Are Renewable Energy Policies Climate Friendly? The Role of Capacity Constraints and Market Power

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Motivation

- Government support for renewable energies
  1. Direct subsidy, mandatory blending, feed-in tariff, R&D support, etc.
  2. Motivation: Global climate change; energy security; high (and uncertain) energy prices
  3. Justifications: help substitute for fossil fuel use; distributed generation (low startup cost); smart grid (future of energy).
- Can be controversial
  1. Debate on biofuel: life cycle analysis, indirect land use change due to price effects. (Searchinger et al, 2008; Hertel et al 2010)
  2. Emission impacts of electric cars (Zivin et al, 2013)

Key question: can renewable energies reduce GHG emissions?

- Impacts of biofuel on oil supply: rather limited in static models (Rajagopal et al, 2011; de Gorter and Drabik, 2011; Thompson et al, 2011)
    1. Reason: small market share of biofuel in gasoline market
- Market share of solar is small in electricity market, so static price effect is low. (Mulder and Scholtens, 2013).

But dynamic aspect of impacts

- Fossil fuel is a dynamic business!
  1. Low price elasticity in the short run, but (delayed) high price elasticity in the long run through adjustments in drilling: responses to future prices and dynamic decision making
  2. Hydraulic fracturing (fracking) and horizontal drilling: more short-run responses
- Fossil fuel supply is *more responsive* to renewable energies when viewed from a dynamic perspective
  1. Simplest example: solar as backstop. No static response, big dynamic response
  2. General: much more elastic response than in a static model (Zhao, 2013)

Green Paradox

- Sinn (2008): dynamic effects can be counter-intuitive and opposite to static effects.
- Growing literature (Sinn (2008, 2012); Hoel, 2008; Van Ploeg and Withagen, 2012; Grafton et al, 2012)
- Example: taxing carbon, improving energy efficiency
  1. Future fossil fuel price decreases: produce more *now*
  2. Story: dynamic impacts can be opposite to (predicted) "static" impacts

Dynamic is important for evaluating the impacts of renewable energies

- Global climate change is about the *time path* of carbon emissions rather than *levels*
  1. Extreme view: all or most carbon stored in fossil fuel will eventually be released
  2. GHG problem: carbon has been released *too fast*, far exceeding rates of dissipation
  3. GHG is a stock pollutant. Earlier emissions cause more NPV damage.
  4. Optimal path: lower emission *now*, implying higher emission in the future
- True Green Paradox should be about NPV of future damages, and can depend on damage functions (and adaptation) and discount rate.
- But literature takes simplified aproach: delay extraction/emissions.

This paper

Question: what are the *dynamic* effects of renewable energy policies *on fossil fuel supply*?

- Dynamic impacts of renewable policies: sensitive to
  1. production capacity constraints of renewables
  2. market power in fossil fuel sector
- Capacity constraints: how much can be produced in a year?
  1. Resource limits: land availability, prime wind sites
  2. Government policy: US blend wall, China's biofuel entry regulation (Chang et al 2012)
- Market power: somewhere between perfect competition and monopoly
  1. OPEC: cartel? oligopoly? Evidence of market power in recent oil price drop
  2. National oil companies: Russia, China, Venezuela
  3. This paper: two extremes (competition vs. monopoly). Companion paper studies cartel-fringe.

More accurate definition of Green Paradox

- Strict sense (strong Green Paradox): NPV of environmental damage increases.
- Literature: earlier exhausion of fossil fuel (Grafton et al 2012); or higher current fossil fuel extraction - weak Green Paradox (Ploeg and Withagen 2012).
- This paper: combined condition - Green Paradox if and only if *both* conditions (increased current extraction and earlier exhausion of resource).

Conceptual model

Focus on dynamics - lots of abstraction: four substitutable energies

- Fossil fuels: nonrenewable, homogeneous (abstract from coal vs. natural gas vs. oil), high GHG emissions
- Two kinds of biofuels: subject to capacity constraint, lower GHG emissions
    1. Low cost biofuels: grain based ethanol. Currently competitive
    2. High cost biofuels: next generation. Not competitive yet.
- Solar: backstop. Lower GHG emissions.

