

Green, Greener or Neutral? Signaling Environmental Quality under Incomplete Information

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1. Motivation & Research Question

- Consumer preferences have increasingly shifted towards more sustainable or ethical versions of certain products (IPSOS-MORI, 2003 “Ethical Companies”).
- Issue: Observability of the true environmental quality of the product beyond observable efforts → credence attribute.
- Example:



1. Motivation & Research Question

Question

How can a monopolistic firm, whether green or neutral, use price and costly effort to signal its environmental type to consumers?

Model overview:

- Monopoly of type green or neutral.
 - Green: higher cost of production, creation of a positive externality (impure public good).
 - Neutral: lower cost of production, no benefit for society.
- Costly effort:
 - Exerted by green: further enhances the positive externality.
 - Exerted by neutral: purely dissipative signal.
- Consumers enjoy a warm glow from green consumption (Andreoni, 1990).

1. Motivation & Research Question

Main results:

1. Benchmark under complete information: monopoly strategies and welfare-maximizing solution.
2. Signaling strategies under incomplete information: separating perfect Bayesian equilibrium with one or two instruments used + welfare implications.
3. Role of green subsidies.

1. Motivation & Research Question

Literature

1. Literature on signaling games:

- Wolinsky (1983), Farrell (1981), Cooper and Ross (1984), Klein and Leffler (1981), Shapiro (1982). Bagwell and Riordan (1991)
- Milgrom and Roberts (1986)
- Mahenc and Volle (2021)

2. Literature on the private provision of public goods:

- Warr (1983) and Bergstrom et al. (1986).
- More recently, Besley and Ghatak (2007) and Bagnoli and Watts (2003).

2.1 Model Setup

Monopoly

- The firm can be either of two types, randomly chosen by nature: $\theta \in \{g, n\}$.
- Firm of type θ chooses price p_θ and effort e_θ to maximize profits:

$$\pi_\theta(p_\theta, e_\theta) = (p_\theta - c_\theta)q_\theta(\cdot) - \gamma_\theta e_\theta$$

- Assume $c_g > c_n = 0$.
- Assume $\gamma_n > \gamma_g > 0$.

2.1 Model Setup

Consumers

- Unit demand. Valuation of intrinsic features of the product: $v_i \sim \mathcal{U}[0, 1]$.

Facing **neutral**: $\theta = n$

- $u_i^n = v_i - p_n$ if consumes.
- $u_0^n = 0$ if no consumption.

Facing **green**: $\theta = g$

- $u_i^g = v_i - p_g + \underbrace{b}_{\text{warm glow}} + \underbrace{B(q_g, e_g)}_{\text{public good benefit}}$ if consumes,

where $B(0, e_g) = 0$

and $B(q_g, e_g) = \beta + \underbrace{h(e_g)}_{h(0)=0, h'>0, h''\leq 0} \quad \forall q_g > 0.$

- $u_0^g = B(q_g, e_g)$ if no consumption.

Assume $b > c > 0$.

2.2 Complete Information Benchmark & First-Best

Demands:

- For the neutral product: $q_n(p_n) = 1 - p_n$.
- For the green product: $q_g(p_g) = 1 + b - p_g$.

Monopoly strategies:

- Zero effort. Under-provision of the public good if $\theta = g$.
- Monopoly pricing:
 - $p_n^m = 1/2$ when neutral.
 - $p_g^m = \frac{1 + b + c}{2} > p_n^m$ when green.

2.2 Complete Information Benchmark & First-Best

First-best solution:

- Maximization of welfare = profits + consumer surplus + public good benefit if green.
- Neutral firm:
 - Zero effort.
 - $p_n^{FB} = 0$ to serve all consumers.
- Green firm:
 - Positive effort level such that $\gamma_g = \frac{\partial B(\cdot)}{\partial e_g}$ (MB = MC).
 - Higher quantity (price = MC) given by $q_g^{FB} = 1 + b - c$.

