Mandates and the Incentive for Environmental Innovation*

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A tale of two mandates

U.S. Corn-Ethanol Mandate and Nameplate Capacity, billions of gallons

U.S. Cellulosic Ethanol Mandate and Production Capacity, billions of gallons

- Key difference:
  - **corn ethanol** was a mature technology, mandate served to catalyze investment in physical plants
  - **cellulosic ethanol** requires new technologies to make it commercially viable and scalable
    - R&D is key, this is an innovation challenge
“Mandates” as a policy tool

- Two effects of renewable energy policies (Jaffe, Newell & Stavins 2003; Popp, Newell & Jaffe 2010)
  - ameliorate pollution **externality**
    — substitute cleaner energy for fossil fuel
  - promote **innovation**

- Impact on innovation arguably more important (Jaffe, Newell & Stavins 2005; Popp 2010)
  - twin market failures → pervasive innovation **under-provision**

- Two families of policy tools (Parry, 1995; Denicolo, 1999; Scotchmer, 2010; ...)
  - **price** instruments – e.g., **carbon tax**
  - **quantity** instruments – e.g., (tradable) **pollution permits**

- Ranking of policy instruments **inconclusive** (Fischer, Parry & Pizer 2003)
  - review of evidence may favor price-based policies (Requate 2005)

- Where do renewable energy “mandates” fit in?
  - what is the impact of **mandates** on **innovation**?
  - how do mandates **perform**, compared with **other policy tools**?

*Our Paper*
Innovation and market for renewable energy

Perfectly Competitive Producers

Fossil Fuel $Q_1$
MC = $c_1$

Renewable Fuel $Q_2$
MC = $c_2 - \theta + Q_2$

Perfectly Competitive Blending Sector

Blender
$Q = Q_1 + Q_2$

Externality:
marginal damage $x$ per unit produced

Consumer Demand $P(Q)$

Innovation
A model of stochastic innovation

- Analyze three settings: *laissez faire*, *mandate*, and *carbon tax*

- There is an **R&D sector** that produces innovations that are licensed to the production sector
  - two R&D structures: *single* innovator and *multiple innovators*
    - **endogenous number** of innovators (free entry with *Bertrand pricing*)

- We model innovation as a “*replacement technology*” (rather than abatement technology)
  - also, throughout, consider case of “*non-drastic innovation*”

- Assume **constant marginal** environmental damage of *externality*
  - level of naïve carbon tax is obvious and it is *time-consistent*
  - assume *policymaker can commit* to mandate

- $G(\omega)$ can be anything, $F(\theta \mid \omega)$ is uniform
Innovation and market for renewable energy – *laissez faire*

- Innovation decreases the MC of producing renewable energy
  - model maintains scalability disadvantage of renewable energy relative to fossil fuel

\[
\frac{\partial C_2(Q_2, 0)}{\partial Q_2}, \quad \frac{\partial C_2(Q_2, \theta)}{\partial Q_2}, \quad \frac{\partial C_1(Q_1)}{\partial Q_1}
\]

Innovation decreases the MC of producing renewable energy
- model maintains scalability disadvantage of renewable energy relative to fossil fuel
Innovation with a mandate – one innovator

$\hat{Q} = \text{mandate}$

$P(Q)$

$\theta$

$c_1$

$c_2 - \theta$

$c_2$

$\text{MC of renewable energy before innovation}$

$\text{MC of renewable energy post-innovation}$

$\text{MC of fossil fuel}$

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Innovation with a mandate – multiple innovators

- MC of renewable energy before innovation
- MC of renewable energy with 2nd best innovation
- MC of renewable energy with best technology
- MC of fossil fuel

\[
\hat{Q} = \text{mandate}
\]

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Innovation with a carbon tax – one innovator

\[ p \]

\[ Q \]

\[ c_1 \]

\[ c_2 \]

\[ c_2 - \theta \]

\[ t \]

\[ \theta \]

\[ \text{MC of fossil fuel} \]

\[ \text{MC of fossil fuel + carbon tax} \]

\[ \text{MC of renewable energy before innovation} \]

\[ \text{MC of renewable energy with best technology} \]

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Innovation with a carbon tax – multiple innovators

- MC of renewable energy before innovation
- MC of renewable energy with 2nd best innovation
- MC of renewable energy with best technology
- MC of fossil fuel + carbon tax
- MC of fossil fuel

\[ P(Q) \]

\[ Q \]

\[ \theta_1, \theta_2, c_1, c_2, t \]
Some results: single innovator

**RESULT 1.** The welfare maximizing quantity mandate is increased when the social planner takes into account its impact on innovation.

- Ranking of policy tools: need **comparable levels** of “mandate” and “carbon tax”

**Remark 1.** *When the mandate is calibrated to yield the same probability of R&D as the carbon tax, the expected value of the innovation is the same under both policies.*

**Remark 2.** *As the cost of R&D increases, the level of the mandate must be progressively increased in order to attain the same probability of R&D as a fixed carbon tax.*

**RESULT 2.** When a mandate is chosen so that R&D is equally probable under a mandate or a carbon tax, then expected welfare is higher with a carbon tax.

