCO_2}$ for global emission reductions.

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Extension: Liquefaction (CTL)

Liquefaction: Overview

-Depleting Oil soon expensive; then CTL delivers SynOil
-OECD does not liquefy coal by itself, due to pricing of emissions.

-SynOil in medium-run and large abundance of coal $\Rightarrow$ *domestic* oil consumption *translates* $\approx$1:1 to *global* oil consumption

$\Rightarrow$ Each bbl oil bought by OECD implies $\approx$1 more barrel of SynOil to be produced, with well-to-wheel emissions $>$2x as high.

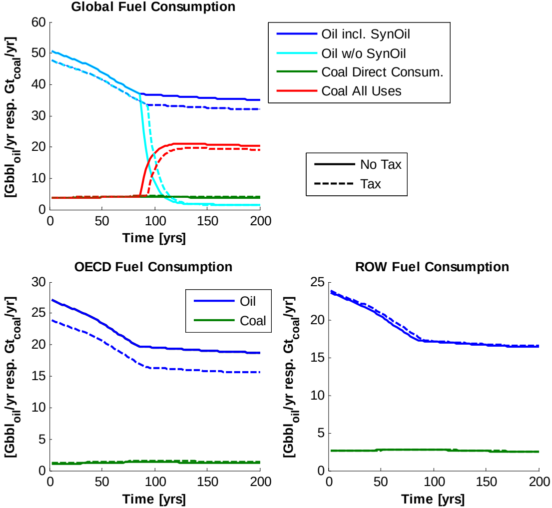
$\Rightarrow$**Uniform tax very inefficient**: favouring of oil over coal as energy source, despite larger induced emissions.

Liquefaction: Implementation

CTL

- Yield: $2\,\mathrm{bbl}_{\mathrm{oil}}/\mathrm{ton}_{\mathrm{coal}}$, [4,5]
- Overhead cost: $15\,\$/\mathrm{bbl}$
- Emissions $\varepsilon_{\mathrm{SynOil}}/\varepsilon_{\mathrm{CrudeOil}} = 2.3$. [6,7]

Tax effect, e.g. oil (Tax in CTL-scenario)



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Liquefaction: Results

Optimal tax rates (Scenario with CTL)

	Tax [$/ tCO_2]
Oil	70 1¾WTP
Coal	36 WTP

for WTP 40 $/ tCO_2 for global emission reductions.

Summary Model Results

- Coal leakage low
- Oil leakage: $\approx 50\,\%$ in BAU scenario, $\approx -70\,\%$ in CTL scenario

⇒ **Optimal taxes**

	BAU		CTL	
Oil	20	½WTP	70	1¾WTP
Coal	38	WTP	36	WTP

in $\$/\,\mathrm{tCO_2}$ for WTP=40$\$/\mathrm{tCO}_{2,\mathrm{glob}}$

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in $\$/\,tCO_2$ for WTP=$40\$/tCO_{2,glob}$

! Note !

If CTL expands in *future*, this implies *already for current tax* on oil emissions: $\tau^*_{oil} > WTP_{CO_{2,glob}}$!

Robustness

Largely robust to:

(i) Longer time-horizon, (ii) cross-elasticities, (iii) resources belonging to OECD&ROW, (iv) faster coal depletion, (v) growing demand, (vi) emission intensity unconventional oil

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Some influence:

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- Late CTL: more uniform tax (larger leakage & discounting of CTL-emissions)
- Exogenous stoch. backstop: less pronounced tax differentiation (depending on CTL-timing and discount rate)

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  - ▶ **Confirms:** Future Developments & Discounting of prim. import.!

Interpretation

- Leakage inherently dynamic problem, cannot reasonably be dealt with in static (supply) setting
- Future climate relevant developments crucial for attributable leakage from current policies
- Ditto for discount factor (absolutely missing in traditional leak.lit.)
- Fuel-differentiation potentially important

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Limits of this analysis

- Only very rough estimates
- Fuel trade costs and final goods trade to be modelled
- Demand can be modelled in more detail

Thank you for your attention

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Literature

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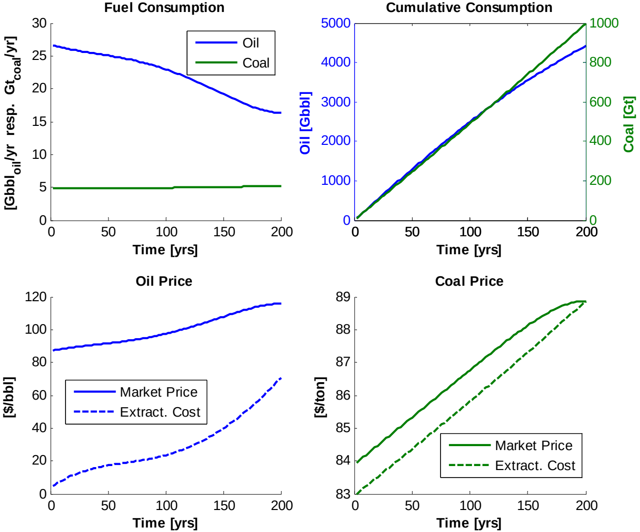
Appendix

Time Path, Monopolistic Supply (BAU)



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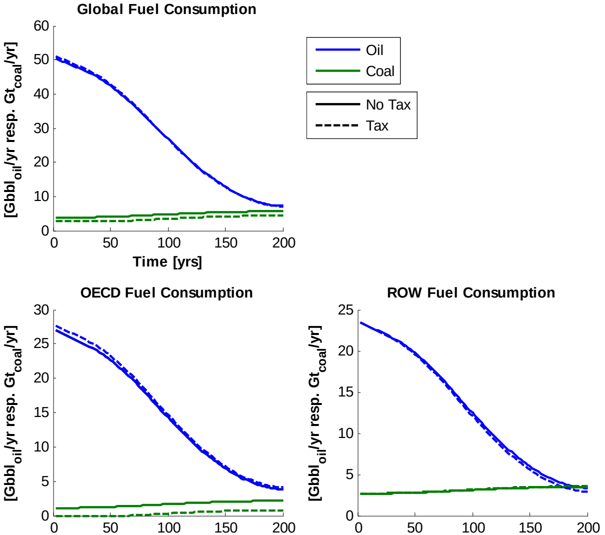

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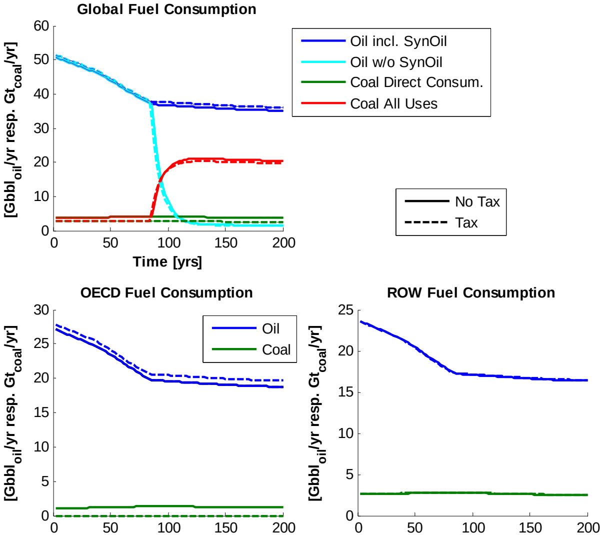

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