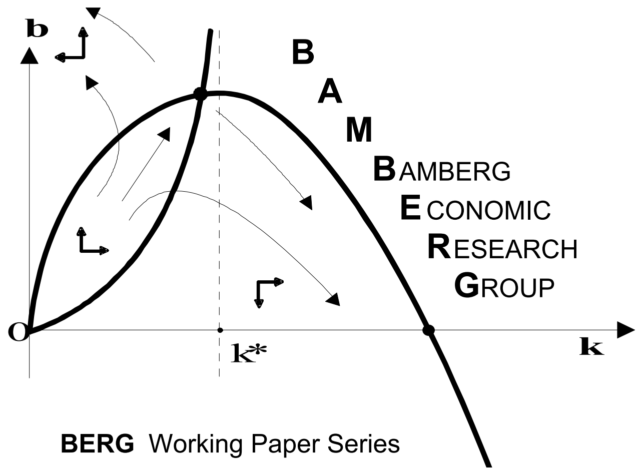
Investments in environmental quality under limited attention

Stefanie Y. Schmitt

Working Paper No. 202
February 2025



Bamberg Economic Research Group
Bamberg University
Feldkirchenstraße 21
D-96052 Bamberg
Telefax: (0951) 863 5547
Telephone: (0951) 863 2687
felix.stuebben@uni-bamberg.de
http://www.uni-bamberg.de/vwl/forschung/berg/

ISBN 978-3-949224-23-2

Redaktion:
Dr. Felix Stübben*

* felix.stuebben@uni-bamberg.de

Investments in environmental quality under limited attention*

Stefanie Y. Schmitt†

February 24, 2025

Abstract

Consumers increasingly care about the environmental quality of the goods they consume. However, limited attention impairs consumers' ability to compare and evaluate the environmental quality of goods. I show that investments in environmental quality, consumer surplus, producer surplus, and welfare are non-monotonic functions of attention. Average environmental quality, consumer surplus, producer surplus, and welfare are highest under intermediate (but different) levels of attention. In addition, limited attention influences the effectiveness of policy interventions. I identify conditions under which emission taxes, subsidies, information campaigns, and mandatory disclosure lead to less investments in environmental quality, more emissions, lower consumer surplus, or lower welfare.

KEYWORDS: environmental quality, environmental policies, limited attention.
JEL CODES: D91, L13, Q55, Q58.

*I am grateful to Dominik Bruckner, Florian Herold, Pavel Ilinov, Corinne Langinier, Nick Netzer, Marco Sahm, Armin Schmutzler, and participants at the Oligo Workshop 2023, the Annual Meeting of the Verein für Socialpolitik 2023, EAERE 2024, EARIE 2024, and seminars at the University of Bamberg and the ZHAW for valuable comments and suggestions. I gratefully acknowledge financial support from the Joachim Herz Foundation.

†University of Bamberg, Feldkirchenstr. 21, 96052 Bamberg, Germany, stefanie.schmitt@uni-bamberg.de.

1 Introduction

Consumers increasingly care about the environmental quality of the goods they consume.[1] Yet, environmental quality is not an obvious characteristic of the goods that can be experienced easily in the store. Comparing goods with respect to their environmental qualities is often difficult and requires attention. However, increasing evidence documents that consumers display limited attention in consumption decisions.[2]

The objective of this article is to analyze the implications of consumers' limited attention on firms' investments in environmental quality and on the resulting welfare. In addition, I analyze the effectiveness of different policy interventions in the presence of consumers with limited attention. I consider a model where two symmetric firms can invest in environmental quality to reduce the emissions caused by their goods. Consumers have heterogeneous preferences for environmental quality but display limited attention. I model consumers' limited attention to environmental quality with a perception threshold.[3] That means, consumers notice the difference in environmental quality between the goods if and only if the difference exceeds the perception threshold. A lower perception threshold then implies a higher level of attention.

Modeling limited attention as a perception threshold captures situations where large differences in environmental quality are salient and draw consumers' attention. For example, if the difference in fuel efficiency between cars is large, consumers notice this difference and this difference sticks to consumers' minds during the consumption decision. In contrast, if the difference in fuel efficiency between cars is small, this dimension is not salient and will not come to mind during the consumption decision. In addition, in situations where the environmental quality of the goods consists of different aspects (e.g., transportation costs and packaging), a perception threshold captures that if one good is better in all dimensions, i.e., the difference in environmental quality is large, consumers are able to infer more easily which good has the higher environmental quality. Yet, if the goods perform differently in the different dimensions of environmental quality, i.e., if the difference in environmental quality is small, inferring whether one good has overall higher environmental quality is more difficult.

I show that limited attention affects firms' investments in environmental quality and the resulting welfare: Environmental quality, consumer surplus, producer surplus, and

---

[1]See, e.g., Ward, Clark, Jensen, and Yen (2011); Löschel, Sturm, and Vogt (2013); Diederich and Goeschl (2014); Kuhn and Uler (2019); Hulshof and Mulder (2020); Bartling, Valero, and Weber (2022).

[2]See, e.g., Chetty, Looney, and Kroft (2009); Brown, Hossain, and Morgan (2010); Lacetera, Pope, and Sydnor (2012); Busse, Lacetera, Pope, Silva-Risso, and Sydnor (2013); Allcott and Taubinsky (2015); Sexton (2015); Englmaier, Schmöller, and Stowasser (2018); Tiefenbeck, Goette, Degen, Tasic, Fleisch, Lalive, and Staake (2018); Wang, Lee, Yan, and Thompson (2018); Andor, Gerster, Gillingham, and Horvath (2020); Boogen, Daminato, Filippini, and Obrist (2022); Sejas-Portillo, Moro, and Stowasser (2025).

[3]See also Allen and Thisse (1992); Bachi (2016); Webb (2017); Balart (2021); Chung, Liu, and Lo (2021); Horan, Manzini, and Mariotti (2022); Schmitt (2022).

overall welfare are non-monotonic functions of attention. Environmental quality, consumer surplus, producer surplus, and overall welfare are highest for intermediate (but different) levels of attention.

For high levels of attention, i.e., for low perception thresholds, firms differentiate in the environmental quality dimension: One firm produces goods with zero and the other firm produces goods with a strictly positive environmental quality. This differentiation allows firms to charge prices above marginal costs. The extent of differentiation depends on the costs of investing in environmental quality. For intermediate levels of attention, firms need to increase the difference in environmental quality between the goods to ensure that consumers notice—and are willing to pay for—the difference in environmental quality. Consequently, with decreasing attention the equilibrium difference in environmental quality increases. For low levels of attention, i.e., for high perception thresholds, firms need to choose very different environmental qualities to ensure that consumers perceive the quality difference. But then the costs of the firm with the higher environmental quality are not covered by the revenues. Therefore, the firm produces goods with lower environmental quality. However, as consumers are then unable to discern an environmental quality difference and buy from the firm with the lower price, Bertrand competition yields zero revenues. Thus the firm has costs but no revenue. Consequently, the firm has no incentive to choose an environmental quality above zero and both firms produce goods with zero environmental qualities.

As environmental qualities and prices depend on consumers' level of attention, producer surplus, consumer surplus, and welfare also depend on consumers' level of attention. Producer surplus is highest under intermediate levels of attention where product differentiation is higher and firms can charge higher prices. The consumer surplus results are driven by a trade-off between prices and emissions. Consumer surplus is highest for that level of attention, where firms produce the goods with the highest environmental quality. This increases prices, but, as consumers have preferences for environmental quality, benefits consumers directly as well as indirectly by reducing damages caused by emissions. As producer surplus and consumer surplus are highest for intermediate levels of attention, overall welfare is also highest for intermediate levels of attention.

In Section 6, I analyze the effectiveness of policy interventions under limited attention. In particular, I analyze the implications of (i) emission taxes, (ii) subsidies, (iii) information campaigns, and (iv) mandatory disclosure. If the market authority introduces an emission tax, the environmental quality in the market increases and emissions decrease. However, as an emission tax also increases prices, the effects on consumer surplus are ambiguous. I identify conditions under which an emission tax reduces consumer surplus.

Subsidizing investments weakly increases environmental qualities, producer surplus, and consumer surplus and weakly decreases emissions. Yet, for a range of situations small subsidies have no effect. In addition, as subsidies are costly, the overall welfare effect may be negative.

The effect of information campaigns that increase attention in the market depends on the consumers' original level of attention and the strength of the campaign: Information campaigns are beneficial in markets with low levels of attention, where firms do not invest in environmental quality. Then, an information campaign that increases attention to an intermediate or high level of attention leads to higher investments in environmental quality, consumer surplus, producer surplus, and welfare. However, environmental quality, consumer surplus, producer surplus, and overall welfare are highest for intermediate levels of attention. Therefore, in markets with intermediate levels of attention, an information campaign that increases attention reduces investments in environmental quality, consumer surplus, and welfare.[4]

Mandatory disclosure implies that all consumers observe the environmental qualities of both firms perfectly. Consequently, the same equilibrium as under full attention occurs. Firms use product differentiation to increase market power: One firm produces goods with strictly positive environmental quality, the other firm produces goods with zero environmental quality. Whether the effect of mandatory disclosure on emissions, producer surplus, consumer surplus, and welfare is positive or negative depends on consumers' level of attention. I identify a range of intermediate levels of attention, for which the effect of mandatory disclosure is negative: Without mandatory disclosure, average environmental quality would be higher which would lead to lower emissions and higher producer surplus, consumer surplus, and welfare.

The remainder of this article is structured as follows: Section 2 describes the contribution to the related literature. Section 3 introduces the model. Section 4 derives the equilibria and Section 5 discusses the welfare implications. In Section 6, I analyze the implications of different environmental policies on the equilibrium and welfare. Section 7 summarizes the results and concludes.

2 Related Literature

This article contributes to two strands of the literature. First, this article contributes to the literature on competition with limited attentive consumers. Second, this article contributes to the literature on markets with externalities.

An increasing number of articles analyze the implications of limited attention on market equilibria.[5] I model limited attention to the environmental quality of goods with

[4]The effect on producer surplus depends on the exact level of attention in the market.

[5]See, for example, Gabaix and Laibson (2006); Armstrong and Chen (2009); Eliaz and Spiegler (2011a,b); Haan and Moraga-González (2011); Ghosh and Galbreth (2013); de Clippel, Eliaz, and Rozen (2014); Bordalo, Gennaioli, and Shleifer (2016); Heidhues, Köszegi, and Murooka (2016, 2017); Boyacı and Akçay (2018); Hefti (2018); Manzini and Mariotti (2018); Astorne-Figari, López, and Yankelevich (2019); Hefti and Liu (2020); Heidhues, Johnen, and Köszegi (2021); Armstrong and Vickers (2022); Saur, Schlatterer, and Schmitt (2022); Carroni, Mantovani, and Minniti (2023); Janssen and Kasinger (2024).

a perception threshold (as in Allen and Thisse, 1992; Bachi, 2016; Webb, 2017; Balart, 2021; Chung, Liu, and Lo, 2021; Horan, Manzini, and Mariotti, 2022; Schmitt, 2022). That means, consumers notice differences in environmental qualities between the goods if the difference exceeds the perception threshold and consumers perceive the environmental qualities of the goods as identical if the difference is smaller than the perception threshold.

That perception of differences is imperfect has first been analyzed in decision-making models (see, e.g., Luce, 1956; Rubinstein, 1988).[6] In markets, consumers' limited attention to differences between goods affects firms' behavior and thus market equilibria: A perception threshold on prices allows firms to set prices above marginal costs (Allen and Thisse, 1992; Bachi, 2016). A perception threshold on the horizontal characteristics of goods may increase product differentiation (Balart, 2021). A general perception threshold on differences between two options affects firms' incentives to offer additional goods that help consumers to infer which of the original two options is better (Chung, Liu, and Lo, 2021). Webb (2017) is the first to introduce a perception threshold into a classical vertical product differentiation model. Webb (2017) shows that firms always produce noticeably different qualities in equilibrium and that the threshold has a (weakly) negative impact on consumers.[7] In contrast, Schmitt (2022) shows that whether firms differentiate noticeably on the quality dimension or undercut the quality of the rival unnoticeably depends on the market power of firms. I contribute to this literature by extending the analysis of limited attention to markets with externalities and by analyzing the effectiveness of different policy interventions.

Therefore, I also contributes to the literature on markets with externalities. I consider consumers who value environmental quality, but display limited attention. The presence of consumers who value environmental quality may incentivize firms to invest more into environmental quality (Arora and Gangopadhyay, 1995), but does not necessarily make policy interventions obsolete (Eriksson, 2004). Yet, minimum standards (Moraga-González and Padrón-Fumero, 2002) and taxes (Bansal and Gangopadhyay, 2003; Langinier and Ray Chaudhuri, 2024) may also lead to higher aggregate emissions. Ambec and De Donder (2022) show that, although standards lead to higher welfare, consumers prefer taxes. Schmutzler (2024) considers different types of innovation (environmental, process, and product innovations) and shows that whether emissions increase or decrease depends on the type of innovation and how it reallocates market shares. Herweg and Schmidt (2022)

See Gabaix (2019) for a survey on limited attention.

[6]However, such limited attention to differences is not always harmful to consumers. Horan, Manzini, and Mariotti (2022) show that if perception is noisy, conditions exist under which coarser perception of differences leads to better choices.

