Green Patents in an Oligopolistic Market with Green Consumers

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Developing climate change mitigation technologies are critical to reaching net-zero emissions (Barrett, 2009; Galiana and Green, 2009; Probst et al, 2021).

- Large scale efforts to promote green innovation (G8 summit, COP 21, 22, 23, 24, 26)

**No consensus** on what are the most effective policy instruments to encourage the development of green (less polluting) technology
Introduction: Related literature

- Green innovation: **Environmental** externality + **Knowledge** externality

- **Environmental policy tools to foster green innovation:** carbon tax, cap-and-trade system, ...
  - Porter Hypothesis (e.g. Porter, 1991; Porter and van der Linde, 1995; Ambec et al., 2013; Dechezleprêtre and Sato, 2017; Cohen and Tubb, 2018)

- **Innovation policy tools to foster green innovation:** (e.g. Popp, 2006, 2019; Fischer and Newell, 2008; Acemoglu et al., 2012; Hepburn et al., 2018; Lehmann and Söderholm, 2018)
  - R&D subsidies
  - **Patent policy tools:** Langinier and Ray Chaudhuri (2020); Langinier and Ray Chaudhuri (2022) (this paper)
Introduction: Motivation

- **Green patents on the rise:**
  - 2000-2011: Green patent applications rose by: 78% (OECD); 528% (BRICS)
  - 2000-2011: All patent applications rose by: 3.9% (OECD); 363% (BRICS)
  - Probst et al (2021): Annual growth rate in high-value invention of climate change mitigation technologies across 170 countries: 10% (1995 to 2012); 6% (2013 to 2017)

- **No consensus on role of green patents** (Hall and Helmers, 2013)
  - International organizations advocate excluding green technologies from patenting
  - Fast-track patenting system for green innovations (Australia, Brazil, Canada, China, UK, US, Japan, South Korea): reduced the time from application to grant by up to 75% (Dechezleprêtre, 2013)
How do **patent policies** impact the efficacy of **emission taxes** in terms of fostering green innovation and reducing emission levels?

- patenting costs
- patentability requirements

**Key factors driving our results:**

- Endogenizing firms’ **licensing** decisions within an **oligopolistic** market
- Heterogeneity of **environmentally friendly (green) consumers** (e.g. Bansal and Gangopadhyay, 2003; Bansal, 2008; Doni and Ricchiuti, 2013)
  - eco-labeling is on the rise: e.g. 50% of the market share for certain products consists of the environmentally friendly variant in Sweden; green marketing in transportation and electricity markets
Model Setting

- Two firms are producing a polluting (dirty) good
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- Constant marginal cost, $c$, identical across firms
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For each firm $i, i = 1, 2$, the emission of the pollutant generated per unit of production is

$$\gamma_i \equiv \frac{e_i}{q_i}$$
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emission

output
Model Setting

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- Constant marginal cost, $c$, identical across firms
- For each firm $i$, $i = 1, 2$, the emission of the pollutant generated per unit of production is

\[
\gamma_i \equiv \frac{e_i}{q_i}
\]

- Each firm $i$ can invest $l_i \in \{0, l_P\}$ to reduce emission-output ratio

\[
\gamma_i = \begin{cases} 
\gamma_H & \text{if } l_i = 0 \\
\gamma_P & \text{if } l_i = l_P
\end{cases}
\]
Model Setting

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- Constant marginal cost, \( c \), identical across firms
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  \]
  where
  - emission
  - output

- Each firm \( i \) can invest \( l_i \in \{0, l_P\} \) to reduce emission-output ratio

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\gamma_i = \begin{cases} 
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\end{cases}
\]

- with \( \Delta \equiv \gamma_H - \gamma_P >> 0 \)
Environmental conscious consumers can observe the emission-output ratio of each firm, $\gamma_i$ (effective eco-labeling)

Examples:
- share of renewables in energy (22.1% in EU in 2020, but unprecedented transformation in the energy system necessary to meet the target of 32% set for 2030)
- proportion of recycled inputs used in production the process: recycling in EU increased by 34% (2005-2016)
Model Setting