- in the absence of innovation, mandate is not capable of achieving first best allocation
  – when the two tools achieve same R&D probability, innovation cannot make up for that
- not clear what happens if mandate is high enough to induce more R&D ...
  – numerical analysis
**RESULT 3.** Under a mandate, the gain in consumer surplus from innovation can be more than offset by an increase in damages from the externality when demand is sufficiently elastic and marginal damage is sufficiently high.
**RESULT 4.** There is a threshold $\hat{\omega}_t(\hat{n})$ such that
- whenever technological opportunity is “good”, i.e., $\omega \geq \hat{\omega}_t(\hat{n})$, the number of innovators is (weakly) higher under a carbon tax than under a mandate.
- whenever technological opportunity is “weak”, i.e., $\omega \leq \hat{\omega}_t(\hat{n})$, the number of innovators is (weakly) higher under a mandate policy than a carbon tax.

**RESULT 5.** When the mandate is tuned so that the probability of R&D under a mandate is equal to the probability of R&D under a carbon tax, then the expected technology realized after innovation is better under a carbon tax.

**RESULT 6.** When the mandate is tuned so that the expected best technology is the same under either policy, then the distribution of outcomes under a carbon tax is more disperse than under a mandate.
**RESULT 7 (numerical).** In all parametric combinations that we considered, expected welfare under the optimal mandate is always lower than under the optimal carbon tax.

**RESULT 9 (numerical).** In all parametric combinations considered, with multiple innovators, expected welfare with the optimal mandate is always lower than with the naïve carbon tax.
### Numerical Results: Optimal policy instruments

<table>
<thead>
<tr>
<th></th>
<th>Optimal Mandate</th>
<th>Optimal Carbon Tax</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Innovation</td>
<td>Single Innovator</td>
</tr>
<tr>
<td>Baseline</td>
<td>2.4</td>
<td>18.6</td>
</tr>
<tr>
<td>$\eta = 0.25$</td>
<td>1.1</td>
<td>1.5</td>
</tr>
<tr>
<td>$\eta = 1$</td>
<td>5.2</td>
<td>15.2</td>
</tr>
<tr>
<td>$x = 10$</td>
<td>0.0*</td>
<td>0.0*</td>
</tr>
<tr>
<td>$x = 40$</td>
<td>30.3</td>
<td>41.8</td>
</tr>
<tr>
<td>$k = 0.03\bar{\pi}$</td>
<td>2.4</td>
<td>18.6</td>
</tr>
<tr>
<td>$k = 0.12\bar{\pi}$</td>
<td>2.4</td>
<td>18.1</td>
</tr>
<tr>
<td>$E[\omega] = 15$</td>
<td>2.4</td>
<td>9.5</td>
</tr>
<tr>
<td>$E[\omega] = 60$</td>
<td>2.4</td>
<td>31.4</td>
</tr>
</tbody>
</table>

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## Numerical Results: Welfare Gains Decomposition

<table>
<thead>
<tr>
<th></th>
<th>$\Delta W$ with innovation, <em>laissez faire</em></th>
<th>static $\Delta W$ with naïve level of policy</th>
<th>additional $\Delta W$ due to policy-induced innovation</th>
<th>additional $\Delta W$ due to optimal choice of policy instrument</th>
<th>Total $\Delta W$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$W_1^0 - W_0^0$</td>
<td>$W_0^n - W_0^0$</td>
<td>$(W_1^n - W_0^n) - (W_1^0 - W_0^0)$</td>
<td>$W_1^* - W_1^n$</td>
<td>$W_1^* - W_0^0$</td>
</tr>
<tr>
<td>Mandate</td>
<td>412</td>
<td>2</td>
<td>3</td>
<td>37</td>
<td>455</td>
</tr>
<tr>
<td>Carbon Tax</td>
<td>412</td>
<td>97</td>
<td>173</td>
<td>7</td>
<td>689</td>
</tr>
</tbody>
</table>
Conclusions

- In addition to correcting externalities, environmental policy has another important effect:
  - promote innovation

- How effective are “mandates” vis-à-vis this twin challenge?
  - mandates can be useful tools – can improve outcomes relative to laissez faire
    - the prospect of innovation is crucial – it increases the level of mandates significantly
  - optimal mandate levels are however sensitive to the innovation process
    - technological opportunity; structure of R&D industry (e.g., single or multiple innovators)

- But: relative to a carbon tax, the performance of mandates appears inferior
  - a naïve carbon tax tends to yield higher welfare than a (ex ante optimal) mandate
  - mandates provide stronger incentives when technological opportunities are weak
    - carbon tax provides stronger incentives when technological opportunities are strong

THANK YOU