Coase, Hotelling and Pigou: Perspectives on a Carbon Tax

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Outline

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Overview

- General agreement that a price on carbon is a prerequisite to solving the climate problem
- Tax in the range \$20-\$50/ton CO2 often recommended
- Evaluation generally in a static context - but this is a dynamic problem that will play out over decades

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Framework

- Usual inspiration is Pigou - but Hotelling also has something to contribute
- All fossil fuels are exhaustible resources not produced goods
- Can be used now or in the future - depends on price trajectory. Price trajectory rather than price level determines supply.
- So we have to consider that a tax may change the pattern of use over time

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Conclusions

- Simplest case - tax will not reduce consumption at all but merely delay it
- More generally tax may make high cost supplies unprofitable and drive them out of the market
- Tax will have a big impact on coal and gas demand but little on oil demand
- Some high-cost oil supplies will be driven from the market but unless the tax is > $250 most supplies will still be consumed but at a later date

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Literature

- Based heavily on Dasgupta and Heal (1979) and Dasgupta Heal and Stiglitz (1980)
- More recently Sinn on the "Green Paradox" and later papers by Hoel and Cairns: could a tax increase CO2 emissions?
- Gerlagh distinguishes between weak and strong green paradoxes: weak paradox occurs when policies increase near-term carbon emissions, but not total emissions. The strong paradox is used for cases when total emissions are increased. van der Ploeg and Witthagen show that the anticipation of a drop in the price of renewable energy may also generate a green paradox, encouraging the more rapid use of fossil fuels

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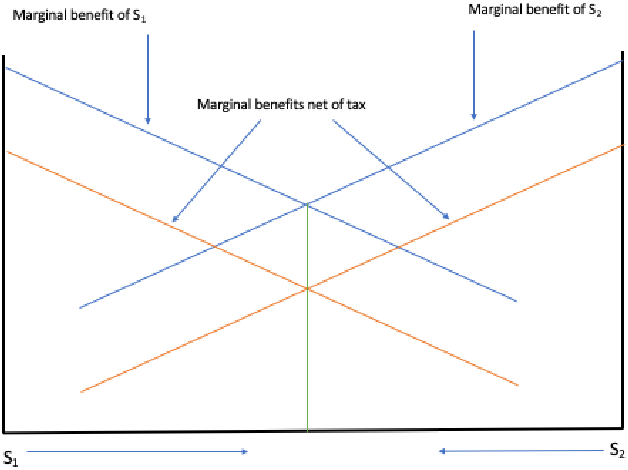
Marginal benefit of S_1
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Marginal benefits net of tax
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S_2

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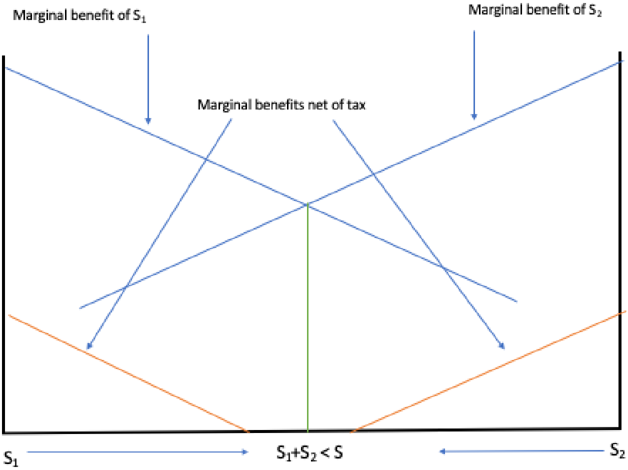
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Simplest case

- Stock $S_0 > 0$ of fossil fuel, selling at price p_t at date t in competitive market. Marginal extraction cost constant at $m > 0$ and price p_t given by

$$p_t = h_t + m + \tau \tag{1}$$

  τ is per unit tax paid on sales. A carbon tax, calculated from the carbon released when fuel burned: does not depend on value of the product. h_t is scarcity rent or Hotelling rent.

- In a competitive market equilibrium rent will rise exponentially at prevailing interest rate r. Hence

$$p_t = h_0 e^{rt} + m + \tau \tag{2}$$

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Assumptions.

- Renewable resource available in unlimited amounts at marginal & average cost $R > m$. Perfect substitute for the fossil fuel ("backstop technology"), so if the fuel is consumed we must have

$$p_t \leqq R \tag{3}$$

- Demand given by $D(p_t)$
- We know the market price of the fuel will rise exponentially away from $m + \tau$ at rate r, and that $p_t = h_0 e^{rt} + m + \tau \leqq R$ if the fuel is sold.

