Dynamic Effects of Renewable Energy Policies on Climate Change

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1. Introduction

- Major economies increase government support for renewable energies
  - Global climate change; High energy prices.
  - Aimed to reduce the demand for fossil fuels: price subsidy and mandatory blending.
  - Justification: help substitute fossil fuel use and reduce carbon emission.

- Critique:
  - Static analysis;
  - Indirect market effects mostly exclude the response of the supply side of fossil fuels.
  - Green Paradox (Sinn, 2008): Green policy may exacerbate the damage of climate change;
  - Wang and Zhao (2011):
    - fossil fuel supply effects could be large in dynamic models
    - capacity constraints of renewable energies and market structure.

- This paper: evaluate the long-run policy impacts on oil market and carbon emission by incorporating oil owners’ response in a dynamic (Cartel-Fringe) world by means of calibration.
Oil market structure

- The supply of renewable energies is competitive;
- Oil sector: open loop Cartel-Fringe:
  - Cartel (OPEC) controls the oil price
  - Fringes (other oil producing countries) are the price takers;

Renewable energies

- Backstop (solar): can supply the whole market when its price becomes competitive.
  - Electricity car with electricity generated from solar photovoltaic technology.
- Capacity constrained (biofuels): supply is limited due to natural constraint, like land availability.
  - Low cost biofuels: first generation biofuels;
  - High cost biofuels: second generation biofuels.

Oil, low cost biofuels, high cost biofuels and solar are perfect substitutes.
Pirce policy and quantity policy for each renewable energy:

- Cost reduction policies for high cost biofuels and solar;
  - E.g. direct price subsidy or R&D support;
- Capacity expansion policies for low cost biofuels and high cost biofuels.
  - E.g. subsidy for agricultural infrastructure, R&D support or mandatory blending;

Our approach?

- Baseline: solve for oil supply path given cost and capacity constraints of renewable energies;
- Comparative dynamics: If cost or capacity constraint is exogenously changed by policy (or technology innovation), how fringe and cartel change the path of oil supply.
- Climate change impacts: How the path change of oil supply affects carbon accumulation and the damage of climate change.
2. The model

Market:

- Four substitutional energies: oil, low cost biofuels, high cost biofuels and solar.
  - Unit production cost: $c_o < c_{b,l} < p(0) < c_{b,h} < c_s$;
- Energy supply in period $t$: $q_f(t)$, $q_c(t)$, $q_{b,l}(t)$, $q_{b,h}(t)$ and $q_s(t)$.
  - Capacity constraints: $q_{b,l}(t) < \bar{q}_{b,l}$; $q_{b,h}(t) < \bar{q}_{b,h}$;
- Gasoline demand function $p = h(Q)$.
2.1. Renewable energy supply

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

$$q_{b,i}(t) \begin{cases} 
= 0, & \text{if } p(t) < c_{b,i} \\
\in [0, \bar{q}_{b,i}], & \text{if } p(t) = c_{b,i} \\
= \bar{q}_{b,i}, & \text{if } p(t) > c_{b,i} 
\end{cases}$$  \hspace{1cm} (1)

• Supply of solar

$$q_s(t) \begin{cases} 
= 0, & \text{if } p(t) < c_s \\
\in [0, h^{-1}(c_s) - \bar{q}_b - q_f(t)], & \text{if } p(t) = c_s 
\end{cases}$$  \hspace{1cm} (2)
2.2. Oil supply (Nash-Cournot solutions)

- Fringe’s problem

\[
\max_{\{q_f(t)\}} \int_0^\infty e^{-rt} \left[ p(t) q_f(t) - c_o q_f(t) \right] dt
\]

\[s.t. X_f(t) = -q_f(t); \int_0^\infty q_f(t) dt = X_{0,f};\]

Optimal condition:

\[h(Q(t)) = c_o + \lambda_f e^{rt}\] (3)

- Cartel’s problem

\[
\max_{\{q_c(t)\}} \int_0^T e^{-rt} \left[ h(Q(t)) q_c(t) - c_o q_c(t) \right] dt
\]

\[s.t. X_c(t) = -q_c(t); \int_0^T q_c(t) dt = X_{0,c};\]

Optimal condition:

\[h'(Q(t)) q_c(t) + h(Q(t)) = c_o + \lambda_c e^{rt}\] (4)
2.3. Theoretical results: policies for high cost biofuels

- The rental values $\lambda_c$ and $\lambda_f$ determine the path of oil supply and thus carbon accumulation;
- Effects of high cost biofuel policies on rental value
  - Case 1: the results of competitive market apply, \textit{reducing} both cartel’s and fringe’s rental value;
  - Case 2: the results of monopoly market apply, \textit{increasing} both cartel’s and fringe’s rental value;
Effects of solar policies on rental value

- Case 1: the results of competitive market apply, *reducing* both cartel’s and fringe’s rental value;
- Case 2: the results of monopoly market apply, *increasing* both cartel’s and fringe’s rental value;
3. Calibration

- Gasoline demand function: \[ Q(t) = AP(t)^\alpha GDP(t)^\beta \]
  - \(\alpha = -0.43; \beta = 0.81; GDP(t)\) grows at 2\% per year.
  - One barrel oil can produce 0.6 barrel gasoline and diesel.

- Cost structure: \(c_f = $20 + $50/\text{barrel}; c_{b,h} = $180/\text{barrel}; c_s = $450/\text{barrel}\).

- Biofuel capacity (based on gasoline and diesel equivalent basis): \(\bar{q}_{b,l} = 0.5 \text{ billion barrels}; \bar{q}_{b,l} = 1 \text{ billion barrels}\).

- Climate change model: DICE model;

- Damage of climate change (DICE model): \[
  \int_{0}^{100} e^{-0.01 \times t} D(\text{Temp}(t)) \, dt;
\]

- Interest rate: \(r = 0.05\);

Cost reduction policies for solar
Cost reduction policies for high cost biofuels
Capacity expansion policies for high cost biofuels
Capacity expansion policies for low cost biofuels
Green Paradox applies to solar cost reduction policies;
Capacity constraints do generate big difference on policy effects.
  - Limit the substitution effect of renewable energies;
  - Reduce the competition pressure for oil owners.
Climate damage effect of capacity expansion policies

Low cost biofuels

High cost biofuels
4. Conclusion

- Change of the supply path of exhaustible resource is indeterminate in Cartel-Fringe model.
- "Green Paradox" apply to the backstop technology.
- "Green Paradox" can be avoided by the capacity constraints.
  - Capacity constraints limit the competition from renewable energies;
- Well understanding of policy impacts is necessary for designing climate change policies.