Curbing fossil fuels through global reward payment funds inducing countries to reduce supply, reduce demand and expand substitutes

Lennart Stern

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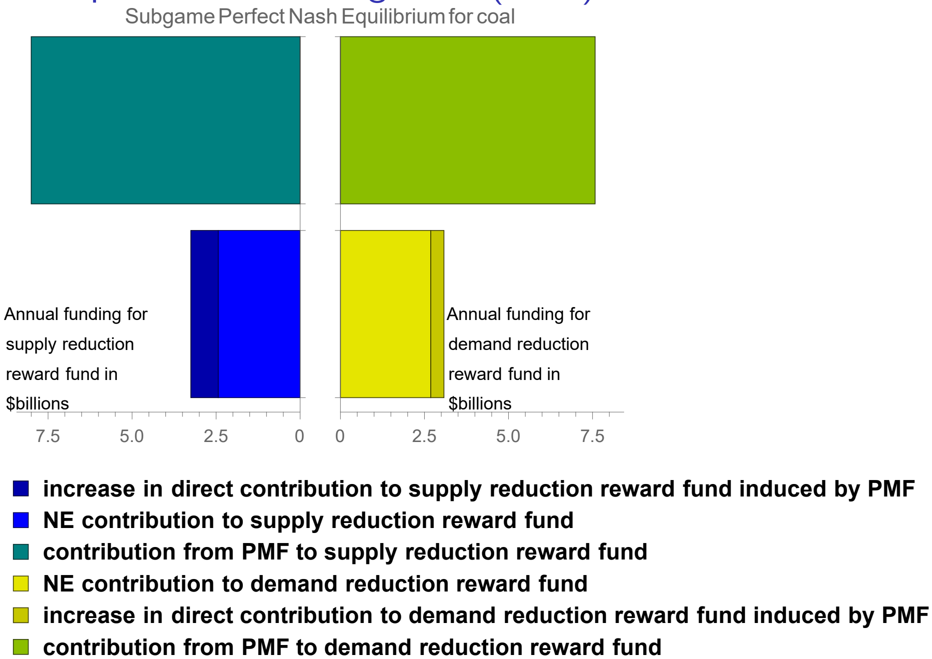
A Proportional Matching Fund (PMF)



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The model

- I= set of countries of the world, all price takers
- country i chooses:
  x_i: coal extraction
  y_i: energy use
  z_i: renewable energy production
- global market for coal, price p
- $x_i - y_i + z_i$ = country i's net export of coal
- $U_i(x_i, y_i, z_i) = \underbrace{B_i(y_i)}_{\substack{B_i' > 0 \\ B_i'' < 0}} - \underbrace{G_i(z_i)}_{\substack{G_i' > 0 \\ G_i'' > 0}} - \underbrace{C_i(x_i)}_{\substack{C_i' > 0 \\ C_i'' > 0}} + p(x_i - y_i + z_i) + f_i(x_i, y_i, z_i)$

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The global institution's problem

- Global institution announces reward payment schemes: $f_{ix}(x_i), f_{iy}(y_i), f_{iz}(z_i) \geq 0$r
- Countries choose their (x_i, y_i, z_i)

Definition

A **market equilibrium under a given set of reward payment scheme** $(f_{ix}, f_{iy}, f_{iz})_{i \in I}$ is a combination of an allocation $(x_i, y_i, z_i)_{i \in I}$ and a price p such that:

1) market clearing: $\sum_{i \in I} x_i - y_i + z_i = 0$

2) individual rationality:

$x_i = argmax_x px - C_i(x) + f_{ix}(x)$

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Viewing the global institution as choosing the allocation and the price

market equilibrium

(surjective map)

$$(f_{xi}, f_{yi}, f_{zi})_{i\in I} \longrightarrow (p, (x_i, y_i, z_i)_{i\in I})$$

minimal required transfers

$$(F_{ix}, F_{iy}, F_{iz})$$

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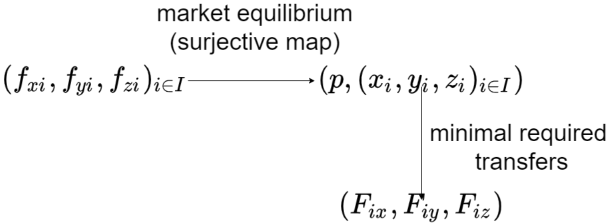

