

How Much Greener is Really Green? Carbon Taxation Design and Resource Extraction (joint with Darko Jus)

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Outline

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Global Warming

- Carbon dioxide (CO_2) is the most important greenhouse gas; atmospheric concentration has risen by 35% since 1835.
- Carbon atoms in oil, gas or coal extracted from ground to be used as fuel end up in the atmosphere.
- Current environmental policy addresses mainly the demand of carbon but neglects the supply.
- Can today's carbon taxation design actually induce resource owners to extract on a lower scale?

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Literature

- Gray (1914), Hotelling (1931): price of a natural resource must rise at the rate of interest (“Hotelling Rule”)
- Long (1975): impact of insecure property rights on resource extraction
- Dasgupta and Heal (1979): comprehensive treatment of resource extraction problems
- Long and Sinn (1985): consequences of surprise price shifts on resource extraction
- Sinn (2007): demand reducing policies (i.e. increasing carbon taxes) may lead to more extraction in the short-run

Research question

- What is the effect of taxation on the demand side on the extraction path of a carbon resource?
- It is well known what are the effects in a static equilibrium type of analysis, BUT in a dynamic analysis things are different.
- What policy recommendation can we derive from the analysis in order to reduce carbon extraction?

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Model set-up

- Resource owner faces an aggregated global demand: $D(p)$
- Resource owner faces an aggregated global tax-policy: $v(\theta)$
- The consumer side is taxed (NOT the producer side)
- We observe the (positive not normative) behaviour of a single resource owner who has certain characteristics:
 - Cost structure: C
 - Endowment: S_0
 - Market share: $D(p(R))$
- Continuous time structure $0 \leftrightarrow \infty$ which is split in:
 - $0 \leftrightarrow w$, the informed short-run for which the tax-policy is known.
 - $w \leftrightarrow \infty$, the uninformed long-run for which tax-policy expectations are build depending on the short-run tax-policy

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- We use a dynamic optimization approach to solve the resource owners maximization problem.
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 - First step: solve the long-run problem to use the result in the
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- Analyse the reaction of the extraction path in order to derive recommendable tax-policies.

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Dynamic maximization problem

$$\begin{aligned} \max_{R_t} \int_0^w e^{-\rho t} [p_t(R_t) \cdot R_t - c_t \cdot R_t - v_t(\theta) \cdot R_t] dt \\ + \int_w^\infty e^{-\rho t} [p_t(R_t) \cdot R_t - c_t \cdot R_t - \tilde{v}_t(\theta) \cdot R_t] dt \end{aligned} \quad (1)$$

$$\dot{S} = -R_t \quad (2)$$

$$S(0) = S_0 \quad (3)$$

$$\lim_{t \rightarrow \infty} S(t) \geq 0 \quad (4)$$

where S is the stock of the non-renewable resource, R the

Tax function

For the short-run the announced tax policy is a function of time t and θ where θ is the government policy variable (with $\partial v_t(\theta) / \partial \theta > 0$ and differentiable towards time and tax policy parameter).

$$v_t = v_t(\theta) \quad \text{for} \quad t \leq w \quad (5)$$

For the long-term the resource owner has simple expectations regarding the tax policy:

$$v_t = D + \beta \cdot v_w[\theta] \quad \text{for} \quad t > w \quad (6)$$

Inverse demand function

Market inverse demand function, where Q is the total extracted quantity:

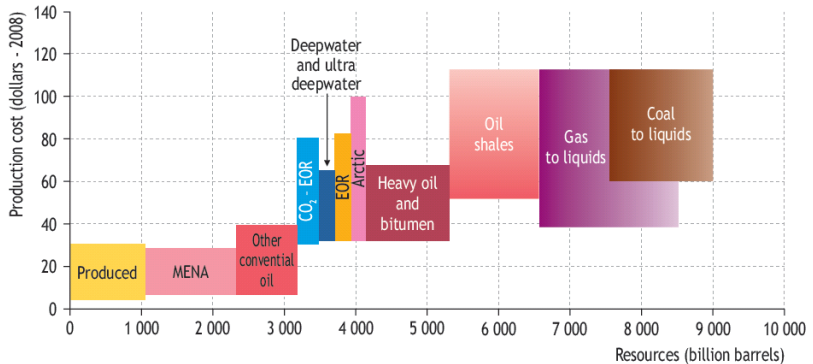
$$\tilde{p}_t(Q_t) = A - B \cdot Q_t \quad (7)$$

Individual inverse demand function which the representative resource owner faces (η being the market share):

$$p_t = A - B \cdot \left([1 - \eta] \cdot Q_t + \underbrace{\eta \cdot Q_t}_{R_t} \right) \quad (8)$$

We allow for any market structure.