Conceptual model (cont'd)

Renewable policies - synthesizing real world policies

- Subsidies (cost reduction): for biofuels and solar
- Capacity expansion for biofuels
  1. R&D that expands feedstocks
  2. Relaxation of restrictive policies.

Focus on: policies' impacts on (i) supply paths of energies, and (ii) associated GHG paths (the latter the better).

Model setup

- Four substitutional energies: fossil fuels, low cost biofuels, high cost biofuels and solar.
  1. Unit production cost: $c_f < c_{b,l} < p(0) < c_{b,h} < c_s$
  2. Can extend to convex costs with similar results.
- Energy supply in period t: $q_f(t)$, $q_{b,l}(t)$, $q_{b,h}(t)$ and $q_s(t)$.
  1. Capacity constraints: $q_{b,l}(t) < \overline{q}_{b,l}$; $q_{b,h}(t) < \overline{q}_{b,h}$;
  2. Restrictive enough that biofuels won't drive out solar or fossil fuels.
- Renewable energy sectors are competitive.
- Stationary energy demand function $p = h(Q)$

Renewable energy supply rule

- Supply of biofuels, for $i = \{l, h\}$

$$q_{b,i}(t) \begin{cases} = 0, & \text{if } p(t) < c_{b,i} \\ \in \left[0, \overline{q}_{b,i}\right], & \text{if } p(t) = c_{b,i} \\ = \overline{q}_{b,i}, & \text{if } p(t) > c_{b,i} \end{cases}$$

- Supply of solar

$$q_s(t) \begin{cases} = 0, & \text{if } p(t) < c_s \\ \in \left[0, h^{-1}(c_s) - \overline{q}_b - q_f(t)\right], & \text{if } p(t) = c_s \end{cases}$$

Optimal supply of fossil fuels: perfect competition

- Optimization problem

$$\underset{\{q_f(t)\}}{Max} \int_0^\infty e^{-rt} \left[p(t)\, q_f(t) - c_f q_f(t)\right] dt$$

$$\text{s.t.} \quad \dot{X}(t) = -q_f(t)\,; \int_0^\infty q_f(t)\, dt = X_0;$$

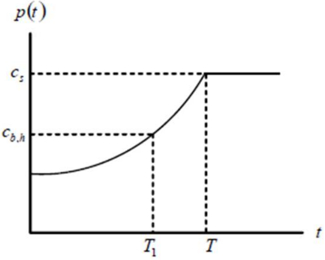
  1. $X(t)$: the reserve of fossil fuels at period t.
  2. X_0: initial reserve.

- Solutions: Hotelling rule

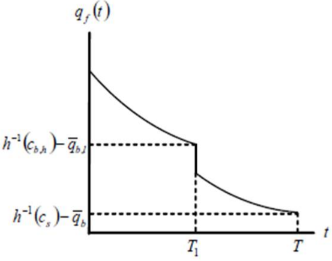
$$h\left(q_f(t) + q_b(t) + q_s(t)\right) = c_f + \lambda e^{rt}$$

  1. LHS: fossil fuel price $p(t)$.
  2. RHS: augmented marginal cost, including Hotelling rent.
  3. Hotelling rent increases at rate of interest (since no stock effects)

Solution paths



Price path



Fossil fuel supply

- T_1: high cost biofuels become available; fossil fuel supply drops by $\bar{q}_{b,h}$.
- Price is continuous, but $q_f(t)$ jumps at T_1.
- T: exhaustion time of fossil fuels.

Optimal fossil fuel supply: monopoly

- Cartel-fringe model: fossil fuel owner is Stackelberg leader.
- Optimization problem

$$\underset{\{q_f(t)\}}{Max} \int_0^T e^{-rt} \left[h\left(Q\left(t\right)\right) q_f\left(t\right) - c_f q_f\left(t\right)\right] dt$$

$$\text{s.t.} \quad \dot{X}\left(t\right) = -q_f\left(t\right); \int_0^T q_f\left(t\right) dt = X_0;$$