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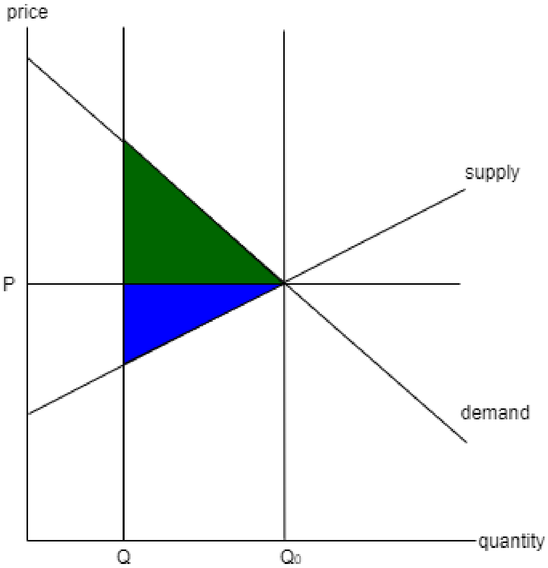
The Price Preservation Lemma

Lemma

At the optimal mechanism:
The world market price p for coal ends up being the same as in the absence of any mechanism.

The Price Preservation Lemma



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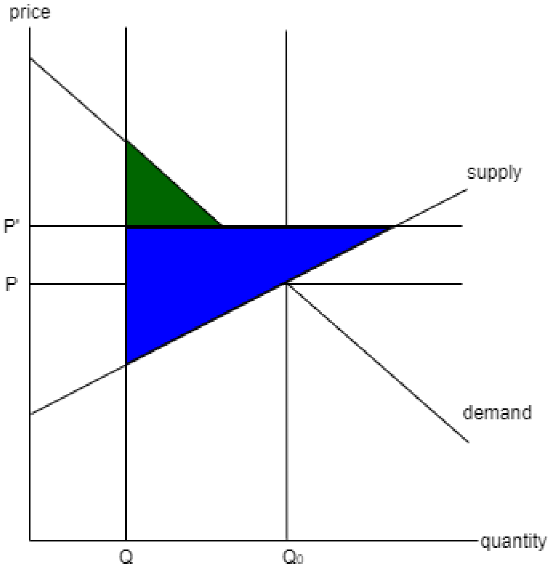

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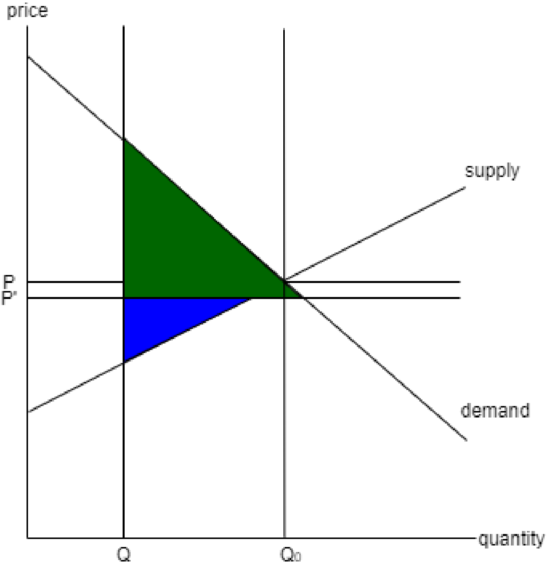