Cost function



Source: WEO 2008

Model Solution

First step: solve stage 2 optimization:

$$\max_{R_t} \int_w^{\infty} e^{-\rho t} [p_t(R_t) \cdot R_t - c_t \cdot R_t - v_t(\theta) \cdot R_t] dt \quad (9)$$

Result:

$$R_t = \frac{A - C - (D + \beta \cdot v_w[\theta]) - e^{\rho \cdot (t-T)} (A - C - (D + \beta \cdot v_w[\theta]))}{B \cdot m} \quad (10)$$

Model Solution

Rearrange to get the intertemporal optimality condition:

$$\underbrace{\underbrace{A - m \cdot B \cdot R_t}_{\text{marginal revenue}} - \underbrace{C}_{\text{marginal cost}} - \underbrace{(D + \beta \cdot v_w [\theta])}_{\text{marginal tax}}}_{\text{marginal profit}}$$

$$= \underbrace{e^{\rho \cdot (t-T)} (A - C - (D + \beta \cdot v_w [\theta]))}_{\text{PV of marginal profit of extraction in T}} \quad \text{for } t > w \quad (11)$$

Model Solution

Second step: solve stage 1 optimization given stage 2 results:

$$\max_{R_t} \int_0^w e^{-\rho t} [p_t(R_t) \cdot R_t - c_t \cdot R_t - v_t(\theta) \cdot R_t] dt \quad (12)$$

Result: Hotelling Rule

$$\rho = \frac{\dot{p}_t - \frac{\partial v_t[\theta]}{\partial t}}{p_t - C - v_t[\theta]} \quad (13)$$

Model Solution

Result:

$$R_t = \frac{A - C - v_t[\theta] - e^{\rho \cdot t} \cdot \lambda_0}{B \cdot m} \quad \text{for } t < w \quad (14)$$

$$\lambda_0 = -W \left[-e^{-1 - \rho \cdot w \cdot \frac{S_0 \cdot B \cdot m}{w} - D - \beta \cdot V_w[\theta] + \frac{\int_0^w v_t[\theta] dt}{w}} \right] (A - C - D - \beta \cdot v_w[\theta]) \quad (15)$$

$$T[\theta] = -\frac{1}{\rho} \cdot \ln \left[-W \left[-e^{-1 - \rho \cdot w \cdot \frac{S_0 \cdot B \cdot m}{w} - D - \beta \cdot V_w[\theta] + \frac{\int_0^w v_t[\theta] dt}{w}} \right] \right] \quad (16)$$

Tax-elasticity of the stock

What happens if green taxes increase? For a carbon tax policy to mitigate global warming it is necessary that this policy induces resource owners to postpone extraction! Thus we analyze now the effect of a change in the tax trend θ on the stock of the resource for any given point in time.

$$S_t = S_0 - \int_0^t R_x \, dx \quad \text{for } t < w$$

Tax-elasticity of the stock

The tax-elasticity of the stock is then:

$$\varepsilon_{S_t, \theta} = \frac{\partial S_t}{\partial \theta} \frac{\theta}{S_t} = \frac{e^{-\rho \cdot T[\theta]} \cdot \theta}{\underbrace{\rho \cdot m \cdot B \cdot S_t}_{\oplus}} \cdot \underbrace{\left(e^{\rho \cdot T[\theta]} \cdot \rho \cdot \int_0^t \frac{\partial v_t[\theta]}{\partial \theta} dt - (e^{\rho \cdot t} - 1) \cdot \left(\rho \cdot \lambda_{T[\theta]} \cdot \frac{\partial T[\theta]}{\partial \theta} - \frac{\partial \lambda_{T[\theta]}}{\partial \theta} \right) \right)}_{?} \quad (17)$$

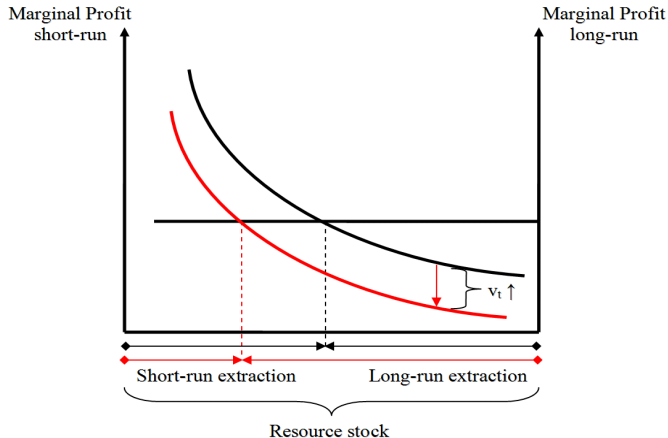
The sign of the elasticity therefore depends only on the term shown in brackets.