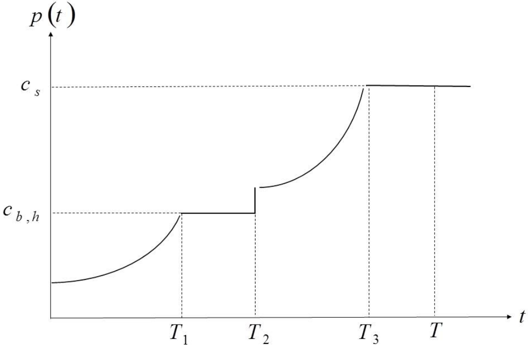
Supply rules of biofuels and solar

- Optimal condition: (residual) MR vs. augmented MC
  1. If interior solution:

$$h'\left(Q\left(t\right)\right) q_f\left(t\right) + h\left(Q\left(t\right)\right) = c_f + \lambda e^{rt}$$

  2. But possible corner solution: MR $>$ AMC. Key condition driving important results.

Monopoly supply path: staving-off period



- T_1: high cost biofuel: competitive but off market (stave-off: due to corner solution).
- T_2: high cost biofuels starts to supply the market;
- T_3: solar: competitive but off market;
- T: fossil fuels exhausted, solar starts to supply market

Policy analysis: effects of renewable policies

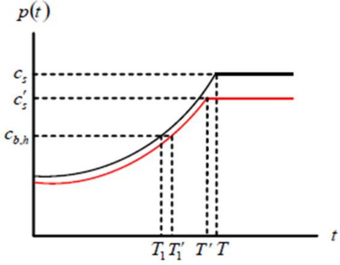
- Focus on GHG emission paths
- Climate friendly? Green Paradox? Complete evlauation needs info on
  1. Changes in supply paths due to policy
  2. Marginal damages over time
  3. Discount rate(s)
- Compromise (and more refined than Green Paradox literature):

Definition: A renewable energy policy is

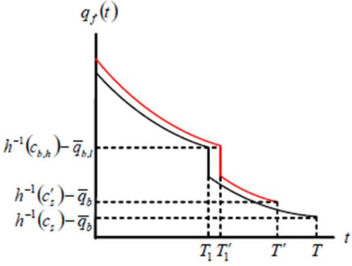
- *climate friendly* if it both *reduces current fossil fuel supply* and *delays exhaustion time* of the fossil fuel.
- *subject to Green Paradox* if it both *raises current fossil fuel supply* and *speeds up exhaustion time* of the fossil fuel.

Note: many “in-between” cases. Then emphasizes *current fossil fuel supply*.

Policy analysis: solar subsidies under perfect competition



Price path



Fossil fuel supply

Solar subsidies are subject to Green Paradox under perfect competition

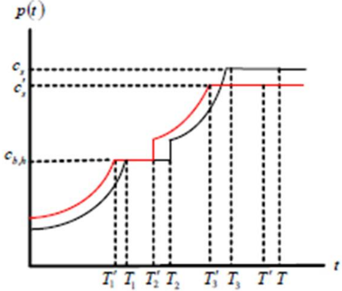
Solar subsidies under perfect competition

- Increase fossil fuel use for all periods;
- Speed up exhaustion of fossil fuels.
- *Strong version* of Green Paradox.

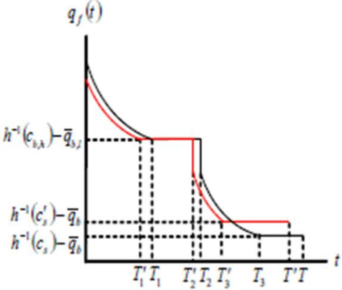
Intuition

- Fossil fuel owners have to exhaust its stock at T, when solar becomes competitive.
- Lower solar cost: pushes down fuel price, also solar kicks in earlier.
- Lower $p(t) \rightarrow$ higher extraction.
- Earlier T: fossil fuel exhausted earlier.

Solar subsidies: monopoly



Price path



Fossil fuel supply

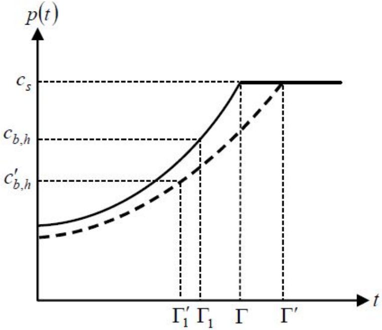
Solar subsidies under monopoly

- Reduce current use of fossil fuels (positive).
- Speed up exhaustion of fossil fuels (negative).