[7]In contrast to Webb (2017) who focuses on a relative perception threshold, I focus on an absolute perception threshold (see also Bachi, 2016; Balart, 2021; Chung, Liu, and Lo, 2021; Schmitt, 2022). In my model, a relative perception threshold would have no effect on the equilibrium or the welfare: Under perfect perception, one firm chooses zero and the other firm a strictly positive environmental quality. Then, the relative difference is infinite and thus always larger than any relative perception threshold.

show that with moral consumers taxes are better than quotas.

A common assumption in these models is that consumers are fully informed about the environmental qualities of all goods. If consumers are not fully informed about the environmental qualities of all goods, firms can employ labels (e.g., Ibanez and Grolleau, 2008; Li and van't Veld, 2015; Fischer and Lyon, 2019; Heyes, Kapur, Kennedy, Martin, and Maxwell, 2020) or signal environmental quality through prices (e.g.. Sengupta, 2012, 2015). If consumers misperceive environmental quality, firms may invest more in environmental quality (Lambertini, Pignataro, and Tampieri, 2020).

In contrast, I focus on consumers who display limited attention. Only a few other articles consider models with externalities and consumers who display limited attention. Farhi and Gabaix (2020) and Gilbert and Graff Zivin (2020) focus on optimal taxes. Farhi and Gabaix (2020) show that optimal taxes should be higher if consumers pay limited attention than if consumers pay full attention. Gilbert and Graff Zivin (2020) show that the optimal tax depends on price salience. Houde and Myers (2019) find that standards are mostly preferable to taxes and Allcott, Mullainathan, and Taubinsky (2014) find that the optimal policy combines a tax with a subsidy. In Heyes, Lyon, and Martin (2018), firms and an NGO invest effort to affect the attention that consumers pay to the damages caused by the firms. Heyes, Lyon, and Martin (2018) show that firms prefer obfuscation to abatement efforts.

I contribute to this literature by analyzing how consumers' limited attention affects firms' investments in environmental quality. I also analyze equilibrium emissions and welfare. In addition to analyzing the effectiveness of taxes and subsidies, I also analyze the effectiveness of information campaigns and mandatory disclosure in incenitvizing investments, reducing emissions, and increasing welfare. I identify conditions under which these policy interventions have negative effects on emissions, consumer surplus, or welfare.

3 Model

Two firms, firm 1 and firm 2, compete for a unit mass of consumers. Firms produce goods with identical base value $v \in \mathbb{R}_0^+$ to consumers. But goods can differ in prices and environmental quality: Firm $i \in \{1, 2\}$ produces goods with price $p_i \in \mathbb{R}_0^+$ and environmental quality $q_i \in \mathbb{R}_0^+$. I assume that the production of one unit of a good without environmental quality leads to emissions $\bar{e} > 0$. Firms can invest in environmental quality to reduce emissions. An environmental quality of q_i reduces the per-unit emissions to $\bar{e} - q_i$. The emissions caused by firm $i \in \{1, 2\}$ are then $E_i(q_i, x_i) = (\bar{e} - q_i)x_i$ where $x_i = x_i(p_i, p_j, q_i, q_j)$ with $j \in \{1, 2\}$ and $j \neq i$ is the demand for the good of firm i.[8]

[8]I assume that the firms only produce those units that are demanded.

Total emissions are $E = E_1(q_1, x_1) + E_2(q_2, x_2)$.[9] Investing in environmental quality is costly: I assume that firms have identical costs for environmental quality $C(q_i) = cq_i^2$ with $c > 0$. All other production costs are set to zero. That means, firms have fixed costs for providing environmental quality, for example, R&D costs, costs for making machines more energy efficient, or costs for investing in green electricity for production. Each firm $i \in \{1, 2\}$ chooses its price p_i and its environmental quality q_i to maximize its profit

$$\Pi_i(p_i, p_j, q_i, q_j) = p_i x_i(p_i, p_j, q_i, q_j) - C(q_i).$$

For simplicity, denote by h the firm that produces the higher environmental quality, i.e., q_h at price p_h, and by l the firm that produces the lower environmental quality, i.e., q_l at price p_l. Whether firm 1 or firm 2 is the high-quality firm depends on the firms' quality choices.

Each consumer buys exactly one unit of the good. The utility from buying the good from firm $i \in \{1, 2\}$ is

$$u_\theta(i) = v + \theta q_i - p_i - D(E), \tag{1}$$

where v describes consumers' valuation for the good. I assume that v is large enough such that all consumers buy one unit of the good, i.e., the market is covered. Consumers differ in their valuation of the environmental quality: θ measures the consumer's marginal willingness to pay for environmental quality and is individually and independently drawn from a uniform distribution on $[0, 1]$. $D(E)$ describes the damage that emissions cause consumers. The functional form of $D(E)$ is not relevant to derive the subgame-perfect equilibria: As there is a continuum of consumers, the effect that the consumption of an individual consumer has on the total emissions and, therefore, on the damage is negligible. Consequently, in their consumption decision, consumers do not take their effect on total emissions and on the resulting damages into account. To obtain closed form solutions for the welfare analysis, I use the following linear damage function: $D(E) = E$. As a robustness check, I include a welfare analysis for $D(E) = E^2$ in the Appendix. For sufficiently high $\bar{e}$, the qualitative results of the welfare analysis remain the same.

Consumers decide between buying from firm 1 and firm 2 dependent on the environmental qualities and prices of the goods. However, consumers only notice differences in environmental quality between the goods if the absolute quality difference exceeds the perception threshold $\tau \in \mathbb{R}_0^+$, i.e., if $|q_1 - q_2| \geq \tau$. If the difference is below the perception threshold, i.e., if $|q_1 - q_2| < \tau$, consumers perceive the environmental qualities as identical.

[9] The emission function allows for negative emissions. I assume that $\bar{e}$ is large enough such that, in equilibrium, emissions are positive.

Therefore, the perceived environmental quality $\hat{q}_i$ is

$$\hat{q}_i = \begin{cases} q_i & \text{if } |q_1 - q_2| \geq \tau \\ q(q_1, q_2) & \text{if } |q_1 - q_2| < \tau, \end{cases}$$

where $q(q_1, q_2) > 0$. That is, if the quality difference exceeds the perception threshold, i.e., if $|q_1 - q_2| \geq \tau$, consumers notice the quality difference and perceive each environmental quality perfectly. If the quality difference is below the perception threshold, i.e., if $|q_1 - q_2| < \tau$, consumers perceive the environmental quality of both firms as identical: $q(q_1, q_2)$. For example, $q(q_1, q_2)$ could be the mean of q_1 and q_2. The actual form of $q(q_1, q_2)$ is not relevant for the results, important is only that consumers perceive q_1 and q_2 as identical. I assume that all consumers have the same perception threshold. The higher the perception threshold, the more inattentive consumers are to the differences in environmental quality between the goods. A perception threshold of $\tau = 0$ captures the benchmark of full attention.

A consumer prefers to buy from firm 1 if her perceived utility from buying the good from firm 1 is higher than her perceived utility from buying the good from firm 2. If the quality difference exceeds the perception threshold, her perceived utility is her true utility given in (1). If the quality difference is smaller than the perception threshold, her perceived utility is distorted in the environmental quality. A consumer thus prefers to buy from firm 1 if $\hat{u}_\theta(1) \geq \hat{u}_\theta(2) \Leftrightarrow v + \theta\hat{q}_1 - p_1 \geq v + \theta\hat{q}_2 - p_2$. If the quality difference is below the perception threshold, i.e., $|q_1 - q_2| < \tau$, consumers think that the goods only differ in prices and buy from the firm with the lower price:

$$\begin{aligned} &\hat{u}_\theta(1) \geq \hat{u}_\theta(2) \\ \Leftrightarrow &v + \theta q(q_1, q_2) - p_1 \geq v + \theta q(q_1, q_2) - p_2 \\ \Leftrightarrow &p_1 \leq p_2. \end{aligned}$$

Therefore, the demand for the good of firm $i \in \{1, 2\}$ depends only on the prices of firm i, p_i, and its competitor, p_j,

$$x_i^{\text{inattentive}}(p_i, p_j) = \begin{cases} 1 & \text{if } p_i < p_j \\ \frac{1}{2} & \text{if } p_i = p_j \\ 0 & \text{if } p_i > p_j. \end{cases}$$

In contrast, if the quality difference exceeds the perception threshold, i.e., $|q_1 - q_2| \geq \tau$, consumers perceive the environmental qualities perfectly: $\hat{q}_1 = q_1$ and $\hat{q}_2 = q_2$. A consumer then buys from the high-quality firm if $\hat{u}_\theta(h) \geq \hat{u}_\theta(l) \Leftrightarrow v+\theta q_h - p_h \geq v+\theta q_l - p_l$.

Let $\hat{\theta}$ denote the indifferent consumer:

$$\hat{\theta} \equiv \frac{p_h - p_l}{q_h - q_l}.$$

Then, all consumers with $\theta \leq \hat{\theta}$ buy from the low-quality firm l and all consumers with $\theta > \hat{\theta}$ buy from the high-quality firm h. The demand for the good of the low-quality firm l and the demand for the good of the high-quality firm h are thus[10]

$$\begin{aligned} x_l^{\text{attentive}}(p_h, p_l, q_h, q_l) &= \hat{\theta} \\ x_h^{\text{attentive}}(p_h, p_l, q_h, q_l) &= 1 - \hat{\theta}. \end{aligned}$$

The profit of firm i is then

$$\Pi_i(p_i, p_j, q_i, q_j) = \begin{cases} p_i x_l^{\text{attentive}}(p_i, p_j, q_i, q_j) - cq_i^2 & \text{if } q_i \leq q_j - \tau \\ p_i x_i^{\text{inattentive}}(p_i, p_j) - cq_i^2 & \text{if } q_j - \tau < q_i < q_j + \tau \\ p_i x_h^{\text{attentive}}(p_i, p_j, q_i, q_j) - cq_i^2 & \text{if } q_i \geq q_j + \tau. \end{cases}$$

Thus firm i's profit depends on whether the firms choose qualities such that the quality difference exceeds the consumers' perception threshold and on whether the firm is the high- or low-quality firm.

Firms compete in environmental qualities and prices for consumers in the following two-stage game: First, firms independently and simultaneously choose their environmental qualities.[11] Second, firms observe the environmental quality of their competitor and then independently and simultaneously choose prices. Afterwards, consumers make their consumption decision. I solve the game by backward induction for the pure-strategy subgame-perfect equilibria.

4 Investments in environmental quality

In the price-setting stage, firms simultaneously and independently set prices given the environmental qualities from the previous stage. If the difference in environmental qualities is below the perception threshold, i.e., $|q_1 - q_2| < \tau$, consumers think that the goods differ only in prices and buy from the firm with the lowest price. Then, Bertrand competition leads to prices equal to marginal costs: $p_1^* = p_2^* = 0$.

If the difference in environmental quality exceeds the perception threshold, i.e., $|q_1 -$

[10] In equilibrium, both firms have a positive demand. If the firms would instead set prices such that one firm captures all consumers, the other firm would make zero revenue. Then, that firm could increase its revenue by decreasing its price and capturing some of the demand.

[11] If a firm is indifferent between two levels of environmental quality, I assume that the firm chooses the higher environmental quality.

$q_2| \geq \tau$, consumers notice that the goods differ in environmental quality. Then, the profits of firm 1 and firm 2 depend on whether they are the firm with the higher (h) or lower (l) environmental quality. All consumers with $\theta > \hat{\theta}$ buy from the firm with the higher environmental quality, all others buy from the firm with the lower environmental quality. The profits of the high- and low-quality firm are then

$$\Pi_h(p_h, p_l, q_h, q_l) = p_h(1 - \hat{\theta}) - cq_h^2$$
$$\Pi_l(p_h, p_l, q_h, q_l) = p_l\hat{\theta} - cq_l^2.$$

The first order conditions yield the following best replies

$$p_h^*(p_l) = \frac{1}{2}(p_l + q_h - q_l)$$
$$p_l^*(p_h) = \frac{p_h}{2}.$$

Consequently, the equilibrium prices are

$$p_h^* = \frac{2}{3}(q_h - q_l)$$
$$p_l^* = \frac{1}{3}(q_h - q_l).$$

Whether firm 1 or firm 2 is the firm with the higher environmental quality depends on the firms' environmental quality choice in the first stage.

In the quality-setting stage, firms maximize profits by choosing their environmental qualities optimally. Three cases exist. First, firm i produces goods with lower environmental quality than firm j and consumers notice the quality difference. Second, the firms choose environmental qualities such that the quality difference is below the perception threshold. Then, all consumers think that the goods have the same environmental quality. In the subsequent price-setting stage, firms set prices equal to marginal costs, i.e., revenues are zero. Third, firm i produces goods with higher environmental quality than firm j and consumers notice the quality difference. Therefore, the profit of firm i is

$$\Pi_i(q_i, q_j) = \begin{cases} \frac{1}{9}(q_j - q_i) - cq_i^2 & \text{if } q_i \leq q_j - \tau \\ 0 - cq_i^2 & \text{if } q_j - \tau < q_i < q_j + \tau \\ \frac{4}{9}(q_i - q_j) - cq_i^2 & \text{if } q_i \geq q_j + \tau. \end{cases} \tag{2}$$

Firms maximize their profits given by (2) simultaneously by choosing their investments in environmental qualities. The resulting equilibrium environmental qualities depend on the perception threshold τ. Overall, dependent on the perception threshold, three different regimes result. Proposition 1 summarizes the subgame-perfect equilibria in pure strategies.