Numerical results for constant elasticity specifications

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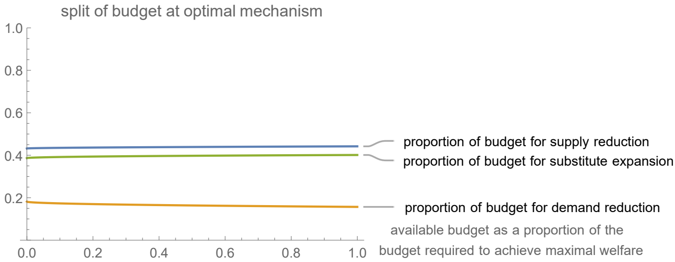

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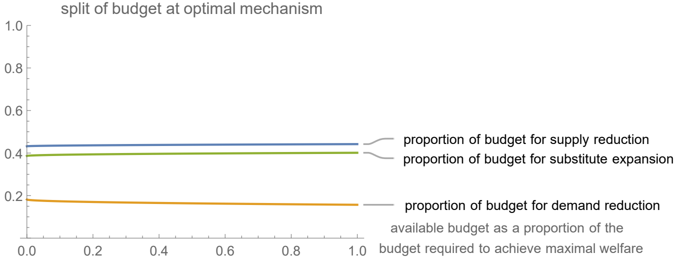

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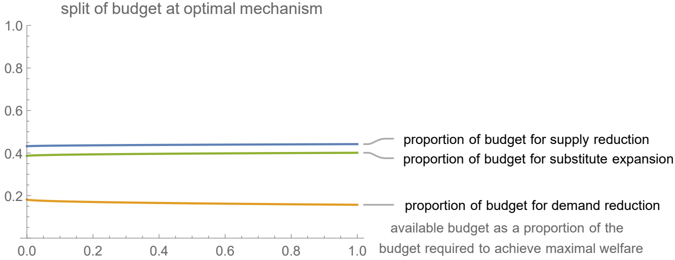

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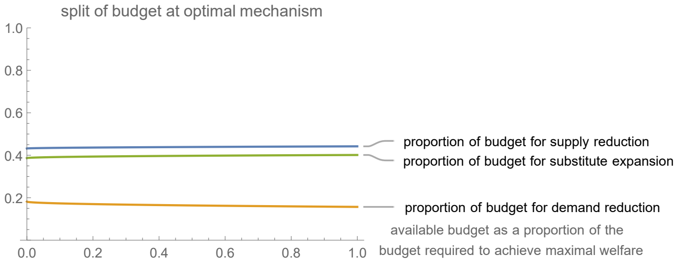
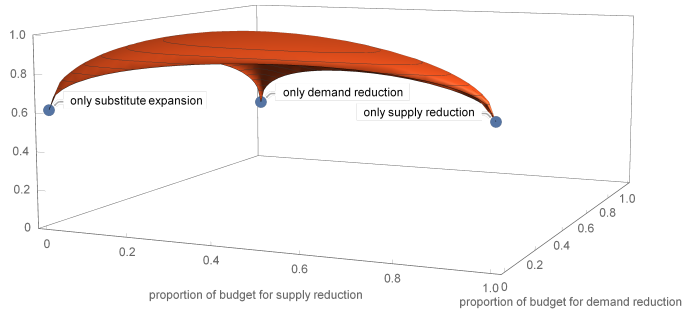


Global welfare as a function of budget split



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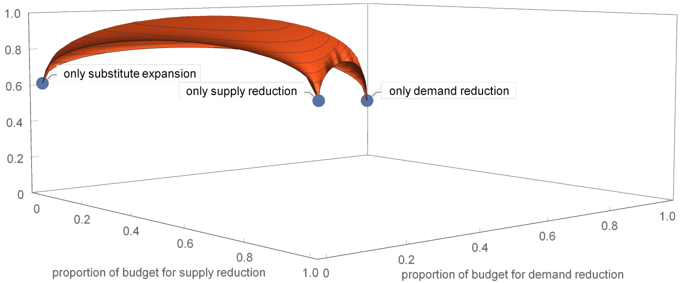