3. Signaling under Incomplete Information

Incomplete information: Costs $(c_\theta, \gamma_\theta)$ are private information of the firm. Consumers observe price and effort level. Full-information monopoly strategies are not separating.

Separating perfect Bayesian equilibrium: Monopoly of type $\theta \in \{g, n\}$ maximizes its profits with respect to the price and effort level ensuring that the following necessary equilibrium constraints are simultaneously satisfied:

$$(1) \quad (p_g - c)q_g(p_g) - \gamma_g e_g \geq (p_n - c)q_n(p_n) - \gamma_g e_n$$

$$(2) \quad p_n q_n(p_n) - \gamma_n e_n \geq p_g q_g(p_g) - \gamma_n e_g$$

$$(3) \quad \pi_g(p_g, e_g) \geq 0$$

$$(4) \quad \pi_n(p_n, e_n) \geq 0$$

(and a single-crossing type of condition for sufficiency).

Further refinement: Off-path beliefs satisfy the Cho-Kreps Intuitive Criterion (Cho & Kreps 1987).
→ Focus on least-cost separating PBE.

3. Signaling under Incomplete Information

Solution:

- Neutral monopoly always offers the same price and zero-effort package as in full-information: $p_n^m = 1/2$; $e_n^m = 0$.
- Green monopoly solves:

$$\max_{p_g, e_g \geq 0} \pi_g(\cdot) = (p_g - c) \underbrace{(1 + b - p_g)}_{q_g(\cdot)} - \gamma_g e_g \quad (5)$$

$$\text{s.t. (1) - (4)}$$

⇒ Two cases can arise.

3. Signaling under Incomplete Information

CASE 1 (POSITIVE EFFORT): if $\sqrt{2b + b^2} > c \frac{\gamma_n}{\Delta\gamma}$

$$\begin{cases} p_g = \frac{1}{2} \left(1 + b + c \frac{\gamma_n}{\Delta\gamma} \right) \text{ above monopoly price.} \\ e_g = \frac{1}{\gamma_n} \left[\frac{1}{4} b^2 + \frac{1}{2} b - \frac{1}{4} c^2 \left(\frac{\gamma_n}{\Delta\gamma} \right)^2 \right] > 0 \text{ (still below FB).} \end{cases}$$

- Happens when:
 - Warm-glow large compared to marginal cost of production,
 - and/or costs of effort different enough.
- Cost of separation:
 1. Loss in profits associated with charging $p_g > p_g^m$.
 2. Cost of providing e_g .

3. Signaling under Incomplete Information

CASE 2 (PRICE-ONLY SIGNALING): if $\sqrt{2b + b^2} \leq c \frac{\gamma_n}{\Delta\gamma}$

$$\begin{cases} p_g = \frac{1 + b + \sqrt{2b + b^2}}{2} & \text{above monopoly price and signaling price of Case 1.} \\ e_g = 0 \end{cases}$$

- Impossible to provide a positive effort level to reduce the price without violating the constraints.
- Cost of separation: Loss in profits associated with charging $p_g > p_g^m$.

Takeaway: Green firm uses costly effort only when it helps reduce the signaling cost (*i.e.*, allows lower p_g) without violating conditions for separation.

3.2 Welfare Implications

How does total welfare change when we move from complete to incomplete information?

If firm is neutral: Welfare unchanged.

If firm is green: It depends.

Case 2 (Price-only signaling): Welfare decreases under incomplete information → two inefficiencies combined.

Case 1 (Positive effort): Welfare can increase under incomplete information compared to the full-information case, provided the net benefit of improved greenness (through effort) is sufficiently large.

- Loss: Price higher than monopoly price and expenditure on effort.
- Gain: Effort improves the public good benefit.
- Gain > Loss if $h(e_g) - \gamma_g e_g$ sufficiently high (net benefit of improved greenness).

⇒ Informational inefficiency corrects part of the public good inefficiency.