Demand side

- $N = 1$ consumers
- Each consumer buys 0 or 1 unit of the good
- Fraction $\lambda$ (resp., $1 - \lambda$) of green conscious (non-green conscious) consumers
- Green conscious consumers care about the greenness ($\gamma$) of the product
- Non-green conscious consumers only care about prices
Model Setting

Demand side

Utility of a non-green conscious consumer

\[ U_{NG} = \min_{p_1, p_2} \gamma f(p) \]

from buying the good at \( P(e) \) from not buying \( P(e) \)

Utility of a green conscious consumer

\[ U_G = \min_{p_1, p_2} \gamma G p \]

from buying the good \( \gamma_i \) at price \( p_i \)

\( G \) degree of environmental friendliness

\( G \) is uniformly distributed on \([G, G]\); \( G = G + 1 \) and \( G > 0 \)
Model Setting
Demand side

- Utility of a **non-green conscious** consumer

\[ U_{NG} = \begin{cases} 
    v - \min\{p_1, p_2\} - P(e) & \text{from buying the good at } p \\
    -P(e) & \text{from not buying}
\end{cases} \]
Model Setting

Demand side

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- \(P(e)\) pollution damage to each consumer
Model Setting

Demand side

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  \]

- \( P(e) \) pollution damage to each consumer

- Utility of a **green conscious** consumer
  \[
  U_G = \begin{cases}
  v - \gamma_i G - p_i - P(e) & \text{from buying the good } \gamma_i \text{ at price } p_i \\
  -P(e) & \text{from not buying}
  \end{cases}
  \]
Model Setting

Demand side

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- \(G\) degree of environmental friendliness
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  \end{cases}
  \]

- \(G\) degree of environmental friendliness
  - \(G\) is uniformly distributed on \([\underline{G}, \bar{G}]\); \(\bar{G} = \underline{G} + 1\) and \(\underline{G} > 0\)
Patent policy

Green innovation can be patented if $\gamma = \gamma_P$. Weak patentability requirement if $\Delta \gamma_H \gamma_P$ is small (U.S.). Strong patentability requirement if $\Delta \gamma_H \gamma_P$ is large (E.U.).

Green patenting cost $C_P$: application fees, waiting time, potential litigation costs, renewal costs.

Environmental policy

Per unit tax $\tau$ on pollution emission such that each firm $i$ pays $\tau e_i$.
Model Setting

Timing

At $t = 1$, each firm $i$ chooses its investment $I_i$ between 0 and $I_{max}$. Once the innovation has been discovered, the innovator decides to patent it or not (if both get the innovation, each firm gets the patent with probability $1/2$). Once firm $i$ has obtained a patent, firm $i$ decides whether to license or not to the other firm.

At $t = 2$, both firms choose their prices $p_1$ and $p_2$. Langinier, Ray Chaudhuri (a University of Alberta, b University of Winnipeg & TILEC, Tilburg University) Green Patents May 2022 10 / 27
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Model Setting

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- At $t = 1$, each firm $i$ chooses its investment $I_i \in \{0, I_p\}$

- Once the innovation has been discovered, the innovator decides to **patent** it or not (if both get the innovation, each firm gets the patent with probability $1/2$)

- Once firm $i$ has obtained a patent, firm $i$ decides whether to **license** or not to the other firm
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- Once the innovation has been discovered, the innovator decides to **patent** it or not (if both get the innovation, each firm gets the patent with probability $1/2$)

- Once firm $i$ has obtained a patent, firm $i$ decides whether to **license** or not to the other firm

At $t = 2$, both firms choose their prices $p_1$ and $p_2$
Benchmark case: Non-green consumers only ($\lambda = 0$)

- **Licensing always occurs in equilibrium**
  - Patent holder chooses royalty rate to obtain monopoly profit
  - Non-patent holder’s outside option is zero
Benchmark case: Non-green consumers only
Investment decisions in Stage 1

\[ CP \]

\[ (0, 0) \]

\[ (I_P, 0) \] or \[ (0, I_P) \]

\[ (I_P, I_P) \]
Benchmark case: Non-green consumers only

Investment decisions in Stage 1

\[ C_P \]