The dynamic model

- y_{it}: country i's energy use in period t
- z_{it}: country i's renewable energy production in period t
- x_{it}: country i's cumulative extraction of coal until the end of period t
- Country i's utility:
  $U_i = \sum_{t=1}^{T} \frac{1}{(1+r)^t}(b_{it}(y_{it}) - g_{it}(z_{it}) - (c_{it}(x_{it}) - c_{it}(x_{it-1})) + f_{it}(x_{it}, y_{it}, z_{it}) + p_t(x_{it} + z_{it} - y_{it}))$

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  $U_i = \sum_{t=1}^{T} \frac{1}{(1+r)^t} (b_{it}(y_{it}) - g_{it}(z_{it}) - (c_{it}(x_{it}) - c_{it}(x_{it-1})) + f_{it}(x_{it}, y_{it}, z_{it}) + p_t(x_{it} + z_{it} - y_{it}))$

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The global institution's problem under full commitment and without constraints on borrowing/saving

- Announce path of reward payment schemes $(f_{ixt}(x_{it}), f_{iyt}(y_{it}), f_{izt}(z_{it}))_{i\in I, t\in\{1,..,T\}}$ and fully commit to it
- Budget constraint: $\sum_{t=1}^{T}\sum_{i\in I}\frac{1}{(1+r)^t}(f_{ixt}(x_{it})+f_{iyt}(y_{it})+f_{izt}(z_{it}))\leq\sum_{t=1}^{T}\frac{1}{(1+r)^t}F_t$
- Objective: $\sum_{i\in I}U_i-\eta(\sum_{i\in I}x_{iT})$

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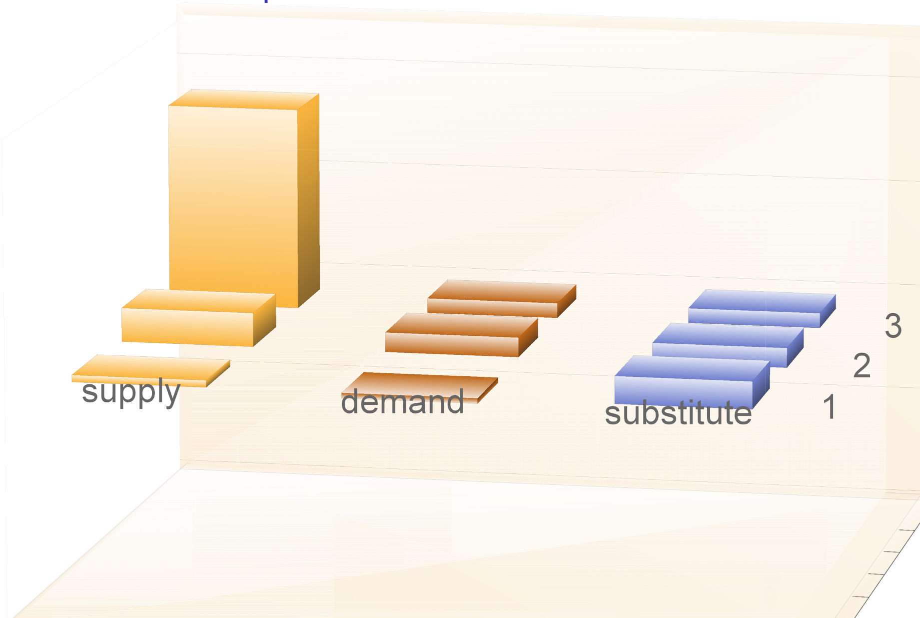
The Dynamic Price Preservation Lemma

Lemma

At the optimal mechanism :
The entire world market price path $(p_t)_{t \in \{1,\dots,T\}}$ is identical to when there is no mechanism.