4. Regulation: Green Effort Subsidies

A simple idea: Consider the implementation of a subsidy for green effort by a benevolent social planner. For simplification, assume $B(\cdot) = \beta + \sqrt{e_g}$.

- If he wants to implement the first-best effort level e_g^{FB} , has to cover the full cost of exerting such effort ($s = \gamma_g$).
- Under complete information: easy!
- Under incomplete information: How does offering s in exchange of setting e_g^{FB} alter the separating equilibrium?
- **Main insight:** Offering the subsidy can be enough to directly achieve separation with $\{(p_g^m, e_g^{FB}, s); (p_n^m, 0)\}$.

$$\frac{\Delta\gamma}{\gamma_g^2} > 2b + b^2 - c^2$$

1. When $\Delta\gamma$ sufficiently large: high cost of mimicking.
2. When b sufficiently low: gain in revenues from mimicking too weak.

Conclusions

- Combination of warm glow effect with impure public good aspect of green products: a perspective on signaling.
- Higher green prices under incomplete information: quality premium & signaling purpose.
- Increase in price can be attenuated if the green firm is able to use costly effort to improve the greenness of its product. Effort as a dual-purpose instrument: signaling and improving social outcomes.
- Some policy recommendations for subsidy implementation.

Thank you

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Single-crossing

With a fixed price p , we have $\frac{\partial \pi_g(\cdot)}{\partial p} = 1 + b + c - 2p$ and $\frac{\partial \pi_n(\cdot)}{\partial p} = 1 - 2p$. The first condition we verify is: $\frac{\partial \pi_g(\cdot)}{\partial p} > \frac{\partial \pi_n(\cdot)}{\partial p} \Rightarrow b + c > 0$ which holds by assumption. With a fixed effort level e , we compute $\frac{\partial \pi_g(\cdot)}{\partial e} = -\gamma_g$ and $\frac{\partial \pi_n(\cdot)}{\partial e} = -\gamma_n$. We verify the second condition: $\frac{\partial \pi_g(\cdot)}{\partial e} < \frac{\partial \pi_n(\cdot)}{\partial e} \Rightarrow \gamma_n > \gamma_g$ which is also true by assumption.

Secondly, it is straightforward to show that the green monopoly strategy is not separating when there is incomplete information. Indeed, we can compute:

$$\pi_n(p_n^m, e_n^m) = 1/4 < \pi_n(p_g^m, e_g^m) = \frac{(1+b-c)(1+b+c)}{4}.$$

Separating Equilibrium Case 2 Graph

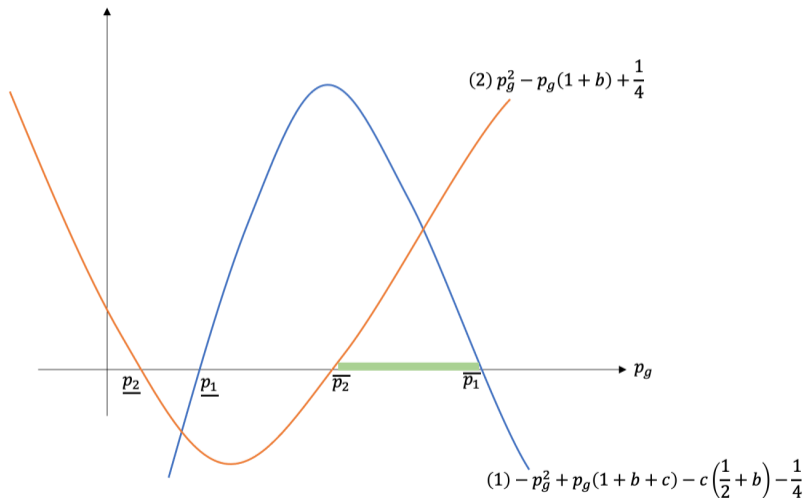


Figure: Graphical Illustration of Constraints (1) and (2) with Zero Effort