Proposition 1 *Let $i \in \{1,2\}$, $j \in \{1,2\}$, and $i \neq j$.*

(i) ***Benchmark regime:*** *If $\tau \leq 2/(9c)$, in the subgame-perfect equilibria, firms produce goods with distinguishable environmental qualities $q_i^* = 2/(9c)$ and $q_j^* = 0$ and prices $p_i^* = 2q_i^*/3$ and $p_j^* = q_i^*/3$.*

(ii) ***Increased-investment regime:*** *If $2/(9c) < \tau \leq 4/(9c)$, in the subgame-perfect equilibria, firms produce goods with distinguishable environmental qualities $q_i^* = \tau$ and $q_j^* = 0$ and prices $p_i^* = 2q_i^*/3$ and $p_j^* = q_i^*/3$.*

(iii) ***No-investment regime:*** *If $\tau > 4/(9c)$, in the subgame-perfect equilibrium, firms produce goods with indistinguishable environmental qualities $q_i^* = q_j^* = 0$ and prices $p_i^* = p_j^* = 0$.*

The proof is in the appendix. Proposition 1 shows that, for a sufficiently low perception threshold, two asymmetric subgame-perfect equilibria exist: One in which firm 1 and one in which firm 2 produces goods with strictly positive environmental quality and the other firm always produces goods without environmental quality. For a sufficiently high perception threshold, one unique symmetric subgame-perfect equilibrium exists in which both firms produce goods without environmental quality.

Figure 1 illustrates the equilibrium environmental qualities as a function of the perception threshold τ. In the benchmark of perfect perception, i.e., $\tau = 0$, the model gives rise to product differentiation, where one firm does not invest in environmental quality and the other firm invests in environmental quality. Therefore, one firm produces goods without environmental quality and the other firm produces goods with strictly positive environmental quality. This product differentiation allows firms to charge prices above marginal costs and make positive profits. The level of product differentiation depends on the investment cost parameter c. With increasing costs, the difference in environmental quality between the goods decreases. As long as the perception threshold is below the benchmark equilibrium quality difference (i.e., if $\tau \leq 2/(9c)$), the benchmark equilibrium results. I call this the *benchmark regime*.

However, if the perception threshold exceeds the benchmark difference in environmental quality (i.e., if $\tau > 2/(9c)$), consumers are unable to discern the difference in environmental quality between the goods that results in the benchmark regime. Then, the firm with the higher environmental quality has costs for investing in environmental quality but consumers are not willing to pay for the higher environmental quality. Therefore, the firm with the higher environmental quality has an incentive to increase its investments in environmental quality such that the quality difference is just noticeable, i.e., to $q_h = \tau$. I call this the *increased-investment regime*. With increasing perception threshold τ, the environmental quality of the high-quality firm increases and thus the costs for environmental quality increase. For $\tau > 4/(9c)$, the costs of producing goods with just noticeably higher environmental quality than the competitor exceed the revenues. Then, the firm prefers to set an environmental quality that is indistinguishable from its competitor's environmental quality and to reduce its costs: Both firms refrain from investing in environmental quality. I call this the *no-investment regime*.

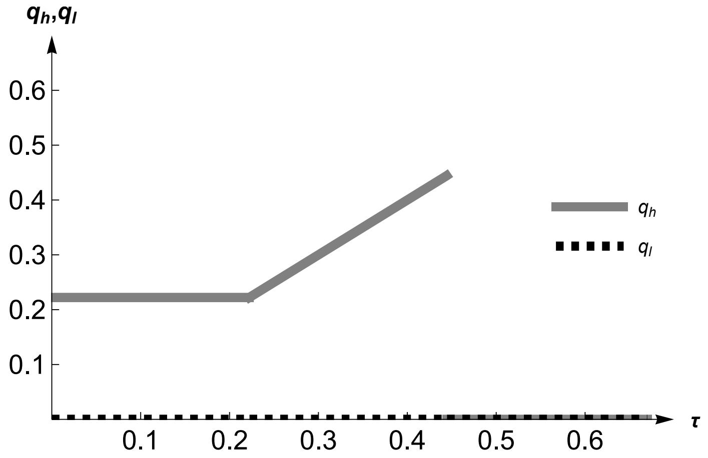


Figure 1: Equilibrium environmental qualities for $c = 1$ as a function of the perception threshold τ. q_h (q_l) is the environmental quality that the firm with the higher (lower) environmental quality chooses in equilibrium.

The cutoffs for the three regimes also depend on the costs for environmental quality (see Figure 2). For a given perception threshold τ, with low costs the benchmark regime occurs. With intermediate costs, the firms differentiate so that the difference in environmental qualities is just noticeable: the increased-investment regime occurs. With high costs, no firm has an incentive to produce goods with positive environmental quality: the no-investment regime occurs. Thus which regime occurs depends on the interplay of the investment costs and the perception threshold. An equilibrium where both firms choose zero environmental quality occurs, if the costs to make the product distinguishable are too high. That implies that either a high perception threshold forces a high environmental quality which is costly even if the unit costs are low or high unit costs make even low environmental qualities costly.

5 Welfare analysis

Figure 3 illustrates consumer surplus, producer surplus, and welfare as a function of the perception threshold τ. For sufficiently low perception thresholds and sufficiently high perception thresholds, i.e., in the benchmark regime and in the no-investment regime, the equilibrium is independent of the threshold and thus consumer surplus, producer surplus, and welfare are constant. For intermediate perception threshold, i.e., in the increased-investment regime, the equilibrium depends on the perception threshold and thus consumer surplus, producer surplus, and welfare depend on the perception threshold.

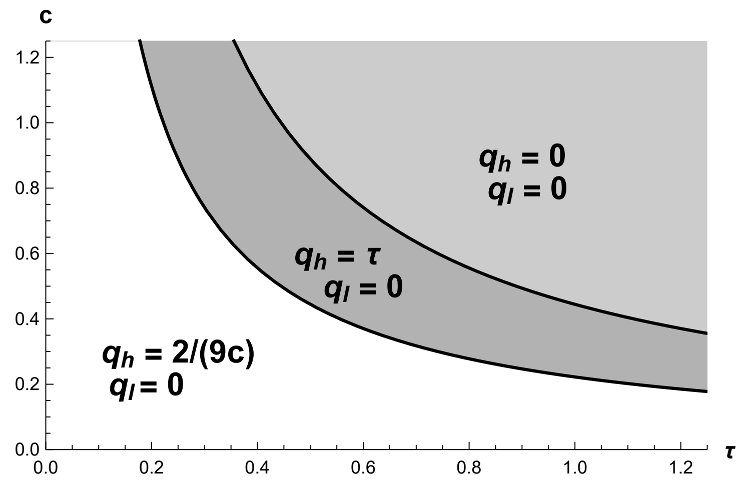


Figure 2: Equilibrium environmental qualities for costs c and perception threshold τ. q_h (q_l) is the environmental quality that the firm with the higher (lower) environmental quality chooses in equilibrium.

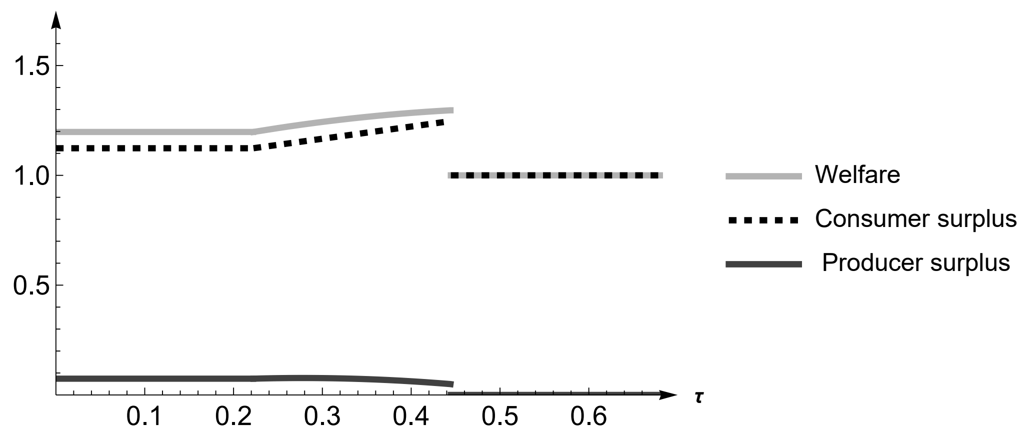


Figure 3: Welfare, consumer surplus, and producer surplus as a function of the perception threshold τ for $c = 1$, $v = 3$, and $\bar{e} = 2$.

Figure 4 illustrates the profits of the high- and the low-quality firm in equilibrium as a function of the perception threshold τ. In the benchmark regime (i.e., if $\tau \leq 2/(9c)$), environmental qualities and prices are independent of the perception threshold and thus profits and producer surplus are constant. In the increased-investment regime (i.e., if $2/(9c) < \tau \leq 4/(9c)$), the firms choose environmental qualities $q_h = \tau$ and $q_l = 0$. Both prices depend on the difference in environmental qualities and increase in the perception threshold τ. The profit of the high-quality firm strictly decreases in the perception threshold τ. Although, the firm charges higher prices with higher perception threshold τ and thus has increasing revenue, the firm also has increasing (quadratic) costs. The additional revenue is absorbed by the additional costs. In contrast, as the low quality firm has zero costs and constant demand but increasing prices, its profit increases in the perception threshold τ. That means, the low-quality firm benefits from the investments in environmental quality of its competitor without incurring the same costs. For

$0 < \tau < 3/(9c)$, the high-quality firm receives a higher profit than the low-quality firm. For $3/(9c) < \tau < 4/(9c)$, the low-quality firm receives a higher profit than the high-quality firm. In the no-investment regime, both firms do not invest in environmental quality and make zero profits. In sum, the producer surplus (weakly) increases until it reaches its maximum at $\tau = 5/(18c)$ and (weakly) decreases thereafter. Consequently, producer surplus is highest under intermediate levels of attention. Under intermediate levels of attention, one firm produces higher environmental quality than under full attention, which allows firms to set higher prices and increases producer surplus.

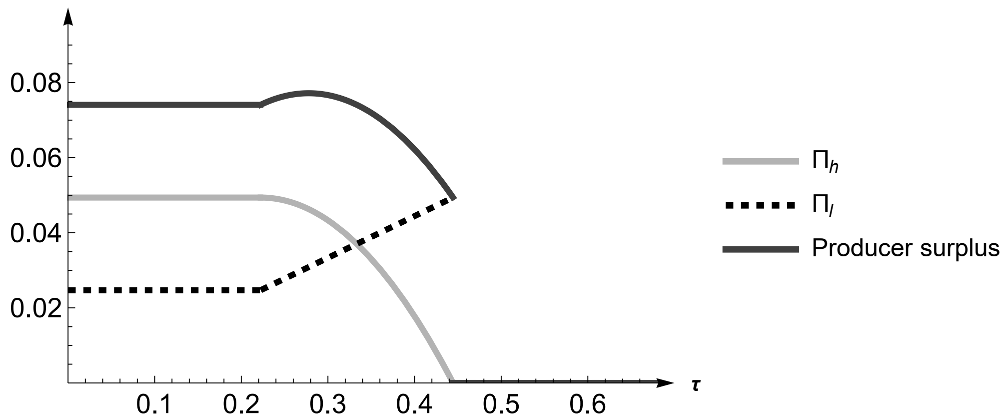


Figure 4: Producer surplus, profit of high-quality firm (Π_h), and profit of low-quality firm (Π_l) as a function of the perception threshold τ for $c = 1$.

Consumers also benefit from intermediate levels of attention. In the increased-investment regime, environmental qualities are higher than in the benchmark and in the no-investment regime. This is beneficial for consumers, because consumers directly benefit from higher environmental qualities and indirectly benefit from higher environmental qualities due to lower damages. Although prices are also increasing, the benefits outweigh the costs. Consumer surplus is thus highest for that perception threshold where firms produce the highest average qualities: $\tau = 4/(9c)$.

As the market is covered, prices are just a reallocation of welfare from consumers to firms and play no role in the overall welfare. Therefore, for the overall welfare only benefits to consumers from environmental quality, costs to firms, and damages matter. In the benchmark and in the no-investment regime, benefits to consumers, costs, and damages are independent of the perception threshold. In the increased-investment regime, environmental quality increases in the perception threshold. The benefits to the consumers outweigh the costs to firms. Thus welfare is highest when firms produce the goods with the highest environmental quality: $\tau = 4/(9c)$. Consequently, welfare is higher under limited attention than under full attention.

Proposition 2 summarizes the results on consumer surplus, producer surplus, and welfare.

Proposition 2 *Producer surplus reaches its unique maximum at $\tau = 5/(18c)$. Consumer surplus and welfare reach their unique maximum at $\tau = 4/(9c)$ where firms produce the highest environmental quality.*

The proof is in the appendix. Appendix C includes an analysis of the welfare under the assumption that the damage function takes the form $D(E) = E^2$. This change in the damage function has no effect on the producer surplus. For sufficiently large upper bounds on the emissions, i.e., for sufficiently large $\bar{e}$, this change also has no effect on the consumer surplus and the overall welfare results.

6 Policy implications

In this section, I discuss the implications of (i) an emission tax, (ii) subsidizing investments, (iii) information campaigns, and (iv) mandatory disclosure.