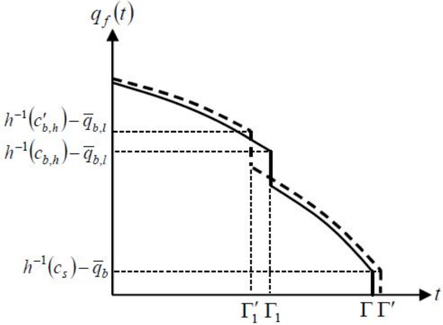
Intuition

- The monopolist's incentive: reduce output in order to raise energy prices.
- But, this incentive is "mitigated" by dynamics: the current vs. future trade-off.
- Depends on *relative* elasticities of *residual demand* facing the monopolist in different periods.
- The monopolist produces more (less) in periods with higher (lower) residual demand elasticities.
- Staving-off period: infinite demand elasticity. Produces more
- As c_s decreases, the period of infinite residual demand elasticity starts earlier: produce less now to enable more production then.

High cost biofuel subsidies under perfect competition



(a) Impact on prices

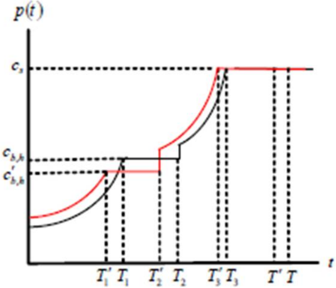


(b) Impact on fossil fuel use

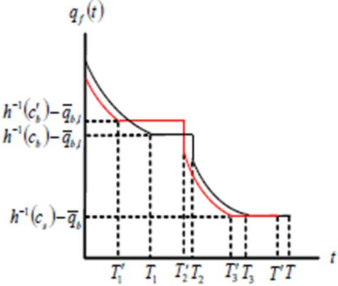
High cost biofuel subsidies: effects

- Subsidies that reduce the cost of high cost biofuels
  - Increase fossil fuel use for early periods (negative);
    1. Intuition: lower biofuel cost pushes down fossil fuel price in all periods.
    2. Thus, more fossil fuel is consumed before high cost biofuel kicks in.
  - Delays exhaustion of fossil fuels (positive).
    1. High cost biofuel becomes competitive at an earlier time, reducing fossil fuel consumption and delays its exhaustion.
- Expanding the capacity of high cost biofuel: similar effects
- Message: conclusion about Green Paradox is contradictionary if one of the two narrow versions is used (early consumption vs. exhaustion time).

High cost biofuel subsidy: monopoly



Price path



Fossil fuel supply

- Reduce early use of fossil fuels (positive).
- Speed up exhaustion time of fossil fuels (negative).

Summary

	solar subsidy	High cost subsidy	Low cost capacity	High cost capacity
Competition	$-$	$-/+$	$+$	$-/+$
Monopoly	$+/-$	$+/-$	$+$	$+/-$

- Capacity expansion for low cost biofuel: climate friendly.
  1. So, relax blendwall?
- Green Paradox: arises only for solar under perfect competition
- Role of capacity constraint (vs solar): exhaustion time effect is opposite to early extraction effect.
- If only concern is with delaying early extraction:
  1. All policies are friendly under monopoly: anticipating future higher elacticity (and thus higher supply), the monopolist reduces current extraction.
  2. Almost all subject to Green Paradox under competition: future renewables suppress current fossil fuel price.
  3. Monopoly is friend of renewable policy

Lessons and next steps

- Lessons
  1. Difference between subsidies and capacity expansion for biofuels
  2. Dynamics important, but be careful about market power: simple dynamic reasoning won't work.
- Calibrated dynamic model
  1. NPV of damages (Wang and Zhao, 2015)
  2. Heterogeneous fossil fuels: more careful GHG footprints
  3. Compare with static predictions
- Combine with indirect land use effects: land use decisions are also dynamic!