Tax-elasticity of the stock

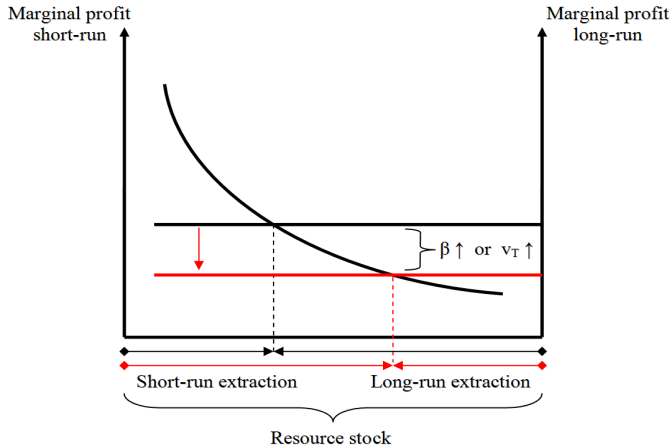
The sign of the elasticity therefore depends only on the term shown in brackets. It is positive, meaning the stock is higher, whenever:

$$e^{\rho \cdot T[\theta]} \cdot \rho \cdot \int_0^t \frac{\partial v_t[\theta]}{\partial \theta} dt \geq (1 - e^{\rho \cdot t}) \cdot \left(\rho \cdot \lambda_{T[\theta]} \cdot \frac{\partial T[\theta]}{\partial \theta} + \beta \cdot \frac{\partial v_w[\theta]}{\partial \theta} \right) \quad (18)$$

Change in the short-run tax-policy



Change in the long-run tax expectations



Sufficient condition to increase the resource stock

What would be at global-tax-policy that satisfies this condition?

$$\int_0^t \frac{\partial v_t [\theta]}{\partial \theta} dt \geq \frac{1 - e^{\rho \cdot t}}{1 - e^{\rho \cdot T[\theta]}} \cdot \left(\frac{1}{\lambda_{T[\theta]}} \cdot (m \cdot B \cdot S_0 - (A - C) \cdot w \right. \\ \left. + \int_0^w v_t [\theta] dt + \frac{(1 - e^{\rho \cdot T[\theta]}) \cdot \lambda_{T[\theta]}}{\rho \cdot e^{\rho \cdot T[\theta]}} \right) \cdot \beta \cdot \frac{\partial v_w [\theta]}{\partial \theta} - \int_0^w \frac{\partial v_t [\theta]}{\partial \theta} dt \quad (19)$$

assume $\beta \cdot \frac{\partial v_w [\theta]}{\partial \theta} = 0$ then:

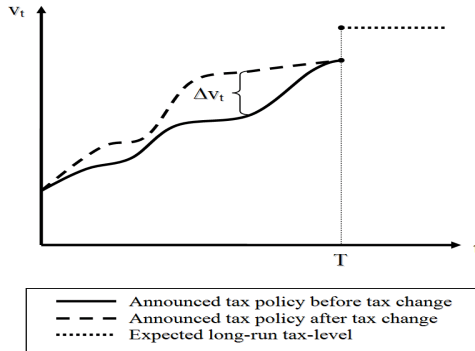
$$\int_0^t \frac{\partial v_t [\theta]}{\partial \theta} dt \geq - \frac{1 - e^{\rho \cdot t}}{1 - e^{\rho \cdot T[\theta]}} \cdot \int_0^w \frac{\partial v_t [\theta]}{\partial \theta} dt \quad (20)$$

which is always fulfilled.

Optimal tax policy

Sufficient condition for a tax increase to be strictly beneficial:

$\beta \cdot e^{\rho[t-T]} \cdot \partial v_T(\theta) / \partial \theta = 0$, i.e. either $\beta = 0$ or $\partial v_T(\theta) / \partial \theta = 0$.



Necessary condition to increase resource stock

What would be a global-tax-policy that just satisfies this condition?

$$\rho \cdot \lambda_{T[\theta]} \cdot \frac{\partial T[\theta]}{\partial \theta} + \beta \cdot \frac{\partial v_w[\theta]}{\partial \theta} = \rho \cdot \frac{e^{\rho \cdot T[\theta]}}{1 - e^{\rho \cdot w}} \cdot \int_0^w \frac{\partial v_t[\theta]}{\partial \theta} dt \quad (21)$$

It is easy to see that, with Υ and v being arbitrary constants, the tax function that satisfies this condition is:

$$v_t[\theta] = \theta \cdot \Upsilon \cdot e^{v \cdot t} \quad (22)$$

with the boundary condition that $v \leq \text{growth}$ in the long run.

Outlook

- Generalization of the model
 - Demand function
 - Cost structure
 - Expectations
- Ad-valorem tax
- Welfare implications beyond climate issues, f.e. transfer of the resource owners oligopolistic rents to the consuming countries.

Conclusions

- As long as not (almost) all countries commit to carbon-caps the aggregated global tax-policy might accelerate carbon-extraction.
- If used sensible and designed carefully, carbon-taxes are an alternative instrument to tradeable-certificates.
- When designing national carbon-tax policy it is important to look beyond borders:
 - What other policies are in place and how will my policy change the world-carbon-tax regime.
 - What are the reactions to the carbon-tax of the consumers AND the resource owners!

End

Thank you for your comments and questions!