6.1 Emission tax

If the market authority imposes a per-unit tax $t(\bar{e} - q_i)$ with $t \in (0, 1]$ on firm $i \in \{1, 2\}$, the profit of firm i becomes

$$\Pi_i(p_i, p_j, q_i, q_j) = \Big(p_i - t(\bar{e} - q_i)\Big)x_i(p_i, p_j, q_i, q_j) - C(q_i).$$

The tax affects the firms' incentives and, therefore, the prices and environmental qualities that the firms choose in the subgame-perfect equilibria. For $t = 0$, the model reduces to the model without a tax (see Section 3). Proposition 3 summarizes the equilibrium. The detailed model and the detailed analysis are included in Appendix D.

Proposition 3 *Assume the market authority introduces a per-unit tax $t(\bar{e} - q_i)$ with $t \in (0, 1]$ on firm i and let $i \in \{1, 2\}$, $j \in \{1, 2\}$, $i \neq j$, and*

$$\bar{\tau} \equiv \frac{(2+t)^2}{18c} + \frac{1}{18c}\sqrt{(2+t)^4 - 81t^2}.$$

(i) If $\tau \leq \bar{\tau}$, in the subgame-perfect equilibria, firms choose distinguishable environmental qualities $q_i^* = max\{(2+t)^2/(18c), \tau\}$ and $q_j^* = 0$ with prices $p_i^* = 1/3(2(1-t)q_i^* + 3t\bar{e})$ and $p_j^* = 1/3((1-t)q_i^* + 3t\bar{e})$.

(ii) If $\tau > \bar{\tau}$, in the subgame-perfect equilibria, firms choose indistinguishable environmental qualities $q_i^* = t/(2c)$ and $q_j^* = 0$ with prices $p_i^* = p_j^* = t\bar{e}$.

The environmental quality is weakly higher with the tax than without the tax. The tax imposes variable costs on the firm. To account for these additional costs, firms increase their prices. As the market is covered, firms earn (weakly) higher revenues and, consequently, firms have more incentives to invest in environmental quality. Firms benefit from the additional revenue and producer surplus is higher with the tax than without the tax.

Nevertheless, such a tax is not always beneficial for all market participants. For a range of values, consumer surplus is lower with the tax than without the tax. In equilibrium, the high-quality firm produces goods with higher environmental quality with the tax than without the tax. The environmental quality of the low-quality firm is zero for all $t \in [0, 1]$. In addition, with the tax more consumers buy the high-quality good than without the tax. Consequently, consumers benefit from higher environmental quality directly and indirectly through lower damages. Nevertheless, with the tax environmental product differentiation is larger, which allows firms to charge higher prices and thus harms consumers. Whether the overall effect of the tax on consumer surplus is positive or negative depends on the emissions without investments in environmental quality $\bar{e}$, the tax rate t, the perception threshold τ, and the investment cost c (see Appendix D for detailed conditions). Figure 5 illustrates the effects of the tax on consumer surplus. In contrast, the overall welfare is higher with the tax than without the tax.

Corollary 1 summarizes the results (see Appendix D for a detailed analysis).

Corollary 1 *Assume the market authority introduces a per-unit tax $t(\bar{e} - q_i)$ with $t \in (0, 1]$ on firm i.*

(i) Environmental quality is (weakly) higher and emissions are (weakly) lower with the tax than without the tax.

(ii) Producer surplus and welfare are higher with the tax than without the tax.

(iii) The effects of the tax on consumer surplus are ambiguous, depending on the size of the tax t, the investment costs c, the perception threshold τ, and the emission parameter $\bar{e}$.

6.2 Subsidizing investments

Instead of taxing emissions, a market authority can subsidize investments in environmental quality. In this model, this translates into a reduction of the cost parameter c. A subsidy reduces the original cost parameter c_0 by the subsidy $s \in [0, c_0]$ to $c = c_0 - s$. According to Proposition 1, any cost reduction (weakly) increases average environmental qualities and thus (weakly) decreases emissions (Figure 6 depicts the equilibrium environmental qualities from Proposition 1 as a function of the cost parameter c).

As higher environmental qualities allow firms to charge higher prices and thus earn higher revenues, lower costs incentivize firms to invest more. Therefore, firms earn higher

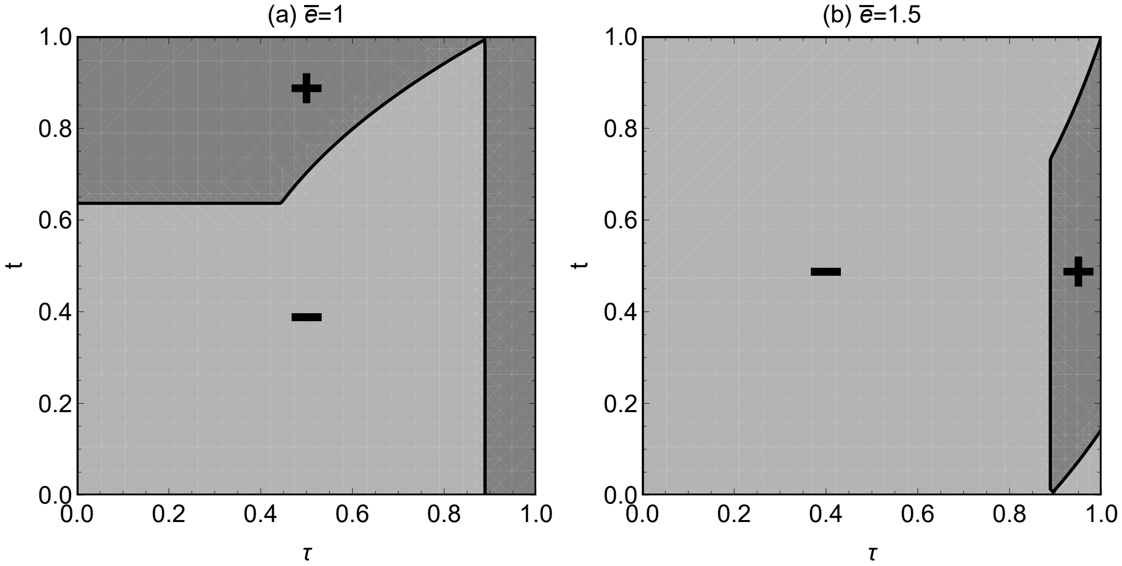


Figure 5: Effect of the emission tax on consumer surplus as a function of the perception threshold τ and the tax t for $c = 1/2$. In the light gray areas, the emission tax has a negative effect. In the dark gray areas, the emission tax has a positive effect (left: $\bar{e} = 1$; right: $\bar{e} = 3/2$).

profits and producer surplus (weakly) increases with a higher subsidies s (see Figure 7). Consumers benefit more from the higher environmental qualities and the lower emission than they are harmed by the higher prices. Consequently, consumer surplus also (weakly) increases with higher subsidies s (see Figure 7).

Nevertheless, the effect on overall welfare (sum of producer surplus, consumer surplus, minus costs for subsidy) is not always positive. The effect of introducing a subsidy s on welfare depends on the original cost parameter c_0 relative to the perception threshold τ as well as on the size of the subsidy s. The original cost parameter determines whether the market is originally in the benchmark, the increased-investment, or the no-investment regime.[12] With sufficiently low subsidies, the market remains in the original regime. With sufficiently high subsidies, the market authority might induce a regime change.

Introducing a subsidy has negative effects on welfare if the subsidy is sufficiently high (see Figure 7). Introducing a subsidy increases investments in environmental quality. This benefits consumers directly as well as indirectly through lower damages, but harms firms through higher costs (net of the subsidy which is a relocation of welfare to firms and thus does not affect welfare). If the subsidy is sufficiently high, the negative effect due to the higher costs dominates and the introduction of the subsidy has a negative effect on welfare.

In contrast, introducing a subsidy has positive effects on welfare if the subsidy is intermediate when the original costs are sufficiently high or if the subsidy is sufficiently

[12]If $c_0 \leq 2/(9\tau)$, the market is originally in the benchmark regime. If $2/(9\tau) < c_0 \leq 4/(9\tau)$, the market is originally in the increased-investment regime. If $c_0 > 4/(9\tau)$, the market is originally in the no-investment regime.

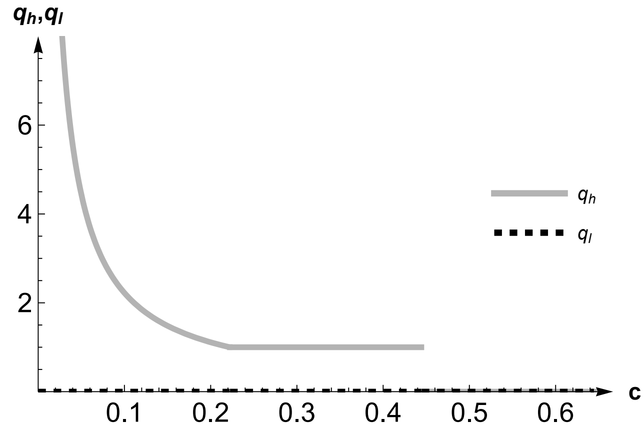


Figure 6: Equilibrium environmental qualities as a function of costs c for perception threshold $\tau = 1$.

low when the original costs are sufficiently low. Then, the the positive effects (higher environmental quality and lower damages) dominate and the introduction of the subsidy has a positive effect on welfare (see Figure 7).

Nevertheless, a subsidy does not always have an effect on welfare. If the original costs are sufficiently high such that the increased-investment or the no-investment regime results, subsidies that do not lead to a regime change have no effect. For example, if the original costs are sufficiently high, i.e., $c_0 \geq 4/(9\tau)$, and the subsidy small enough such that the cost after the subsidy are still $c_0 - s \geq 4/(9\tau)$, the subsidy has no effect on environmental quality, emissions, producer surplus, consumer surplus, and welfare (see Figure 7).

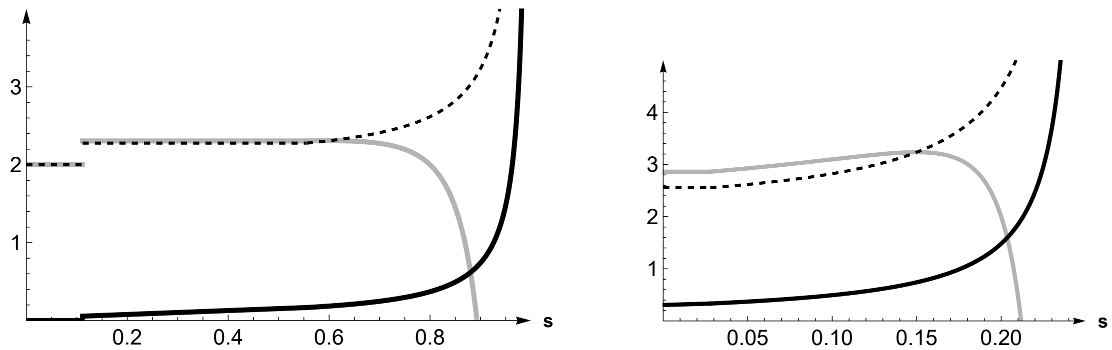


Figure 7: Welfare (gray), consumer surplus (dashed), and producer surplus (black) as a function of the subsidy s for $v = 4$ and $\bar{e} = 2$. In the left panel, $\tau = 1/2$ and $c_0 = 1$ such that the regime for $s = 0$ is the no-investment regime. In the right panel, $\tau = 1$ and $c_0 = 1/4$, such that the regime for $s = 0$ is the increased-investment regime.

Corollary 2 summarizes the results. See Appendix E for details on the effects of introducing a subsidy on welfare.

Corollary 2 *Let c_0 be the original cost parameter. If the market authority introduces a subsidy $s \in [0, c_0]$ that reduces the cost parameter from c_0 to $c_0 - s$, environmental quality,* *producer surplus, and consumer surplus (weakly) increase and emissions (weakly) decrease with increasing subsidies. The effects of the subsidy on welfare depend on the size of the subsidy and on the original cost parameter relative to the perception threshold.*

6.3 Information campaign

Information campaigns to sensitize consumers are another possible policy intervention. In this model, an information campaign that sensitizes consumers reduces the perception threshold τ by $\Delta \in [0, \tau]$, i.e., consumers pay more attention to the differences in environmental quality and thus notice also smaller differences in environmental quality. For a given cost c, environmental qualities, emissions, producer surplus, consumer surplus, and welfare are non-monotonic functions of the perception threshold τ. Consequently, the effects of an information campaign are sensitive to the strength of the campaign and the level of attention in the market (see Figure 1 and Figure 3).

If the level of attention is high, i.e., in the benchmark regime, investments in environmental quality, consumer surplus, producer surplus, and welfare are constant in the perception threshold τ. Therefore, an information campaign that reduces τ by Δ has no effect in the benchmark regime. Similarly, if the level of attention is low, i.e., in the no-investment regime, environmental quality, consumer surplus, producer surplus, and welfare are constant. Therefore, an information campaign that reduced the perception threshold by Δ, but does not lead to a regime change has no effect. Information campaigns that induce a regime change from the no-investment regime to the increased-investment regime or to the benchmark regime lead to higher investments in environmental quality, consumer surplus, producer surplus, and welfare. In the increased-investment regime, an information campaign that reduces the perception threshold reduces investments in environmental quality, consumer surplus, and welfare.[13] In particular, environmental quality, consumer surplus, and welfare are highest if $\tau = 4/(9c)$ (see Proposition 1 and Proposition 2). Therefore, if the original perception threshold is $\tau = 4/(9c)$, then any information campaign reduces the environmental qualities, consumer surplus, and welfare.