\((0, 0)\)

\((I_P, 0)\) or \((0, I_P)\)

\((I_P, I_P)\)
Benchmark case: Non-green consumers only

- $l_1 = l_2 = 0$:
  - Bertrand competition in homogeneous (dirty) product with
    \[ p_1 = p_2 = c + \tau \gamma H \]
  - both firms get zero payoffs

- If one or both firms invest and patent holder, firm 1, **does not license**
  - Bertrand competition with heterogeneous marginal costs with
    \[ p_1 = c + \tau \gamma H - \epsilon \]
  - $\Pi_1 > 0$ and firm 2 does not produce

- If one or both firms invest and patent holder, $i$, **does license**
  - both firms produce the cleaner product $\gamma P$
  - Firm 1 offers a license $(r, F)$ where
    - $r$ is the per-unit royalty rate
    - $F$ is a fixed fee
Benchmark case: Non-green consumers only

Price Competition

- There is a unique Nash equilibrium in prices in which both firms choose
  \[ p_{1P}^L = p_2^L = c + \tau \gamma_P + r \]
- Firm 2 accepts the license only if
  \[ D_2(p_{1P}, p_2; \gamma_P)(p_2 - c - \tau \gamma_P - r) - F \geq 0 \]
- The unique equilibrium: **licensing always occurs**
  \[ (r^*, F^*) = (v - c - \tau \gamma_P, 0) \text{ and } p_{1P}^L = p_2^L = v \]
- Stage 2: Firm 1 obtains monopoly profit: \( (v - c - \tau \gamma_P) > 0 \); Firm 2 gets zero payoff

**Patenting decision**: the innovator patents if and only if
\[ v - c - \tau \gamma_P - C_P \geq 0 \]
Benchmark case: Non-green consumers only

Total emissions when

\[ \lambda = 0 \]
Benchmark case: Non-green consumers only
Reducing patenting cost

As \( C_P \) decreases

\[ \gamma_H \]

\[ \gamma_P \]

\[ \Delta \]

\[ \tau_1 \]
Benchmark case: Non-green consumers only
Making patentability requirements stricter

As $\gamma_P$ decreases
Benchmark case: Non-green consumers only

Policy implications

- **Paradox:** For a given patenting cost, **increasing the emission tax** beyond $\tau_1$ leads to **less innovation** as the tax bill increases.

- **Reducing patenting cost**, $C_P$, (e.g. by fast-tracking green patents) makes it less likely that this paradox occurs.

- Making **patentability requirements stricter**
  - makes it less likely that this paradox occurs
  - lowers emission level for $\tau < \tau_1$
Green conscious and Non-green consumers ($0 < \lambda \leq 1$)

- Licensing does NOT always occur in equilibrium
  
  - For sufficiently large $\lambda$, due to **product differentiation**, non-patent holder’s payoff from NOT purchasing the license may be strictly positive
Non-Green and Green Conscious Consumers

Price Competition

- If $\tau < \tau_L(\lambda)$, firms differentiate products (no licensing)
Non-Green and Green Conscious Consumers

Price Competition

- If $\tau < \tau_L(\lambda)$, firms differentiate products (no licensing)
  - equilibrium prices are $p_{1P}^G > p_2^G$ and payoffs are
    $$\Pi_{1P}^G > 0; \quad \Pi_2^G > 0$$
If \( \tau < \tau_L(\lambda) \), firms differentiate products (no licensing)

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\[
\Pi_{1p}^G > 0; \quad \Pi_2^G > 0
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- **Outside option of firm 2** (from not purchasing license) is **positive**
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- If licensing occurred firm 2 would get zero
Non-Green and Green Conscious Consumers
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Non-Green and Green Conscious Consumers

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Non-Green and Green Conscious Consumers