The global institution's spending path at the optimal mechanism in a 3-period model



The Monotone Mitigation Lemma

Lemma

As the global institution's budget expands:
Cumulative coal extraction decreases *at all times and for all countries.*
Coal use decreases *in all periods.*

The Monotone Optimal Spending Corollary

Corollary

As the global institution's budget expands:
*The **Global Institution's spending increases** for all approaches and at all periods.*

The Coase-Does-Not-Hold Corollary

Corollary

Suppose that the global institutions restricts its supply side spending to the last period.
(This would effectively be the case if the global institution were to restrict itself to buying up coal deposits.)
Then the global institution cannot achieve optimal welfare.

Conclusion

- Optimal mechanism requires rewarding countries in each period for:
  1) **Extracting** less fossil fuel than counterfactually and
  2) **Combusting** less fossil fuel than counterfactually
- Optimal mechanism could be implemented by
  1) A fund rewarding countries each year based on their **tax rates on extraction**
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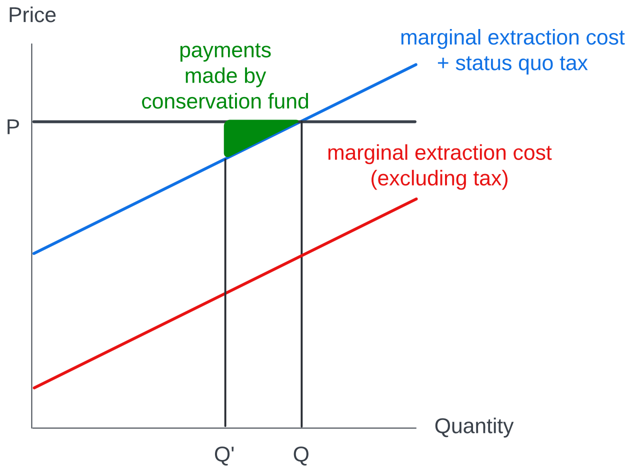
Appendix slides

The Time-Inconsistency Corollary

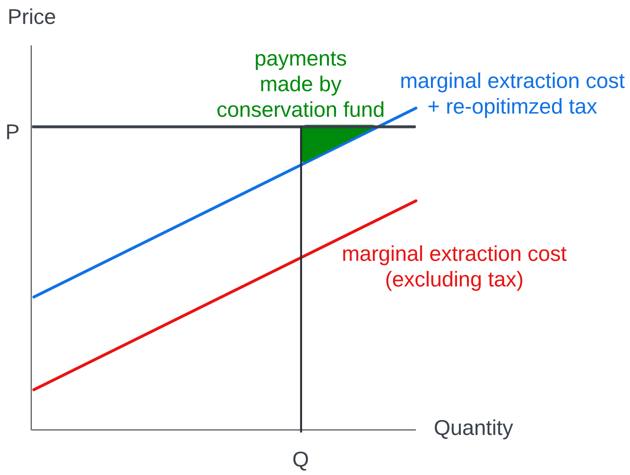
Corollary

Suppose the global institution announces the optimal mechanism under full commitment and all the countries believe it will stick to it. Then the global institution will later have an incentive to renege and spend less on rewarding supply reduction than it announced.

Deposit purchase based on market prices: Naive analysis



Deposit purchase based on market prices: Endogenous tax rate response eliminates impact



A model of the financing game

- player *im*: A group of coal importers:
  -internalizing s_{im} of global climate change damages
  -making up $2s_{im}$ of coal imports
- player *ex*: A group of coal exporters:
  -internalizing s_{ex} of global climate change damages
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2 architectures

- separated architecture:
  -separate funds for rewarding supply reduction and demand reduction
  -donors can earmark contributions
- unified architecture:
  -unified institution splitting its budget to maximize emissions reductions
  -donors cannot earmark contributions
- **Lemma:** Under both architectures there is a unique Nash Equilibrium.
- **Lemma:** Under the unified architecture, generically, exactly one player contributes.
- **Lemma:** Under the separated architecture both funds receive positive funding.
- **Proposition:** The emissions under the separated architecture are always lower or equal to those under the unified architecture

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Results under linear demand and supply functions