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Single fossil fuel

Theorem

*A dynamic competitive equilibrium with a carbon tax τ, $m+\tau<R$, is characterized by $\int_0^T D(p_t)\,dt = \int_0^T D(h_0e^{rt}+m+\tau)\,dt = S_0$ and $p_T = h_0e^{rT}+m+\tau = R$. These determine the initial rental rate h_0 and the date T at which $p_t = R$ and the fossil fuel is exhausted. There is no interval over which the fossil fuel and the renewable energy source are both used. If the tax rate is raised to $\tau' > \tau$, $m+\tau' < R$, then the above remains true so that **total fossil fuel consumption is not changed**. The tax increase **decreases** the initial rental rate h_0 and **increases** the date T at which the fossil fuel is exhausted. If the tax is so high that $m+\tau > R$ then the fossil fuel is never consumed.*

Single Fossil Fuel

Tax increases T and reduces h_0. Either has no impact on emissions or reduces to zero.

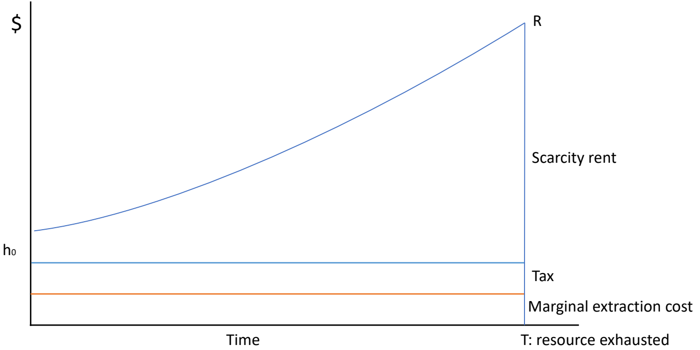

Figure: Equilibrium with single fossil fuel

Imperfect substitutability.

skip

- Demand for fossil fuels depends on the price of renewable energy R: $D(p_t, R)$, $\partial D/\partial R > 0$. Possible co-existence of both energy sources in market, demand transferring from one to the other as price difference changes. Demand function has "choke price" $\bar{p}(R)$: demand for the fossil fuel is zero when price reaches $\bar{p}(R.)$ Choke price depends on the price of substitute.
- All markets for the fuel clear iff the time T at which price of fuel equals choke price, $p_T = \bar{p}(R)$, and initial Hotelling rent h_0 satisfy $\int_0^T D(p_t)\,dt = \int_0^T D(h_0 e^{rt} + m + \tau)\,dt = S_0$ and $p_T = h_0 e^{rT} + m + \tau = \bar{p}(R)$
- This framework leads to similar conclusions to previous one, except that transition from fossil fuel to renewable resource is smooth rather than abrupt.

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Imperfect substitutability.

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Assuming imperfect substitutability between the fossil fuel and renewable energy reflected in the demand function $D(p_t, R)$ with choke price $\bar{p}(R)$, a dynamic competitive equilibrium with a carbon tax τ, $m + \tau < \bar{p}(R)$, is characterized by the previous equations. These determine the initial rental rate h_0 and the date T at which $p_t = \bar{p}(R)$ and the fossil fuel is exhausted. If the tax rate is raised to $\tau' > \tau$, $m + \tau' < \bar{p}(R)$, then the above remains true so that total fossil fuel consumption is not changed. If the tax is so high that $m + \tau > \bar{p}(R)$ then the fossil fuel is never consumed.

- *The important point here is that even with imperfect substitutability and the co-existence of both products in the market, a carbon tax will not affect the total cumulative consumption of the fossil fuel.*

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Assuming imperfect substitutability between the fossil fuel and renewable energy reflected in the demand function $D(p_t, R)$ *with choke price* $\bar{p}(R)$*, a dynamic competitive equilibrium with a carbon tax* τ*,* $m + \tau < \bar{p}(R)$*, is characterized by the previous equations. These determine the initial rental rate* h_0 *and the date* T *at which* $p_t = \bar{p}(R)$ *and the fossil fuel is exhausted. If the tax rate is raised to* $\tau' > \tau$*,* $m + \tau' < \bar{p}(R)$*, then the above remains true so that total fossil fuel consumption is not changed. If the tax is so high that* $m + \tau > \bar{p}(R)$ *then the fossil fuel is never consumed.*

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Differing fuel grades

- I different fuel sources, marginal extraction cost m_i, numbered in increasing order of extraction costs, $m_1 < m_2 < ..... < m_I$ and $m_I < R$. Initial stock of the $i-th$ fuel is $S_{i,0}$.