Corollary 3 summarizes the conditions under which an information campaign has strictly positive, strictly negative, or no effects on environmental quality, consumer surplus, producer surplus, and welfare.[14]

Corollary 3 *Assume the market authority starts an information campaign that reduces the perception threshold τ by $\Delta \in [0, \tau]$.*

(i) If $\tau > 4/(9c)$ and $\tau - \Delta \leq 4/(9c)$, the information campaign strictly increases environmental quality, consumer surplus, and welfare. If $\tau > 4/(9c)$ and $\tau - \Delta >$

[13]The effects on producer surplus depend on the exact perception threshold τ and the exact strength of the information campaign Δ.

[14]The welfare does not include a cost for the policy intervention.

$4/(9c)$ or if $\tau \leq 2/(9c)$, the information campaign has no effect on environmental quality, consumer surplus, and welfare. Otherwise the information campaign has a strictly negative effect on environmental quality, consumer surplus, and welfare.

(ii) If $\tau > 4/(9c)$ and $\tau - \Delta \leq 4/(9c)$, if $1/(3c) < \tau \leq 4/(9c)$, or if $5/(18c) < \tau \leq 1/(3c)$ and $\Delta < (18c\tau - 5)/(9c)$, the information campaign strictly increases producer surplus. If $\tau > 4/(9c)$ and $\tau - \Delta > 4/(9c)$ or if $\tau < 2/(9c)$, the information campaign has no effect on producer surplus. Otherwise, the information campaign has a strictly negative effect on producer surplus.

Corollary 3 shows that the effectiveness of information campaigns depends on the level of attention in the market. Information campaigns are effective if the level of attention is so low that the no-investment regime occurs. Then, information campaigns can induce a regime change. However, information campaigns can also have strictly negative effects on environmental quality, consumer surplus, producer surplus, and welfare.

6.4 Mandatory disclosure

Another possible policy intervention is mandatory disclosure. If the market authority implements mandatory disclosure, all firms have to disclose their exact environmental quality such that all consumers perfectly observe the environmental qualities of all firms. Denote by τ_0 the perception threshold that would realize without policy intervention. In this model, mandatory disclosure then updates the perception threshold to $\tau = 0$. Consequently, under mandatory disclosure, firms choose the benchmark environmental qualities $q_i^* = 2/(9c)$ and $q_j^* = 0$.[15]

A perception threshold of $\tau = 0$ is neither optimal for consumers nor firms and also does not maximize welfare (see Proposition 2). However, depending on the original perception threshold, mandatory disclosure may lead to an improvement. If $\tau_0 > 4/(9c)$, i.e., in the no-investment regime, both firms would produce goods without environmental quality. Then, a mandatory disclosure that updates the perception threshold to $\tau = 0$ incentivizes at least one firm to invest in environmental quality. This reduces emissions and increases consumer surplus, producer surplus, and welfare.

In contrast, for any $\tau_0 \leq 2/(9c)$, i.e., in the benchmark regime, mandatory disclosure has no effects on the investments of the firms and thus has no effect on environmental qualities, emissions, consumer surplus, producer surplus, and welfare.

For any $\tau_0 \in (2/(9c), 4/(9c)]$, i.e., in the increased-investment regime, mandatory disclosure implies that the firm with the higher environmental quality can reduce its investment in environmental quality and consumers still notice the quality difference between the goods. Then, mandatory disclosure leads to lower environmental quality and

[15] That means, in this model, mandatory disclosure is the limiting case of information campaigns with $\Delta = \tau_0$.

higher emissions. Mandatory disclosure thus harms consumers. The firm with the higher environmental quality benefits, but the firm with the lower environmental quality has to reduce its price without any gain in demand or cost saving and thus receives a lower profit. In sum, the producer surplus increases for all $\tau > 1/(3c)$ and decreases otherwise.

Corollary 4 summarizes the effects. Figure 8 illustrates the effects of mandatory disclosure on (a) producer surplus and (b) environmental quality, consumer surplus, and welfare graphically.

Corollary 4 *Assume the market authority initiates mandatory disclosure that implements a change in the perception threshold of the consumers from* τ_0 *to* $\tau = 0$.

(i) If $\tau_0 \leq 2/(9c)$*, mandatory disclosure has no effect on environmental qualities, consumer surplus, producer surplus, and welfare.*

(ii) If $2/(9c) < \tau_0 < 1/(3c)$*, mandatory disclosure has a strictly negative effect on environmental qualities, consumer surplus, producer surplus, and welfare.*

(iii) If $1/(3c) \leq \tau_0 \leq 4/(9c)$*, mandatory disclosure has a strictly negative effect on environmental qualities, consumer surplus, and welfare and a strictly positive effect on producer surplus.*

(iv) If $\tau_0 > 4/(9c)$*, mandatory disclosure has a strictly positive effect on environmental qualities, consumer surplus, producer surplus, and welfare.*

Corollary 4 highlights that mandatory disclosure is especially beneficial if it induces a regime change from the no-investment regime to the benchmark regime, but is harmful if it induces a regime change from the increased-investment regime to the benchmark regime.

7 Conclusion

In this article, I introduce limited attention via a perception threshold into a model where firms invest in the environmental quality of their goods to reduce emissions. I show that accounting for the limited attention of consumers is necessary, because consumers' limited attention affects firms' investments in environmental quality and the effectiveness of policy interventions.

Consumers benefit from intermediate levels of attention, because being sufficiently inattentive incentivizes firms to differentiate more in environmental quality to ensure that consumers notice the difference in environmental quality. Consumers benefit from higher average environmental quality and lower emissions. Firms also benefit from some intermediate levels of limited attention. The larger product differentiation allows firms

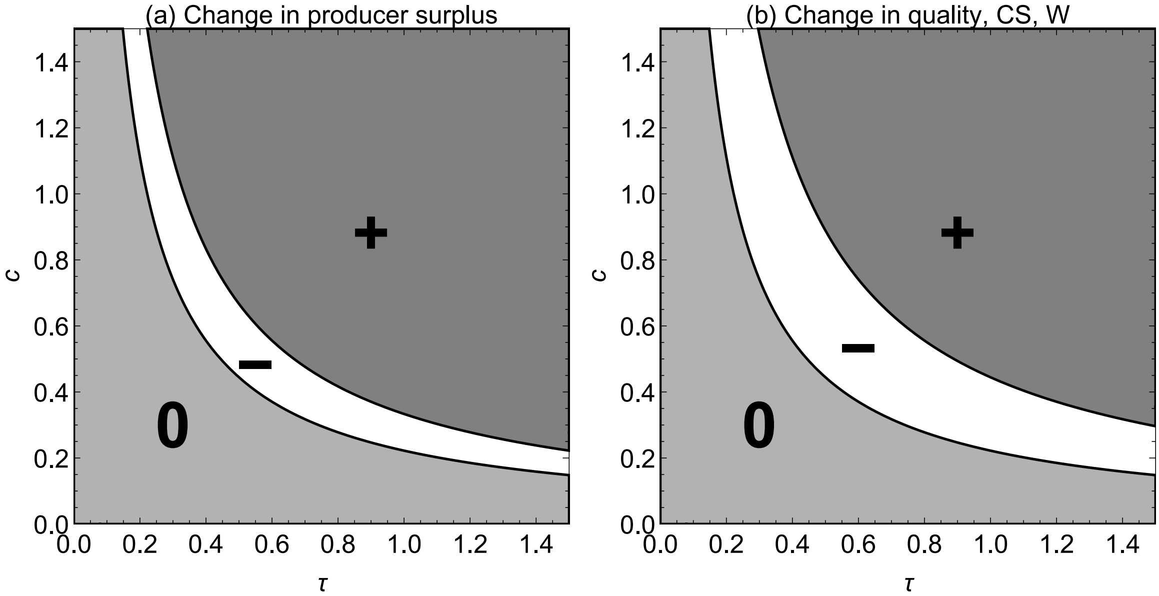


Figure 8: Effect of mandatory disclosure on (a) producer surplus and (b) environmental quality, consumer surplus, and welfare as a function of the perception threshold τ and the cost c. In the light gray areas, mandatory disclosure has no effect. In the white areas, mandatory disclosure has a negative effect. In the dark gray areas, mandatory disclosure has a positive effect.

to charge higher prices which increases producer surplus. Consequently, overall welfare is also highest for intermediate levels of attention.

In addition, I highlight the importance of accounting for consumers' limited attention for evaluating policy interventions. Depending on the level of attention in the market, some policy interventions induce higher investments in environmental quality and thus lead to a reduction in emissions. However, I show that not all policy interventions are universally beneficial. For example, although emission taxes and subsidies increase investments in environmental quality and thus reduce emissions, the effects on consumers or overall welfare might be negative. Introducing information campaigns or mandatory disclosure laws might even reduce investments in environmental quality and thus increase emissions in addition to having negative welfare effects.

Nevertheless, I make a number of assumptions that limit the scope of the analysis. I assume that all consumers have identical perception thresholds and thus that all consumers pay the same attention to the environmental dimension of the goods. In reality consumers differ in their attention to the environmental dimension of goods. In addition, to keep the analysis of the policy interventions tractable, I normalize the marginal damage of emissions to one. I leave these issues to future research.

A Proof of Proposition 1

The profit of firm $i \in \{1,2\}$ with $j \in \{1,2\}$ and $i \neq j$ is

$$\Pi_i(q_i,q_j) = \begin{cases} \frac{1}{9}(q_j - q_i) - cq_i^2 & \text{if } q_i \leq q_j - \tau \\ 0 - cq_i^2 & \text{if } q_j - \tau < q_i < q_j + \tau \\ \frac{4}{9}(q_i - q_j) - cq_i^2 & \text{if } q_i \geq q_j + \tau. \end{cases}$$

For $q_i < q_j + \tau$, the only candidate for the best reply of firm i is $q_i = 0$. For $q_i \geq q_j + \tau$, $\partial\Pi_i(q_i,q_j)/\partial q_i = -2cq_i + 4/9$. Thus the profit on $q_i \geq q_j + \tau$ is strictly increasing for all $q_i < 2/(9c)$ and strictly decreasing for all $q_i > 2/(9c)$. Thus the candidate for best reply on $q_i \in [q_j + \tau, \infty)$ is $q_i = max\{2/(9c), q_j + \tau\}$.

With $q_i = 0$ firm i makes a profit of

$$\Pi_i(q_i = 0, q_j) = \begin{cases} 0 & \text{if } q_j < \tau \\ \frac{1}{9}q_j & \text{if } q_j \geq \tau. \end{cases}$$

With $q_i = max\{2/(9c), q_j + \tau\}$ firm i makes a profit of

$$\Pi_i\left(q_i = max\left\{\frac{2}{9c}, q_j + \tau\right\}, q_j\right) = \frac{4}{9}\left(max\left\{\frac{2}{9c}, q_j + \tau\right\} - q_j\right) - c\left(max\left\{\frac{2}{9c}, q_j + \tau\right\}\right)^2$$

The best reply is the quality that yields the highest profit:

(i) $q_i = max\{2/(9c), q_j + \tau\}$ is the best reply of firm i if

$$\Pi_i\left(q_i = max\left\{\frac{2}{9c}, q_j + \tau\right\}, q_j\right) \geq \Pi_i(q_i = 0, q_j).$$

(ii) $q_i = 0$ is the best reply of firm i if

$$\Pi_i(q_i = 0, q_j) > \Pi_i\left(q_i = max\left\{\frac{2}{9c}, q_j + \tau\right\}, q_j\right).$$

The best reply of firm i is then

for $\tau \leq \frac{4}{45c}$:

$$q_i^*(q_j) = \begin{cases} max\{\frac{2}{9c}, q_j + \tau\} & \text{if } q_j \leq \frac{4}{45c} \\ 0 & \text{if } q_j > \frac{4}{45c}. \end{cases}$$

for $\frac{4}{45c} < \tau \leq \frac{1}{9c}$:

$$q_i^*(q_j) = \begin{cases} max\{\frac{2}{9c}, q_j + \tau\} & \text{if } q_j < \tau \\ 0 & \text{if } q_j \geq \tau. \end{cases}$$

for $\tau > \frac{1}{9c}$:

$$q_i^*(q_j) = \begin{cases} max\{\frac{2}{9c}, q_j + \tau\} & \text{if } q_j \leq \sqrt{\frac{4\tau}{9c}} - \tau \\ 0 & \text{if } q_j > \sqrt{\frac{4\tau}{9c}} - \tau. \end{cases} \tag{3}$$

The intersections of the best replies yield the following subgame-perfect equilibrium environmental qualities and prices ($i \in \{1,2\}$, $j \in \{1,2\}$, and $i \neq j$)

- if $\tau \leq \frac{2}{9c}$: $q_i^* = \frac{2}{9c}$ and $q_j^* = 0$ with $p_i^* = \frac{4}{27c}$ and $p_j^* = \frac{2}{27c}$.
- if $\frac{2}{9c} < \tau \leq \frac{4}{9c}$: $q_i^* = \tau$ and $q_j^* = 0$ with $p_i^* = \frac{2}{3}\tau$ and $p_j^* = \frac{1}{3}\tau$
- if $\frac{4}{9c} < \tau$: $q_i^* = q_j^* = 0$ with $p_i^* = p_j^* = 0$.