Lemma

Suppose the coal importer and the coal exporter are of equal size: $s_{im} = s_{ex} = s$. Switching from the unified architecture to the separated architecture multiplies the emissions reductions by the following factor:

$$1 + \frac{4\frac{\alpha}{(e_d+e_s)}}{\eta} \frac{1}{1 - \frac{s}{1-s}\alpha(\frac{e_d - e_s}{e_d + e_s})^2}$$

- η = *social cost of carbon of coal relative to its price*
- α = *global coal exports divided by global coal use*
- e_d = *current price elasticity of demand for coal*
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- η = *social cost of carbon of coal relative to its price* $= 1.27$
- α = *global coal exports divided by global coal use* $= 0.2$
- e_d = *current price elasticity of demand for coal* $= 0.7$
- e_s = *current price elasticity of supply of coal* $= 1.3$

Results under linear demand and supply functions

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$$1 + \frac{4\frac{\alpha}{(e_d+e_s)}}{\eta} \frac{1}{1-\frac{s}{1-s}\alpha(\frac{e_d-e_s}{e_d+e_s})^2} \approx 9.57$$

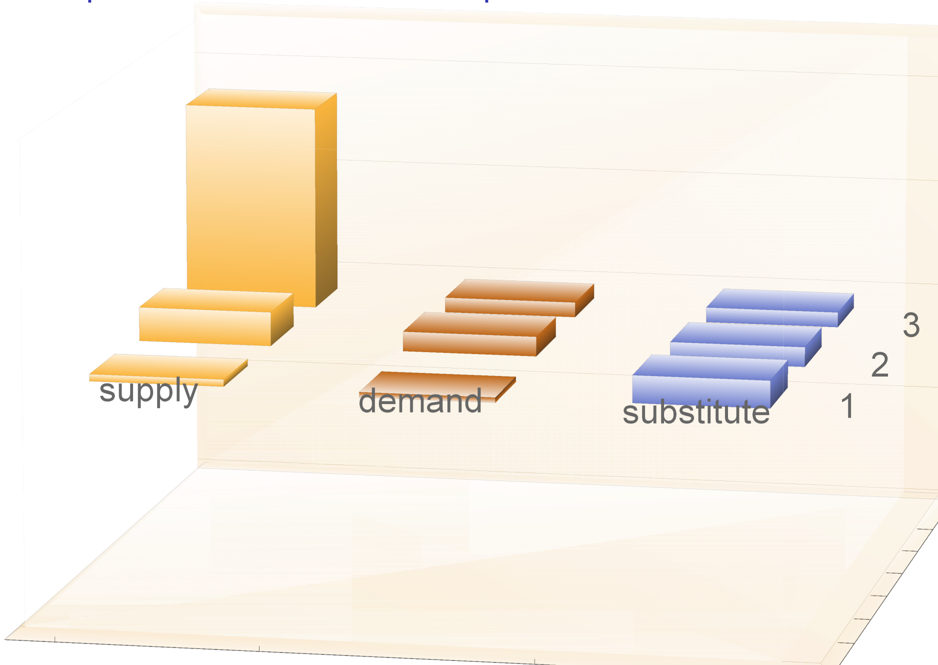
- η = *social cost of carbon of* ***oil*** *relative to its price* $= 0.24$
- α = *global* ***oil*** *exports divided by global* ***oil*** *use* $= 0.425$
- e_d = *current price elasticity of demand for* ***oil*** $= 0.5$
- e_s = *current price elasticity of supply of* ***oil*** $= 0.32$

Constrained Efficiency Lemma

Lemma

At the optimal mechanism we have:
The allocation $(x_{it}, y_{it}, z_{it})_{i \in I, t \in \{1,\dots,T\}}$ *maximises global welfare amongst all allocations having the same value for climate change damages,* $\sum_{i \in I} \eta_i(\sum_{j \in I} x_{j1}, \dots, \sum_{j \in I} x_{jT})$.