Price Competition

- If $\tau < \tau_L(\lambda)$, firms differentiate products (no licensing)
  - equilibrium prices are $p^G_1 > p^G_2$ and payoffs are
    \[ \Pi^G_{1P} > 0; \quad \Pi^G_{2} > 0 \]
  - **Outside option of firm 2** (from not purchasing license) is **positive**
  - If licensing occurred, firm 2 would get zero
  - **No licensing** occurs in equilibrium

- If $\tau \geq \tau_L(\lambda)$, firm 2 would not produce if licensing did not occur
  - **Outside option of firm 2 is zero**
  - If licensing occurs, equilibrium prices are $p^L_1 = p^L_2 = c + \tau \gamma P + r$ and payoffs are
    \[ \Pi^G_{1P} > 0; \quad \Pi^G_{2} = 0 \]
Non-Green and Green Conscious Consumers

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- If $\tau < \tau_L(\lambda)$, firms differentiate products (no licensing)
  - equilibrium prices are $p_{1P}^G > p_2^G$ and payoffs are
    \[ \Pi_{1P}^G > 0; \quad \Pi_2^G > 0 \]
  - **Outside option of firm 2** (from not purchasing license) is positive
  - If licensing occurred firm 2 would get zero
  - **No licensing** occurs in equilibrium

- If $\tau \geq \tau_L(\lambda)$, firm 2 would not produce if licensing did not occur
  - **Outside option of firm 2 is zero**
  - If licensing occurs, equilibrium prices are $p_1^L = p_2^L = c + \tau \gamma_P + r$ and payoffs are
    \[ \Pi_{1P}'^G > 0; \quad \Pi_2^G = 0 \]
  - **Licensing** occurs in equilibrium
Non-Green and Green Conscious Consumers

Price Competition

\[ p_{iP}^G = p_j^G \]

\[ p_{iP}^G > p_j^G \]

License

No License

\[ \tau_L(\lambda) \]

\[ \tau \]

\[ \lambda \]

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Green Patents

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For large values of patenting cost $C_P$
Non-Green and Green Conscious Consumers

Investment decisions for large patenting cost

\[ \tau \]

\[ \tau_L(\lambda) \]

License No License

(0, 0) (\(l_P, 0\)) (\(l_P, l_P\))

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Green Patents

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Non-Green and Green Conscious Consumers

Investment decisions for large patenting cost

\[ \tau \]

\[ (0, 0) \]

\[ (I_P, 0) \]

\[ (I_P, I_P) \]

\[ \tau_L(\lambda) \]

\[ 0 \quad \text{License} \quad \text{No License} \quad 1 \]

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Non-Green and Green Conscious Consumers
Investment decisions for large patenting cost
Non-Green and Green Conscious Consumers

Investment decisions for large patenting cost

$\tau$ $\lambda$

$\tau_L(\lambda)$

$(0, 0)$

$(I_P, 0)$

$(I_P, I_P)$

$(0, 0)$

$(I_P, 0)$

$(I_P, I_P)$

$0$ License $\lambda_1$ No License $1$

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Non-Green and Green Conscious Consumers

Investment decisions for large patenting cost

\[ \tau \]

\[ \lambda \]

\[(0, 0)\]

\[(I_P, 0)\]

\[(I_P, I_P)\]

\[\tau_L(\lambda)\]

\[0\]

\[\lambda_1\]

\[1\]

License

No License

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For large values of patenting cost $C_P$
Non-Green and Green Conscious Consumers

Investment decisions for large patenting cost

\[ (0, 0), (I_P, 0), (I_P, I_P) \]

\[ \tau_L(\lambda) \]

\[ 0, \lambda_1, 1 \]

License, No License

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Non-Green and Green Conscious Consumers
Investment Decisions for small patenting cost

\[ (I_P, I_P) \]

License

\[ \lambda_1 \]

No License

\[ \tau_L(\lambda) \]

\[ 0 \]

\[ 1 \]
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As $\lambda$ increases