B Proof of Proposition 2

Let Π_h (Π_l) be the profit of the firm that produces the higher (lower) environmental quality. For the welfare analysis, I assume the following linear damage function $D(E) = E$.

If $\tau \leq 2/(9c)$, $q_h = 2/(9c)$, $q_l = 0$, $p_h = 4/(27c)$, $p_l = 2/(27c)$, and thus $\hat{\theta} = 1/3$. Then, the consumer surplus (CS), producer surplus (PS), and welfare (W=CS+PS) are

$$\begin{aligned}
CS &= \int_0^{\hat{\theta}} v + \theta \cdot 0 - \frac{2}{27c} - D(E)d\theta + \int_{\hat{\theta}}^1 v + \theta\frac{2}{9c} - \frac{4}{27c} - D(E)d\theta = v + \frac{10}{81c} - \bar{e} \\
PS &= \Pi_l + \Pi_h = \hat{\theta}p_l^* - c(q_l^*)^2 + (1-\hat{\theta})p_h^* - c(q_h^*)^2 = \frac{2}{81c} + \frac{4}{81c} = \frac{6}{81c} \\
W &= CS + PS = v + \frac{16}{81c} - \bar{e}.
\end{aligned}$$

If $2/(9c) < \tau \leq 4/(9c)$, $q_h = \tau$, $q_l = 0$, $p_h = 2\tau/3$, $p_l = \tau/3$, and thus $\hat{\theta} = 1/3$. Then,

$$\begin{aligned}
CS &= \int_0^{\hat{\theta}} v + \theta \cdot 0 - \frac{1}{3}\tau - D(E)d\theta + \int_{\hat{\theta}}^1 v + \theta\tau - \frac{2}{3}\tau - D(E)d\theta = v + \frac{5}{9}\tau - \bar{e} \\
PS &= \Pi_l + \Pi_h = \frac{1}{9}\tau + \frac{4}{9}\tau - c\tau^2 = \frac{5}{9}\tau - c\tau^2 \\
W &= CS + PS = v + \frac{10}{9}\tau - c\tau^2 - \bar{e}.
\end{aligned}$$

If $4/(9c) < \tau$, $q_h = 0$, $q_l = 0$, $p_h = 0$, $p_l = 0$. Thus all consumers are indifferent and randomize. Then,

$$\begin{aligned}
CS &= \frac{v-\bar{e}}{2} + \frac{v-\bar{e}}{2} = v - \bar{e} \\
PS &= 0 + 0 = 0 \\
W &= CS + PS = v - \bar{e}.
\end{aligned}$$

Consumer surplus: The consumer surplus is constant in τ in the intervals $\tau \in [0, 2/(9c)]$ and $\tau \in (4/(9c), \infty)$ and increasing in the interval $\tau \in (2/(9c), 4/(9c)]$. At $\tau = 4/(9c)$, the consumer surplus is

$$CS\left(\tau = \frac{4}{9c}\right) = v + \frac{20}{81c} - \bar{e}.$$

As

$$v + \frac{20}{81c} - \bar{e} > v + \frac{10}{81c} - \bar{e} > v - \bar{e},$$

the consumer surplus reaches its unique maximum at $\tau = 4/(9c)$.

Producer surplus: The producer surplus is constant in τ in the intervals $\tau \in [0, 2/(9c)]$ and $\tau \in (4/(9c), \infty)$. In $\tau \in (2/(9c), 4/(9c)]$, $5/(18c) = \arg\max_\tau 5\tau/9 - c\tau^2$.

At $\tau = 5/(18c)$, the producer surplus is

$$PS\left(\tau = \frac{5}{18c}\right) = \frac{25}{324c}.$$

As

$$\frac{25}{324c} > \frac{6}{81c} > 0,$$

the producer surplus reaches its unique maximum at $\tau = 5/(18c)$.

Welfare: The welfare is constant in τ in the intervals $\tau \in [0, 2/(9c)]$ and $\tau \in (4/(9c), \infty)$. In the interval $\tau \in (2/(9c), 4/(9c)]$, the welfare is increasing in τ. At $\tau = 4/(9c)$, the welfare is

$$W\left(\tau = \frac{4}{9c}\right) = v + \frac{8}{27c} - \bar{e}.$$

As

$$v + \frac{8}{27c} - \bar{e} > v + \frac{16}{81c} - \bar{e} > v - \bar{e}$$

the welfare reaches its unique maximum at $\tau = 4/(9c)$.

C Welfare analysis with $D(E) = E^2$

Assume the following damage function $D(E) = E^2$. As the firms' profits do not depend on the damages, changing the damage function from $D(E) = E$ (see Appendix B) to $D(E) = E^2$ has no effect on the producer surplus.

If $\tau \leq 2/(9c)$, $q_h = 2/(9c)$, $q_l = 0$, $p_h = 4/(27c)$, $p_l = 2/(27c)$, and thus $\hat{\theta} = 1/3$. Then, the consumer surplus (CS) and welfare (W=CS+PS) are

$$\begin{aligned}CS &= \int_0^{\hat{\theta}} v + \theta \cdot 0 - \frac{2}{27c} - D(E)d\theta + \int_{\hat{\theta}}^1 v + \theta\frac{2}{9c} - \frac{4}{27c} - D(E)d\theta \\ &= v - \frac{2}{81c} - \left(\bar{e} - \frac{4}{27c}\right)^2 \\ W &= CS + PS = v + \frac{4}{81c} - \left(\bar{e} - \frac{4}{27c}\right)^2.\end{aligned}$$

If $2/(9c) \leq \tau \leq 4/(9c)$, $q_h = \tau$, $q_l = 0$, $p_h = 2\tau/3$, $p_l = \tau/3$, and thus $\hat{\theta} = 1/3$. Then,

$$\begin{aligned}CS &= \int_0^{\hat{\theta}} v + \theta \cdot 0 - \frac{1}{3}\tau - D(E)d\theta + \int_{\hat{\theta}}^1 v + \theta\tau - \frac{2}{3}\tau - D(E)d\theta = v - \frac{1}{9}\tau - \left(\bar{e} - \frac{2}{3}\tau\right)^2 \\ W &= CS + PS = v + \frac{4}{9}\tau - c\tau^2 - \left(\bar{e} - \frac{2}{3}\tau\right)^2.\end{aligned}$$

If $4/(9c) < \tau$, $q_h = 0$, $q_l = 0$, $p_h = 0$, $p_l = 0$. Thus all consumers are indifferent and randomize. Then,

$$\begin{aligned}CS &= \frac{v - \bar{e}^2}{2} + \frac{v - \bar{e}^2}{2} = v - \bar{e}^2 \\ W &= CS + PS = v - \bar{e}^2.\end{aligned}$$

Consumer surplus: The consumer surplus is constant in τ in the intervals $\tau \in [0, 2/(9c)]$ and $\tau \in (4/(9c), \infty)$. In the interval $\tau \in [2/(9c), 4/(9c)]$, the consumer surplus reaches its highest value either at $\tau = 3/2\bar{e} - 1/8$ or at a boundary. A comparison of the the highest consumer surplus in the three intervals, gives the following result:

(i) For $\bar{e} \leq 2/(27c) + 1/12$, consumer surplus reaches its maximum for all $\tau > 4/(9c)$.

(ii) For $2/(27c) + 1/12 \leq \bar{e} \leq 4/(27c) + 1/12$, consumer surplus reaches its maximum for all $\tau \leq 2/(9c)$.

(iii) For $4/(27c) + 1/12 < \bar{e} \leq 8/(27c) + 1/12$, consumer surplus reaches its maximum $\tau = 3/2\bar{e} - 1/8$.

(iv) For $8/(27c) + 1/12 < \bar{e}$, consumer surplus reaches its maximum for $\tau = 4/(9c)$.

Welfare: The welfare is constant in τ in the intervals $\tau \in [0, 2/(9c)]$ and $\tau \in (4/(9c), \infty)$. In the interval $\tau \in [2/(9c), 4/(9c)]$, the welfare reaches its highest value either at $\tau = (2+6\bar{e})/(4+9c)$ or at a boundary. A comparison of the the highest welfare in the three intervals, gives the following result:

(i) For $\bar{e} \leq 2/(27c) - 1/6$, welfare reaches its maximum for all $\tau > 4/(9c)$.

(ii) For $2/(27c) - 1/6 \leq \bar{e} \leq 4/(27c)$, welfare reaches its maximum for all $\tau \leq 2/(9c)$.

(iii) For $4/(27c) < \bar{e} \leq 8/(27c) + 1/3$, welfare reaches its maximum $\tau = (2+6\bar{e})/(4+9c)$.

(iv) For $8/(27c) + 1/3 < \bar{e}$, welfare reaches its maximum for $\tau = 4/(9c)$.

D Emission tax

If the market authority imposes a per-unit tax $t(\bar{e} - q_i)$ with $t \in (0, 1]$ on firm $i \in \{1, 2\}$, the profit of firm i becomes

$$\Pi_i(p_i, p_j, q_i, q_j) = \Big(p_i - t(\bar{e} - q_i)\Big)x_i(p_i, p_j, q_i, q_j) - C(q_i).$$

Price-setting stage

Given the quality-setting of stage 1, in the price-setting stage, two types of subgames occur. If the environmental qualities are indistinguishable, Bertrand competition leads to prices equal to the marginal cost of the firm with the higher marginal costs

$$p_i^* = max\{t(\bar{e} - q_i), t(\bar{e} - q_j)\}.$$

I assume that all consumers buy from the firm with the higher quality.[16] The corresponding profits are

$$\begin{aligned} \Pi_i(q_i, q_j) &= max\{t(\bar{e} - q_i), t(\bar{e} - q_j)\} - C(q_i) \\ \Pi_j(q_i, q_j) &= max\{t(\bar{e} - q_i), t(\bar{e} - q_j)\} - C(q_j). \end{aligned}$$

If the environmental qualities are distinguishable, firms maximize their profits

$$\begin{aligned} \Pi_h(p_h, p_l, q_h, q_l) &= \Big(p_h - t(\bar{e} - q_h)\Big)(1 - \hat{\theta}) - cq_h^2 \\ \Pi_l(p_h, p_l, q_h, q_l) &= \Big(p_l - t(\bar{e} - q_l)\Big)\hat{\theta} - cq_l^2. \end{aligned}$$

The first order conditions yield the following best replies

$$\begin{aligned} p_h^*(p_l) &= \frac{1}{2}\Big(p_l + q_h - q_l + t(\bar{e} - q_h)\Big) \\ p_l^*(p_h) &= \frac{1}{2}\Big(p_h + t(\bar{e} - q_l)\Big). \end{aligned}$$

Thus the equilibrium prices are

$$\begin{aligned} p_h^* &= \frac{1}{3}\Big(2(q_h - q_l) + 3t\bar{e} - tq_l - 2tq_h\Big) \\ p_l^* &= \frac{1}{3}\Big(q_h - q_l + 3t\bar{e} - 2tq_l - tq_h\Big). \end{aligned}$$

[16] This tie-breaking rule sustains the equilibrium. With another tie-breaking rule, a similar equilibrium would result: The firm with the lower quality could marginally reduce its price and thus capture the complete demand with only a marginally lower profit.

The corresponding profits are

$$\Pi_h(q_h, q_l) = \frac{(2+t)^2}{9}(q_h - q_l) - cq_h^2$$
$$\Pi_l(q_h, q_l) = \frac{(1-t)^2}{9}(q_h - q_l) - cq_l^2.$$

Quality-setting stage

In the quality-setting stage, firm i chooses q_i to maximize the following profit

$$\Pi_i(q_i, q_j) = \begin{cases} \frac{(2+t)^2}{9}(q_i - q_j) - cq_i^2 & \text{if } q_i \geq q_j + \tau \\ t(q_i - q_j) - cq_i^2 & \text{if } q_j \leq q_i < q_j + \tau \\ -cq_i^2 & \text{if } q_j - \tau < q_i \leq q_j \\ \frac{(1-t)^2}{9}(q_j - q_i) - cq_i^2 & \text{if } q_i \leq q_j - \tau. \end{cases} \tag{4}$$

If $q_j < \tau$, the fourth case of (4) does not exist. The environmental qualities that maximize the profit function on the four different intervals are candidates for best reply. In the interval $[q_j + \tau, \infty)$, $\max\{q_j + \tau, (2+t)^2/(18c)\} = argmax_{q_i}\Pi_i(q_i, q_j)$. In the interval $[q_j, q_j + \tau)$, $q_i = t/(2c)$ or a boundary is the candidate for best reply.[17] In the interval $[0, q_j]$, $q_i = 0$ is the candidate for best reply.