The optimal mechanism in a 3 period model



A commitment problem

Corollary

Suppose the global institution announces at time 1 the optimal mechanism assuming it fully commits to it.
Suppose that at time $t > 1$ the global institution announces, to all countries' surprise, a new mechanism that it actually sticks to from then onwards.
Then the new mechanism involves less spending on rewarding supply reduction than the originally announced mechanism.

How severe is the commitment problem?

- From now on suppose that:
  - the global institution cannot commit at all
  - the global institution cannot save or borrow
  - T=3
- $x_t(F_1, F_2, F_3)$:=aggregate cumulative coal extraction in period t
- denote by y_t coal demand in period t

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Additional Funding will always decrease eventual emissions

Proposition

$\frac{\partial x_3}{\partial F_t}|_{(F_1,F_2,F_3)} < 0 \forall (F_1, F_2, F_3) \forall t \in \{1,2,3\}$

The Weak Green Paradox

Proposition

$\frac{\partial x_1}{\partial F_2}\Big|_{(F_1,F_2,F_3)} > 0 \forall (F_1, F_2, F_3)$

Can climate change damages increase as a result of additional funding for the global institution?

Assumption

$$\eta(x_1, x_2, x_3) = \tilde{\eta}(x_1 + \frac{1}{1+r}(x_2 - x_1) + \frac{1}{(1+r)^2}(x_3 - x_2))$$

- By preceding propositions, increasing F_2 will:
  - increase x_1
  - decrease x_2 and x_3

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Necessary and Sufficient Conditions for the Strong Green Paradox to not arise for Small Budgets

Proposition

Denote $e_{xt} := \frac{dx_t^*}{dp_t}\frac{p_t}{x_t^*}$, $e_{yt} := -\frac{dy_t^*}{dp_t}\frac{p_t}{y_t^*}$ *and*

$$a := e_{y1}\frac{1}{(\frac{x_3-x_2}{x_1})((1+\frac{e_{y1}}{e_{x1}})(1+\frac{e_{y2}}{e_{x2}}(\frac{x_2-x_1}{x_2}))\frac{p_1(1+r)}{p_3}+\frac{e_{y1}}{e_{x2}}\frac{x_1}{x_2}\frac{p_2}{p_3})}$$

Then the following condition is sufficient for the Strong Green Paradox to not occur for small budgets:

$$e_{y3} \geq a$$

Moreover, if $e_{y3} < a$ *then the following condition is necessary and sufficient for the Strong Green Paradox to not occur for small budgets:*

$$e_{x3} \geq e_{y1}\frac{\frac{a-e_{y3}}{a}r}{\frac{x_3}{x_2}((1+\frac{e_{y1}}{e_{x1}})(\frac{x_2-x_1}{x_1}+\frac{x_2}{x_1}\frac{e_{y2}}{e_{x2}})\frac{p_1(1+r)^2}{p_3}+\frac{e_{y1}}{e_{x2}}\frac{p_2(1+r)}{p_3})}$$

Necessary and Sufficient Conditions for the Strong Green Paradox to not arise for Small Budgets

Proposition

Suppose that extraction costs do not change over time, so that we can denote them simply by $c(x)$.
Then the Strong Green Paradox occurs for small budgets in the three period model iff $h := g_1 g_2 + g_3 + g_4(g_5 + g_6) < 0$
with the following definitions:

$e_{yt} := -\frac{dy_t^*}{dp_t}\frac{p_t}{y_t^*}$

$g_1 := rc''(x_2)\left(e_{y3} r(x_3 - x_2)c''(x_3) + (1+r)c'(x_3)\right)$

$g_2 := (e_{y1}x_1 + e_{y2}(x_2 - x_1))\left(rc'(x_2) + c'(x_3)\right) - e_{y2} r(1+r)(x_1 - x_2)c'(x_1)$