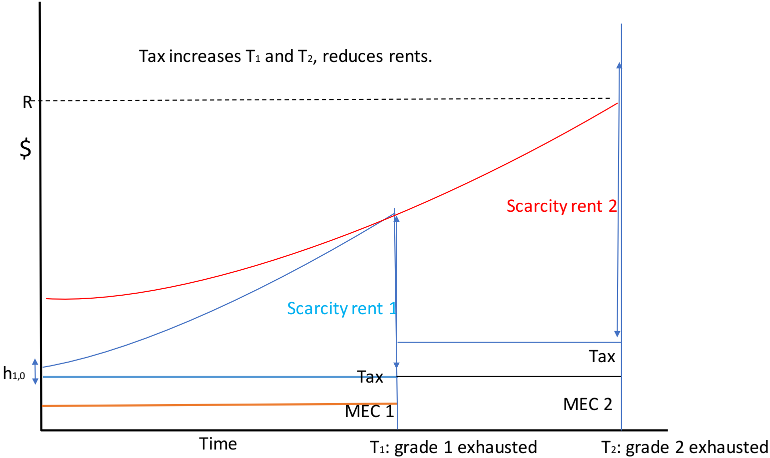
Theorem

Competitive equilibrium: dates T_i, $i = 1,2,....I$, $T_i < T_{i+1}$, and initial rents $h_{0,i}$, $i = 1,2,...,I$ such that for all i, $p_{i,t} = m_i + \tau + h_{i,0}e^{rt}$, $T_{i-1} \leq t \leq T_i$ and $\int_{T_{i-1}}^{T_i} D(p_{i,t})\,dt = S_{i,0}$. The price moves continuously so that

$$p_{i,T_i} = m_i + \tau + h_{i,0}e^{rT_i} = p_{i+1,T_i} = m_{i+1} + \tau + h_{i+1,0}e^{rT_i}\ \forall i \tag{4}$$

and the last price of the fuel equals that of renewable energy: $p_{I,T_I} = R$

Two fuel grades



Tax impacts

- If $m_i + \tau < R$ tax will merely delay consumption of the fuel
- But if $m_j + \tau > R$ then grade j will never be used and total consumption and emissions will fall
- In general tax delays the use of all grades and may force out most expensive grades: the latter effect **reduces** emissions whereas the former merely **reschedules** them
- Key insight from this paper: two distinct mechanisms through which tax affects consumption, rescheduling and reduction

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Fixed costs of extraction

- Extraction may have large fixed costs F to be paid before any fuel produced
- In this case production requires $\int_0^T (p_t - m - \tau)\, dt = \int_0^T h_0 e^{rt} \geq F$ and tax may make production unprofitable
- Only important for investments that have not yet been made

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Extraction-dependent costs

- Extraction at t is given by $E_t \geq 0$, and cumulative extraction denoted $z_t = \int_0^t E_\kappa d\kappa$. Total resource availability is $\hat{z}$. Extraction costs at t, c_t, given by:

$$c_t = g(z_t), \, g(z_t) \leq R \, if \, E_t > 0,: \; g'(z) = \frac{dg}{dz} > 0 \tag{5}$$

- If $g(\hat{z}) + \tau > R$ then tax reduces total consumption of fossil resource, setting a bound on cumulative extraction at $\widetilde{z}$, $g(\widetilde{z}) = R - \tau$, $\widetilde{z} < \hat{z}$.

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- Consumption of unit of fossil fuel emits one unit of GHG, and environmental authority imposes cap of K_0 units on cumulative emissions of greenhouse gases. This implies $\int_0^\infty D\left(p_0 e^{rt}\right) \leq K_0$
- Permits can be banked, constraint is on cumulative emissions. One of the integral constraints is redundant: if $S_0 < K_0$ then emissions constraint redundant, and if $K_0 < S_0$,fossil fuel will be left unused and the binding constraint is $\int_0^\infty D\left(p_0 e^{rt}\right) = K_0$.
- If cap is binding then emissions are reduced to the cap - in contrast with carbon tax's all-or-nothing effect

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- Scarcity rent associated with resource constraint will be zero, but positive scarcity rent will be associated with emissions constraint. Price of fossil fuel will be zero but there will be + price for emissions permits.
- Key point: presence of binding emissions cap reduces resource rent to zero. All rent captured by permit price. So agency that auctions permits now captures all of scarcity rent that previously accrued to resource owners. Financially speaking, resource has been fully expropriated.
- With positive MECs and multiple grades of resource, lowest-cost grades will retain some scarcity rent, but less than without cap.