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Non-Green and Green Conscious Consumers
Investment Decisions

\[
\begin{align*}
\tau_{1}^{NL} & \quad (0, 0) \\
(0, I_P) \text{ or } (I_P, 0) & \\
(I_P, I_P) & \\
\tau_{2}^{NL} & \\
\tau_{1}^{L} & (0, 0) \\
(I_P, 0) \text{ or } (0, I_P) & \\
(I_P, I_P) & \\
\tau_{2}^{L} & \\
\tau_{L} & \\
\end{align*}
\]

No License \quad \tau_{L}(\lambda) \quad License

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Non-Green and Green Conscious Consumers
Investment Decisions

$C_P$

$\tau^N_L$

$\tau^L_1$

$\tau^L_2$

$(0, 0)$

$(I_P, 0)$ or $(0, I_P)$

$(I_P, I_P)$

$\tau_L(\lambda)$

No License

License

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Non-Green and Green Conscious Consumers
Emission Levels for large patenting cost

\[
\Delta \gamma_P \gamma_H \tau_L(\lambda) \tau
\]
Non-Green and Green Conscious Consumers

Emission Levels

\[
\Delta
\]

\[
\gamma_H
\]

\[
\gamma_P
\]

Emissions

No License \( \tau_L(\lambda) \) License

As \( \gamma_P \) decreases

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Non-Green and Green Conscious Consumers

Emission Levels for large patenting cost

As $C_p$ decreases

Emissions

$\gamma_H$

$\Delta$

$\gamma_P$

No License $\tau_L(\lambda)$ License

As $C_p$ decreases
Non-Green and Green Conscious Consumers

Emission levels for small patenting cost

\[ \tau \]

\[ \tau_L(\lambda) \]

\[ \Delta \]

\[ \gamma_H \]

\[ \gamma_P \]

Emissions vs. \( \tau \):

- No License
- \( \tau_L(\lambda) \)
- License

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Emission levels for small patenting cost

\[ \Delta \]

\[ \gamma_P \]

\[ \gamma_H \]

Emissions

As \( \gamma_P \) decrease

\[ \tau_L(\lambda) \]

No License \quad License

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Conclusion

- The greater the proportion of consumers that are green conscious, the less likely that firms are to engage in licensing the green innovation.
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- Higher proportions of green conscious consumers is associated with higher levels of emissions!
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- Policies to reduce emissions when $\lambda$ is high
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- Higher proportions of green conscious consumers is associated with higher levels of emissions!

- Policies to reduce emissions when $\lambda$ is high:
  - Technology standards in order to effectively force licensing.
The greater the proportion of consumers that are green conscious, the less likely that firms are to engage in licensing the green innovation.

Higher proportions of green conscious consumers is associated with higher levels of emissions!

Policies to reduce emissions when $\lambda$ is high
- Technology standards in order to effectively force licensing
- Induce licensing by increasing the emission tax to an intermediate level

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  - Technology standards in order to effectively force licensing
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- Increasing the emission tax too high results in increasing the emission level (paradox)

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Green Patents

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Policies to reduce emissions when $\lambda$ is high

- Technology standards in order to effectively force licensing
- Induce licensing by increasing the emission tax to an intermediate level

Increasing the emission tax too high results in increasing the emission level (paradox)

This paradox can be mitigated by...
Conclusion

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- Higher proportions of green conscious consumers is associated with higher levels of emissions!

- Policies to reduce emissions when $\lambda$ is high:
  - Technology standards in order to effectively force licensing
  - Induce licensing by increasing the emission tax to an intermediate level

- Increasing the emission tax too high results in increasing the emission level (paradox)

- This paradox can be mitigated by
  - decreasing patenting costs

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Conclusion

- The greater the proportion of consumers that are green conscious, the less likely that firms are to engage in licensing the green innovation.
- Higher proportions of green conscious consumers is associated with higher levels of emissions!
- Policies to reduce emissions when $\lambda$ is high
  - Technology standards in order to effectively force licensing
  - Induce licensing by increasing the emission tax to an intermediate level
- Increasing the emission tax too high results in increasing the emission level (paradox)
- This paradox can be mitigated by
  - decreasing patenting costs
  - making the patentability requirements stricter (lower level of emissions as compared to reducing patenting costs)