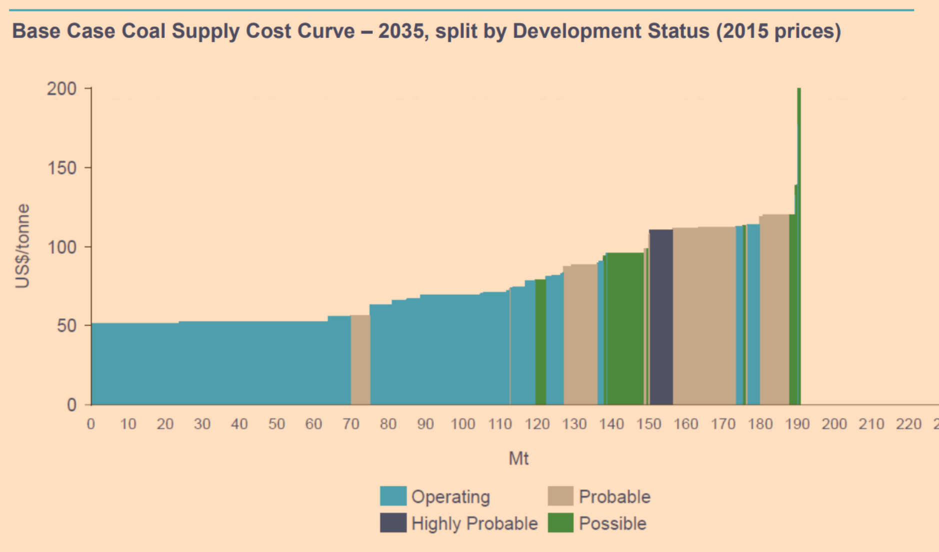
$g_3 := e_{y1} r(1+r)x_1 c''(x_1)\left(e_{y3} r(x_3 - x_2)c''(x_3) + (r+1)c'(x_3)\right)\left(e_{y2} r(x_2 - x_1)c''(x_2) + rc'(x_2) + c'(x_3)\right)$

$g_4 := rc'(x_2) + c'(x_3)$

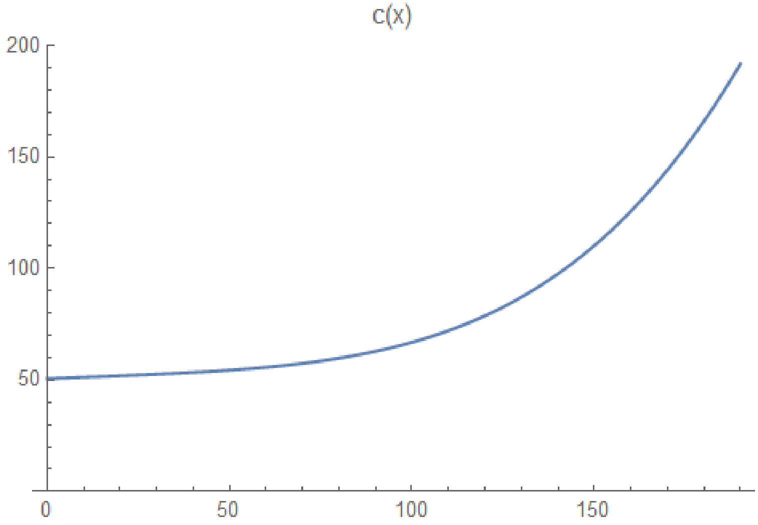
$g_5 := (1+r)c'(x_3)\left(r(1+r)c'(x_1) + rc'(x_2) + c'(x_3)\right)$

$g_6 := rc''(x_3)\left(e_{y3}(x_3 - x_2)\left(r(1+r)c'(x_1) + rc'(x_2) + c'(x_3)\right) - e_{y1}(1+r)x_1 c'(x_3)\right)$

Empirical estimate of $c(x)$



Cubic approximation of the empirical estimate of $c(x)$



Corollary

Suppose that the third period extraction is not more than the second period extraction. Then the Strong Green Paradox can only occur for small budgets if $\frac{e_{y1}}{e_{y2}} > 15.55$ *or* $\frac{e_{y1}}{e_{y3}} > 15.55$.