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Cap & Trade: limited banking

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Fuel	units	CO2, mt	Price, $	Tax, $
Coal	mt	2.86	50	143
Gas	mmbtu	0.053	3	2.65
Oil	bbl	0.35	60	17.6

Table: CO2 tax per unit fuel

- $50/ton CO2 tax doubles gas price and quadruples coal price. Coal is completely uncompetitive and gas far less competitive
- Less than rent on oil market. Lowers effective price to $40-50, where many sources are profitable - and this is if none is passed on to consumers. Oil remains competitive

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Data

- Requires three inputs - marginal extraction cost of oil, price of the backstop technology R, and the demand function
- For costs we use proprietary data from Rystad Energy. Gives estimated MECs for 15,000 discovered and 27,000 undiscovered oil assets around the world
- For demand we assume constant long-term elasticity of -0.6 following Hamilton 2009.
- Rystad estimates the choke price for oil to be roughly $250/bbl so we work with this
- Conduct sensitivity analysis to PED and choke price

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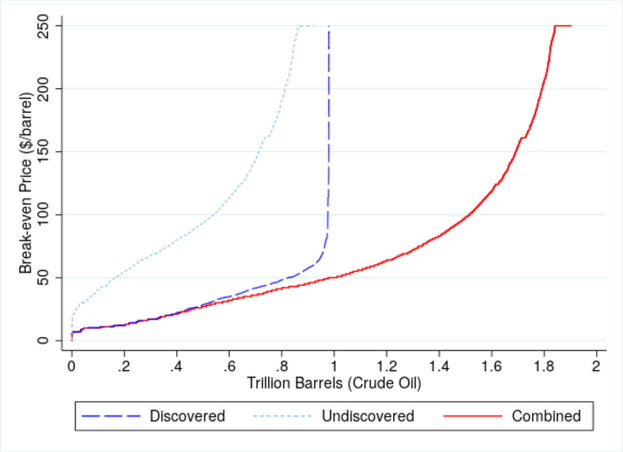
Data

- Requires three inputs - marginal extraction cost of oil, price of the backstop technology R, and the demand function
- For costs we use proprietary data from Rystad Energy. Gives estimated MECs for 15,000 discovered and 27,000 undiscovered oil assets around the world
- For demand we assume constant long-term elasticity of -0.6 following Hamilton 2009.
- Rystad estimates the choke price for oil to be roughly $250/bbl so we work with this
- Conduct sensitivity analysis to PED and choke price

Oil supply curves

Figure: Oil MEC vs quantity



Simulation

- Solve numerically using multiple grades of oil from supply curve.
- Demand is $q_t = \alpha p_t^{\eta}$ where we take $\eta = -0.6$.
- Solve model backward using daily time steps for p_{2019} and q_{2019} . Pick value of α that gives best match to current demand ($\alpha = 1203$). Implied price is $63.
- For $r = 0.03$, $R = 250$ and $\eta = -0.6$ we have $p_{2019} = \$63.22$ and $q_{2019} = 100mbd$.
- Note backstop price R and tax τ are linked $p_t = h_0 e^{rt} + m + \tau \leq R$ so reducing R reduces τ. Changing R from $250 to $150 means that $300 tax now does what $400 tax used to

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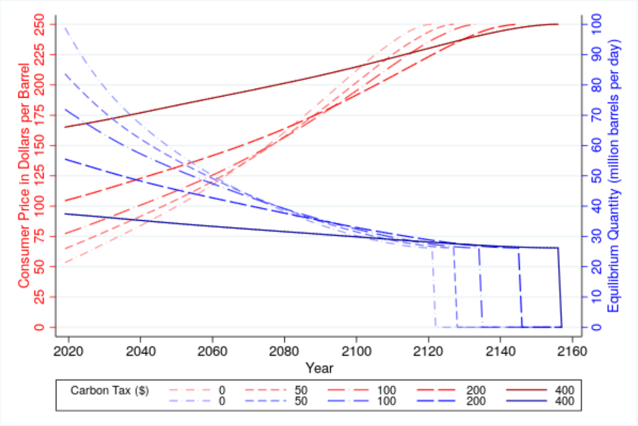
Prices and Quantities