The overall best reply depends on the perception threshold τ:

(i) If $\tau \leq (2+t)^4/(36c(5+2t+2t^2))$, the best reply of firm i is

$$q_i^*(q_j) = \begin{cases} \frac{(2+t)^2}{18c} & \text{if } q_j \leq \frac{(2+t)^4}{36c(5+2t+2t^2)} \\ 0 & \text{if } q_j \geq \frac{(2+t)^4}{36c(5+2t+2t^2)}. \end{cases}$$

(ii) If $(2+t)^4/(36c(5+2t+2t^2)) < \tau \leq (2+t)^2/(36c)$, the best reply of firm i is

$$q_i^*(q_j) = \begin{cases} \frac{(2+t)^2}{18c} & \text{if } q_j < \tau \\ 0 & \text{if } q_j \geq \tau. \end{cases}$$

(iii) If $(2+t)^2/(36c) < \tau \leq (8-t+2t^2)/(36c) + 1/(18c)\sqrt{16-4t-12t^2-t^3+t^4}$, the best reply of firm i is

$$q_i^*(q_j) = \begin{cases} \frac{(2+t)^2}{18c} & \text{if } q_j \leq \frac{(2+t)^2}{18c} - \tau \\ q_j + \tau & \text{if } \frac{(2+t)^2}{18c} - \tau < q_j \leq \frac{\sqrt{4\tau + 4t\tau + t^2\tau}}{3\sqrt{c}} - \tau \\ 0 & \text{if } q_j \geq \frac{\sqrt{4\tau+4t\tau+t^2\tau}}{3\sqrt{c}} - \tau. \end{cases}$$

[17] Note that $q_j + \tau$ is not included in the interval. However, if $t/(2c) \notin [q_j, q_j + \tau)$, the firm always has an incentive to deviate to a $q_i \notin [q_j, q_j + \tau)$.

(iv) If $\tau > (8-t+2t^2)/(36c)+1/(18c)\sqrt{16-4t-12t^2-t^3+t^4}$, the best reply of firm i is

$$q_i^*(q_j) = \begin{cases} \frac{(2+t)^2}{18c} & \text{if } q_j \leq \frac{(2+t)^2}{18c} - \tau \\ q_j + \tau & \text{if } \frac{(2+t)^2}{18c} - \tau < q_j \leq \frac{t-2c\tau}{2c} + \frac{\sqrt{4\tau-5t\tau+t^2\tau}}{3\sqrt{c}} \\ \frac{t}{2c} & \text{if } \frac{t-2c\tau}{2c} + \frac{\sqrt{4\tau-5t\tau+t^2\tau}}{3\sqrt{c}} \leq q_j \leq \frac{t}{4c} \\ 0 & \text{if } q_j \geq \frac{t}{4c}. \end{cases}$$

Consequently, the equilibrium environmental qualities also depend on the perception threshold:

(i) If $\tau \leq \bar{\tau}$, there exist subgame-perfect equilibria where firms choose distinguishable environmental qualities $q_i^* = \max\{(2+t)^2/(18c), \tau\}$ and $q_j^* = 0$ with prices $p_i^* = 1/3(2(1-t)q_i^* + 3t\bar{e})$ and $p_j^* = 1/3((1-t)q_i^* + 3t\bar{e})$.

(ii) If $\tau \geq \bar{\tau}$, there exist subgame-perfect equilibria where firms choose indistinguishable environmental qualities $q_i^* = t/(2c)$ and $q_j^* = 0$ with prices $p_i^* = p_j^* = t\bar{e}$.

Comparison tax and no tax

To avoid negative emissions, assume that $\bar{e} > max\{q_i, q_j\}$

Environmental quality: The environmental quality is (weakly) higher with the tax than without the tax. For $\tau \leq 4/(9c)$,

$$\max\left\{\tau, \frac{(2+t)^2}{18c}\right\} \geq \max\left\{\tau, \frac{2}{9c}\right\}.$$

For $4/(9c) < \tau \leq \bar{\tau}$,

$$\max\left\{\tau, \frac{(2+t)^2}{18c}\right\} > 0.$$

For $\tau > \bar{\tau}$,

$$\frac{t}{2c} > 0.$$

Producer surplus: The producer surplus is higher with the tax than without the tax. For $\tau \leq 2/(9c)$, the producer surplus with the tax is

$$PS_t = \frac{(2+t)^2 + (1-t)^2}{9} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - c\left(\max\left\{\frac{(2+t)^2}{18c}, \tau\right\}\right)^2 > \frac{6}{81c}.$$

For $2/(9c) < \tau \leq 4/(9c)$, the producer surplus with the tax is

$$PS_t = \frac{(2+t)^2 + (1-t)^2}{9} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - c\left(\max\left\{\frac{(2+t)^2}{18c}, \tau\right\}\right)^2 > \frac{5}{9}\tau - c\tau^2.$$

For $4/(9c) < \tau \leq \bar{\tau}$, the producer surplus with the tax is

$$PS_t = \frac{(2+t)^2 + (1-t)^2}{9} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - c\left(\max\left\{\frac{(2+t)^2}{18c}, \tau\right\}\right)^2 > 0.$$

For $\tau > \bar{\tau}$, the producer surplus with the tax is

$$PS_t = \frac{t^2}{4c} > 0.$$

Consumer surplus: For $\tau \leq 2/(9c)$, the consumer surplus with the tax is

$$\begin{aligned} CS_t &= v - (1+t)\bar{e} + \frac{10+16t+t^2}{18} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} > v + \frac{10}{81c} - \bar{e} \\ \Leftrightarrow \bar{e} &< \frac{1}{t}\left(\frac{10+16t+t^2}{18} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - \frac{10}{81c}\right). \end{aligned}$$

For $2/(9c) < \tau \leq 4/(9c)$, the consumer surplus with the tax is

$$\begin{aligned} CS_t &= v - (1+t)\bar{e} + \frac{10+16t+t^2}{18} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} > v + \frac{5}{9}\tau - \bar{e} \\ \Leftrightarrow \bar{e} &< \frac{1}{t}\left(\frac{10+16t+t^2}{18} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - \frac{5}{9}\tau\right) \end{aligned}$$

For $4/(9c) < \tau \leq \bar{\tau}$,the consumer surplus with the tax is

$$\begin{aligned} CS_t &= v - (1+t)\bar{e} + \frac{10+16t+t^2}{18} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} > v - \bar{e} \\ \Leftrightarrow \bar{e} &< \frac{10+16t+t^2}{18t} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\}. \end{aligned}$$

For $\tau > \bar{\tau}$, the consumer surplus with the tax is

$$CS_t = v - (1+t)\bar{e} + \frac{3t}{4c} > v - \bar{e} \Leftrightarrow \bar{e} < \frac{3}{4c}.$$

Welfare: The welfare is the sum of producer surplus, consumer surplus, and tax revenue. The welfare with the tax is higher than the welfare without the tax. For $\tau \leq 2/(9c)$, the welfare with the tax is

$$W_t = v + \frac{20+8t-t^2}{18} \max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - c\max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - e > v + \frac{16}{81c} - \bar{e}.$$

For $2/(9c) < \tau \leq 4/(9c)$, the welfare with the tax is

$$W_t = v + \frac{20 + 8t - t^2}{18}\max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - c\max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - e > v + \frac{10}{9}\tau - c\tau^2 - \bar{e}.$$

For $4/(9c) < \tau \leq \bar{\tau}$, the welfare with the tax is

$$W_t = v + \frac{20 + 8t - t^2}{18}\max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - c\max\left\{\frac{(2+t)^2}{18c}, \tau\right\} - e > v - \bar{e}.$$

For $\tau > \bar{\tau}$, the welfare with the tax is

$$W_t = v - \bar{e} + \frac{3t - t^2}{4c} > v - \bar{e}.$$

E Subsidy

Assume the current cost parameter is c_0. The market authority subsidizes investments, i.e., reduces the cost parameter by s to $c_0 - s$ with $s \in [0, c_0]$. The resulting welfare (sum of producer surplus and consumer surplus, minus costs of the subsidy), depends on the size of the subsidy s:

If $\tau \leq 2/(9(c_0 - s)) \Leftrightarrow s \geq c_0 - 2/(9\tau)$, i.e., in the benchmark regime, the welfare is

$$W_s = v + \frac{16}{81(c_0 - s)} - \bar{e} - s\left(\frac{2}{9(c_0 - s)}\right)^2. \tag{5}$$

If $2/(9(c_0 - s)) < \tau \leq 4/(9(c_0 - s)) \Leftrightarrow c_0 - 4/(9\tau) \leq s < c_0 - 2/(9\tau)$, i.e., in the increased-investment regime, the welfare is

$$W_s = v + \frac{10}{9}\tau - c_0\tau^2 - \bar{e}. \tag{6}$$

If $4/(9(c_0 - s)) < \tau \Leftrightarrow s < c_0 - 4/(9\tau)$, i.e., in the no-investment regime, the welfare is

$$W_s = v - \bar{e}. \tag{7}$$

Whether the introduction of the subsidy has a positive, a negative, or no effect on welfare depends on the original cost parameter c_0 relative to the perception threshold τ and the size of the subsidy s:

(i) If $c_0 \leq 2/(9\tau)$, without a subsidy, the benchmark regime results. Any subsidy $s \in [0, c_0]$ affects investments in environmental quality, but cannot lead to a regime change. The welfare dependent on s is given in (5). As $v + 16/(81(c_0 - s)) - \bar{e} - s\,(2/(9(c_0 - s)))^2 > v + 16/(81c_0) - \bar{e} \Leftrightarrow s < 3c_0/4$, the introduction of a subsidy $s < 3c_0/4$ has a positive effect on welfare. The introduction of a subsidy $s \geq 3c_0/4$ has a negative effect on welfare.

(ii) If $2/(9\tau) < c_0 \leq 4/(9\tau)$, without a subsidy, the increased-investment regime results. Consequently, with any $s < c_0 - 2/(9\tau)$, the market remains in the increased-investment regime. Then, the subsidy has no effect on investments in environmental quality or on welfare (given in (6)). In contrast, a subsidy $s \geq c_0 - 2/(9\tau)$ induces a regime change to the benchmark regime. Then, the subsidy affects investments in environmental quality and welfare (given in (5)). Note that

$$v + \frac{16}{81(c_0 - s)} - \bar{e} - s\left(\frac{2}{9(c_0 - s)}\right)^2 \geq v + \frac{10}{9}\tau - c_0\tau^2 - \bar{e} \Leftrightarrow c_0 - \frac{2}{9\tau} \leq s \leq \frac{8c_0 - 9c_0^2\tau}{10 - 9c_0\tau}.$$

Consequently, if $2/(9\tau) < c_0 \leq 4/(9\tau)$, the introduction of a subsidy $s < c_0 - 2/(9\tau)$ has no effect on welfare as the market remains in the increased-investment regime. The introduction of a subsidy $c_0 - 2/(9\tau) \leq s \leq (8c_0 - 9c_0^2\tau)/(10 - 9c_0\tau)$ has a positive effect on welfare. In contrast, the introduction of a subsidy $s > (8c_0 - 9c_0^2\tau)/(10 - 9c_0\tau)$ has a negative effect on welfare.

(iii) If $c_0 > 4/(9\tau)$, without a subsidy, the no-investment regime results. Consequently, with any $s < c_0 - 4/(9\tau)$, the market remains in the no-investment regime. Then, the subsidy has no effect on environmental qualities or on welfare (given in (7)). A subsidy $c_0 - 4/(9\tau) \leq s < c_0 - 2/(9\tau)$ induces a regime change to the increased-investment regime with welfare (given in (6)). Note that

$$v + \frac{10}{9}\tau - c_0\tau^2 - \bar{e} > v - \bar{e} \Leftrightarrow c_0 < \frac{10}{9\tau}.$$

A subsidy $s \geq c_0 - 2/(9\tau)$ induces a regime change to the benchmark regime Then, the subsidy affects investments in environmental quality and welfare (given in (5)). Note that

$$v + \frac{16}{81(c_0 - s)} - \bar{e} - s\left(\frac{2}{9(c_0 - s)}\right)^2 > v - \bar{e} \Leftrightarrow s < \frac{4c_0}{5}$$

and

$$\frac{4c_0}{5} > c_0 - \frac{2}{9\tau} \Leftrightarrow c_0 < \frac{10}{9\tau}.$$

In sum, if $4/(9\tau) < c_0 < 10/(9\tau)$, the introduction of a subsidy $s < c_0 - 4/(9\tau)$ has no effect on welfare, the introduction of a subsidy $c_0 - 4/(9\tau) \leq s \leq 4c_0/5$ has a positive effect on welfare, and the introduction of a subsidy $s > 4c_0/5$ has a negative effect on welfare. If $c_0 \geq 10/(9\tau)$, the introduction of a subsidy $s < c_0 - 4/(9\tau)$ has no effect on welfare and the introduction of a subsidy $s \geq c_0 - 4/(9\tau)$ has a negative effect on welfare.

References

Allcott, H., S. Mullainathan, and D. Taubinsky (2014): "Energy policy with externalities and internalities," *Journal of Public Economics*, 112, 72–88.

Allcott, H., and D. Taubinsky (2015): "Evaluating Behaviorally Motivated Policy: Experimental Evidence from the Lightbulb Market," *American Economic Review*, 105(8), 2501–2538.

Allen, B., and J.-F. Thisse (1992): "Price equilibria in pure strategies for homogeneous oligopoly," *Journal of Economics & Management Strategy*, 1(1), 63–81.

Ambec, S., and P. De Donder (2022): "Environmental policy with green consumerism," *Journal of Environmental Economics and Management*, 111, 102584.

Andor, M. A., A. Gerster, K. T. Gillingham, and M. Horvath (2020): "Running a car costs much more than people think—stalling the uptake of green travel," *Nature*, 580(7804), 453–455.

Armstrong, M., and Y. Chen (2009): "Inattentive Consumers and Product Quality," *Journal of the European Economic Association*, 7(2/3), 411–422.

Armstrong, M., and J. Vickers (2022): "Patterns of Competitive Interaction," *Econometrica*, 90(1), 153–191.

Arora, S., and S. Gangopadhyay (1995): "Toward a theoretical model of voluntary overcompliance," *Journal of Economic Behavior & Organization*, 28(3), 289–309.

Astorne-Figari, C., J. J. López, and A. Yankelevich (2019): "Advertising for consideration," *Journal of Economic Behavior & Organization*, 157, 653–669.

Bachi, B. (2016): "Competition with price similarities," *Economic Theory Bulletin*, 4(2), 277–290.

Balart, P. (2021): "Semiorder preferences and price-oriented buyers in a Hotelling model," *Journal of Economic Behavior & Organization*, 188, 394–407.

Bansal, S., and S. Gangopadhyay (2003): "Tax/subsidy policies in the presence of environmentally aware consumers," *Journal of Environmental Economics and Management*, 45(2, Supplement), 333–355.

Bartling, B., V. Valero, and R. A. Weber (2022): "The Causal Effect of Income on Market Social Responsibility," *Available at SSRN 3249788*.

Boogen, N., C. Daminato, M. Filippini, and A. Obrist (2022): "Can information about energy costs affect consumers' choices? Evidence from a field experiment," *Journal of Economic Behavior & Organization*, 196, 568–588.

Bordalo, P., N. Gennaioli, and A. Shleifer (2016): "Competition for Attention," *Review of Economic Studies*, 83(2), 481–513.

Boyaci, T., and Y. Akçay (2018): "Pricing When Customers Have Limited Attention," *Management Science*, 64(7), 2995–3014.

Brown, J., T. Hossain, and J. Morgan (2010): "Shrouded Attributes and Information Suppression: Evidence from the Field," *Quarterly Journal of Economics*, 125(2), 859–876.

Busse, M. R., N. Lacetera, D. G. Pope, J. Silva-Risso, and J. R. Sydnor (2013): "Estimating the Effect of Salience in Wholesale and Retail Car Markets," *American Economic Review*, 103(3), 575–579.

Carroni, E., A. Mantovani, and A. Minniti (2023): "Price signaling with salient-thinking consumers," *Games and Economic Behavior*, 138, 238–253.

Chetty, R., A. Looney, and K. Kroft (2009): "Salience and Taxation: Theory and Evidence," *American Economic Review*, 99(4), 1145–1177.

Chung, K.-S., E. M. Liu, and M. Lo (2021): "Selling to consumers who cannot detect small differences," *Journal of Economic Theory*, 192, Article 105186.

de Clippel, G., K. Eliaz, and K. Rozen (2014): "Competing for Consumer Inattention," *Journal of Political Economy*, 122(6), 1203–1234.

Diederich, J., and T. Goeschl (2014): "Willingness to Pay for Voluntary Climate Action and Its Determinants: Field-Experimental Evidence," *Environmental and Resource Economics*, 57, 405–429.

Eliaz, K., and R. Spiegler (2011a): "Consideration Sets and Competitive Marketing," *Review of Economic Studies*, 78(1), 235–262.

——— (2011b): "On the strategic use of attention grabbers," *Theoretical Economics*, 6(1), 127–155.

Englmaier, F., A. Schmöller, and T. Stowasser (2018): "Price Discontinuities in an Online Market for Used Cars," *Management Science*, 64(6), 2754–2766.

Eriksson, C. (2004): "Can green consumerism replace environmental regulation?—a differentiated-products example," *Resource and Energy Economics*, 26(3), 281–293.

Farhi, E., and X. Gabaix (2020): "Optimal Taxation with Behavioral Agents," *American Economic Review*, 110(1), 298–336.

Fischer, C., and T. P. Lyon (2019): "A Theory of Multitier Ecolabel Competition," *Journal of the Association of Environmental and Resource Economists*, 6(3), 461–501.

Gabaix, X. (2019): "Behavioral inattention," in *Handbook of Behavioral Economics: Foundations and Applications*, ed. by B. D. Bernheim, S. DellaVigna, and D. Laibson, vol. 2, pp. 261–343. Elsevier Science & Technology, Amsterdam.

Gabaix, X., and D. Laibson (2006): "Shrouded Attributes, Consumer Myopia, and Information Suppression in Competitive Markets," *Quarterly Journal of Economics*, 121(2), 505–540.

Ghosh, B., and M. R. Galbreth (2013): "The Impact of Consumer Attentiveness and Search Costs on Firm Quality Disclosure: A Competitive Analysis," *Management Science*, 59(11), 2604–2621.

Gilbert, B., and J. S. Graff Zivin (2020): "Dynamic corrective taxes with time-varying salience," *Journal of Environmental Economics and Management*, 103, 102356.

Haan, M. A., and J. L. Moraga-González (2011): "Advertising for Attention in a Consumer Search Model," *Economic Journal*, 121(552), 552–579.

Hefti, A. (2018): "Limited attention, competition and welfare," *Journal of Economic Theory*, 178, 318–359.

Hefti, A., and S. Liu (2020): "Targeted information and limited attention," *RAND Journal of Economics*, 51(2), 402–420.

Heidhues, P., J. Johnen, and B. Köszegi (2021): "Browsing versus Studying: A Pro-market Case for Regulation," *Review of Economic Studies*, 88(2), 708–729.

Heidhues, P., B. Köszegi, and T. Murooka (2016): "Exploitative Innovation," *American Economic Journal: Microeconomics*, 8(1), 1–23.

——— (2017): "Inferior Products and Profitable Deception," *Review of Economic Studies*, 84(1), 323–356.

Herweg, F., and K. M. Schmidt (2022): "How to Regulate Carbon Emissions with Climate-Conscious Consumers," *Economic Journal*, 132(648), 2992–3019.

Heyes, A., S. Kapur, P. W. Kennedy, S. Martin, and J. W. Maxwell (2020): "*But What Does It Mean?* Competition between Products Carrying Alternative Green Labels When Consumers Are Active Acquirers of Information," *Journal of the Association of Environmental and Resource Economists*, 7(2), 243–277.

Heyes, A., T. P. Lyon, and S. Martin (2018): "Salience games: Private politics when public attention is limited," *Journal of Environmental Economics and Management*, 88, 396–410.

Horan, S., P. Manzini, and M. Mariotti (2022): "When is coarseness not a curse? Comparative statics of the coarse random utility model," *Journal of Economic Theory*, 202, Article 105445.

Houde, S., and E. Myers (2019): "Heterogeneous (mis-) perceptions of energy costs: Implications for measurement and policy design," *NBER Working Paper 25722*.

Hulshof, D., and M. Mulder (2020): "Willingness to Pay for CO2 Emission Reductions in Passenger Car Transport," *Environmental and Resource Economics*, 75(4), 899–929.

Ibanez, L., and G. Grolleau (2008): "Can Ecolabeling Schemes Preserve the Environment?," *Environmental and Resource Economics*, 40(2), 233–249.

Janssen, A., and J. Kasinger (2024): "Obfuscation and Rational Inattention," *Journal of Industrial Economics*, 72(1), 390–428.

Kuhn, K.-U., and N. Uler (2019): "Behavioral sources of the demand for carbon offsets: an experimental study," *Experimental Economics*, 22, 676–704.

Lacetera, N., D. G. Pope, and J. R. Sydnor (2012): "Heuristic Thinking and Limited Attention in the Car Market," *American Economic Review*, 102(5), 2206–2236.

Lambertini, L., G. Pignataro, and A. Tampieri (2020): "The effects of environmental quality misperception on investments and regulation," *International Journal of Production Economics*, 225, 107579.

Langinier, C., and A. Ray Chaudhuri (2024): "Green Patents in an Oligopolistic Market with Green Consumers," *Department of Economics, University of Alberta Working Paper Series*, Working Paper No. 2024-07.

Li, Y., and K. van't Veld (2015): "Green, greener, greenest: Eco-label gradation and competition," *Journal of Environmental Economics and Management*, 72, 164–176.

Löschel, A., B. Sturm, and C. Vogt (2013): "The demand for climate protection—Empirical evidence from Germany," *Economics Letters*, 118(3), 415–418.

Luce, R. D. (1956): "Semiorders and a Theory of Utility Discrimination," *Econometrica*, 24(2), 178–191.

MANZINI, P., AND M. MARIOTTI (2018): "Competing for Attention: Is the Showiest Also the Best?," *Economic Journal*, 128(609), 827–844.

MORAGA-GONZÁLEZ, J. L., AND N. PADRÓN-FUMERO (2002): "Environmental Policy in a Green Market," *Environmental and Resource Economics*, 22(3), 419–447.

RUBINSTEIN, A. (1988): "Similarity and decision-making under risk (is there a utility theory resolution to the Allais paradox?)," *Journal of Economic Theory*, 46(1), 145–153.

SAUR, M. P., M. G. SCHLATTERER, AND S. Y. SCHMITT (2022): "Limited perception and price discrimination in a model of horizontal product differentiation," *Games and Economic Behavior*, 134, 151–168.

SCHMITT, S. Y. (2022): "Competition with limited attention to quality differences," *BERG Working Paper no. 184*.

SCHMUTZLER, A. (2024): "Providing Innovation Incentives for the Green Transition," *University of Zurich, Department of Economics, Working Paper Series, Working Paper No. 462*.

SEJAS-PORTILLO, R., M. MORO, AND T. STOWASSER (2025): "The Simpler the Better? Threshold Effects of Energy Labels on Property Prices and Energy Efficiency Investments," *American Economic Journal: Applied Economics*, 17(1), 41–89.

SENGUPTA, A. (2012): "Investment in cleaner technology and signaling distortions in a market with green consumers," *Journal of Environmental Economics and Management*, 64(3), 468–480.

——— (2015): "Competitive investment in clean technology and uninformed green consumers," *Journal of Environmental Economics and Management*, 71, 125–141.

SEXTON, S. (2015): "Automatic Bill Payment and Salience Effects: Evidence from Electricity Consumption," *Review of Economics and Statistics*, 97(2), 229–241.

TIEFENBECK, V., L. GOETTE, K. DEGEN, V. TASIC, E. FLEISCH, R. LALIVE, AND T. STAAKE (2018): "Overcoming Salience Bias: How Real-Time Feedback Fosters Resource Conservation," *Management Science*, 64(3), 1458–1476.

WANG, X., J. LEE, J. YAN, AND G. D. THOMPSON (2018): "Testing the behavior of rationally inattentive consumers in a residential water market," *Journal of Environmental Economics and Management*, 92, 344–359.

WARD, D. O., C. D. CLARK, K. L. JENSEN, AND S. T. YEN (2011): "Consumer willingness to pay for appliances produced by Green Power Partners," *Energy Economics*, 33(6), 1095–1102.

Webb, E. J. D. (2017): "If It's All the Same to You: Blurred Consumer Perception and Market Structure," *Review of Industrial Organization*, 50(1), 1–25.

BERG Working Paper Series (most recent publications)

186 Daniel M. **Mayerhoffer** and Jan **Schulz**, *Social Segregation, Misperceptions, and Emergent Cyclical Choice Patterns*

187 Sarah **Mignot**, Fabio **Tramontana** and Frank **Westerhoff**, *Complex dynamics in a nonlinear duopoly model with heuristic expectation formation and learning behavior*

188 Leonhard **Ipsen**, Armin **Aminian** and Jan **Schulz**, *Stress-testing Inflation Exposure: Systemically Significant Prices and Asymmetric Shock Propagation in the EU28*

189 Sarah **Mignot** and Frank **Westerhoff**, *Explaining the stylized facts of foreign exchange markets with a simple agent-based version of Paul de Grauwe's chaotic exchange rate model*

190 Roberto **Rozzi** and Stefanie Y. **Schmitt**, *Vertical product differentiation, prominence, and costly search*

191 Florian **Herold** and Christoph **Kuzmics**, *Farkas' Lemma and Complete Indifference*

192 Sarah **Mignot**, Paolo **Pellizzari**, and Frank **Westerhoff**, *Fake News and Asset Price Dynamics*

193 Fabian **Dietz** and Marco **Sahm**, *Fairness in Round-Robin Tournaments with Four Players and Endogenous Sequences*

194 Jan **Schulz**, Caleb **Agoha**, Anna **Gebhard**, Bettina **Gregg** and Daniel M. **Mayerhoffer**, *Excessive White Male Privilege Biases the Measurement of Intersectional Wage Discrimination*

195 Leonhard **Ipsen** and Jan **Schulz**, *The (Dis-)Equalizing Effects of Production Networks*

196 Ivan **Savin**, Philipp **Mundt** and Margherita **Bellanca**, *The paradox of climate policy diffusion*

197 Dominik **Bruckner** and Marco **Sahm**, *Party Politics: A Contest Perspective*

198 Lasare **Samartzidis**, Philipp **Mundt** and Jan **Schulz**, *Input specificity and labor's bargaining power: A production tree approach to functional income distribution*

199 Maybrit **Wächter**, Christian R. **Proaño**, and Juan Carlos **Peña**, *How Fitting is "one-size-fits-all"? Revisiting the Dynamic Effects of ECB's Interest Policy on Euro Area Countries*

200 Sarah **Mignot**, *Coevolution of stock prices and their perceived fundamental value*

201 Arne **Lauber**, Christoph **March** and Marco **Sahm**, *Round-Robin Tournaments in the Lab: Lottery Contests vs. All-Pay Auctions*

202 Stefanie Y. **Schmitt**, *Investments in environmental quality under limited attention*

Free access to all publications at: www.uni-bamberg.de/en/economics/research/wp/