Figure: Effect of tax on price and consumption



Tax incidence

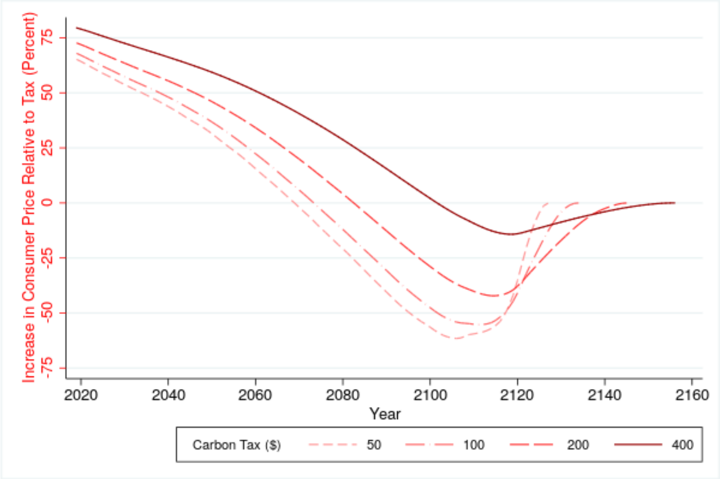


Figure: Tax incidence

Cumulative drop in oil use

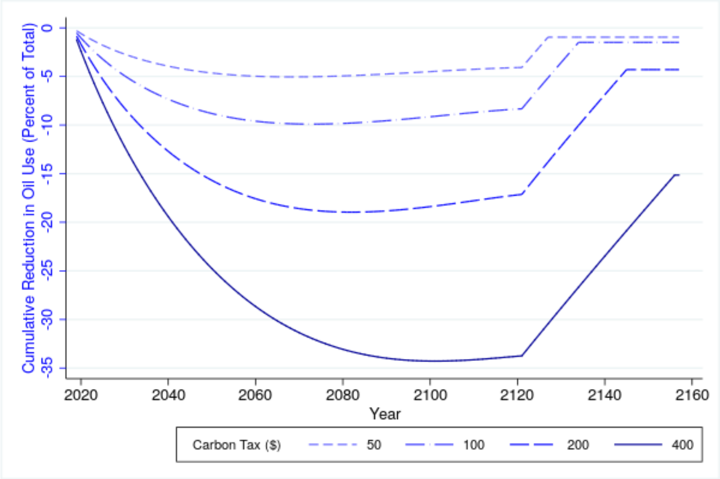


Figure: Drop in oil use vs tax rate

Required carbon tax

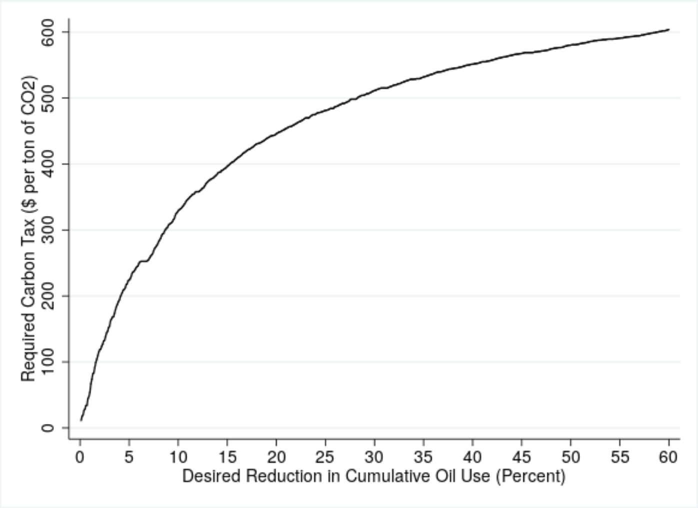


Figure: Required carbon tax

Tax ($/ton CO2)	0	50	100	400	600
Reserves used (Bn bbl)	1842	1824	1812	1560	1321
Producer surplus ($ tn)	57.36	49.53	42.77	16.89	5.41
Consumer surplus ($ tn)	86.77	80/07	73.03	28.38	3.35
Tax revenue ($ tn)	0	13.71	26.16	80.43	95.09
Total surplus ($ tn)	144.13	143.32	141.96	125.71	95.09

Table: Surplus vs tax rate

Table of Contents

Conclusions

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- Tax tends to postpone consumption rather than prevent it
- But tax can force high-cost reserves out of the market
- Tax can easily reduce consumption of coal and gas - but coal is going anyway
- Need a high tax to have an impact on the oil market

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