A vertically differentiated duopoly model with environmental awards

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Abstract We investigate the impact of an environmental award in a Betrand duopoly with green consumers considering a three stage game. First, the regulator designs the environmental contest. Second, firms choose their green investments and the contest winner is awarded. Third, firms compete in prices and consumption takes place. We illustrate that the award not only incentivizes green investments and thus reduces the environmental externalities. As consumers perceive the product of the awarded firm to be of superior quality, it also gives rise to vertical product differentiation. This induces market power and thus anticompetitive effects: rents shift from consumers to producers and consumer surplus may decrease.

Keywords Bertrand competition · Contests · Environmental award · Green consumer · Product differentiation

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1. Introduction

Traditional responses to climate change, as emission trading or taxation, are partly reaching their limits. The IPCC Sixth Assessment Report warns that global net carbon emissions need to decline by 45% of 2010 levels by 2030 to reach net zero around 2050 (Ara Begum et al., 2022). The OECD (2017) underlines that promoting policy packages to mobilize investment in carbon-neutral infrastructure and technologies is one of the key steps to combat global warming. Therefore, this paper suggests an innovative incentive and internalization measure: environmental contests.

The observable environmental changes also affect consumers' purchasing bahavior. The rising consumer awareness reflects this movement. We see that a growing fraction of consumers prefers to buy products from firms using environmental-friendly production technologies and accepts to pay a higher price for goods perceived as clean (Berger, 2019; European Commission, 2014; Growth from Knowledge (GfK), 2022). This trend opens new possibilities for firms when investing in green technologies, as firms can use this investment as a way to differentiate their product from the ones of their competitors. To make their sustainable performance visible for the public, firms can participate in environmental contests and get the chance to win an environmental award. By publishing the award, value and reputation of their product increase. The UN Global Climate Action Award or the German Sustainability Award, for example, use this format.

By using green investment as strategic variables, firms can differentiate and release price competition. Therefore, it is reasonable to analyze environmental quality competition using product quality models. To do so we use a vertical product differentiation model where two firms offer a good that is characterized by its environmental quality. Vertical preferences imply that consumers prefer the product of higher environmental quality and that they are willing to pay a higher price to acquire it. Most vertical differentiation models evolve in two stages, where firms first choose their product quality and then market prices. To examine the effectiveness of an environmental contest within a vertically differentiated market model, we extend the usual duopoly model by adding one further stage: Firstly, the social planner sets the level of the environmental award. Secondly, firms implicitly determine their product quality by choosing green investment levels and thus determine their chance of winning the contest. We assume that firm's green investment internalizes part of the externality. Thirdly, firms compete in prices.

To create an incentive scheme for green investment we develop a theoretical model based on contest theory (for an overview see Konrad (2009)). The most related studies contributing to the public goods literature by using a contest approach are Morgan (2000), Giebe and Schweinzer (2014), Kolmar and Sisak (2014) and Bos et al. (2016). Morgan (2000) investigates a lottery mechanism where revenues from ticket sales are used to finance public goods. His lottery design leads to efficient public goods provision as the lottery prize increases. Giebe and Schweinzer (2014) combine an ad-valorem consumption tax with a lottery to correct for distortions in private consumption due to the tax. Kolmar and Sisak (2014) discuss requirements for a multiple-prize contest to ensure the efficient public goods provision with heterogeneous producers. Bos et al. (2016) implement a contest to reduce harmful emissions to the socially efficient level without sacrificing productive efficiency. These studies underline the welfare-enhancing effect of contests. In contrast, our approach reveals that using a contest may also have anti-competitive effects which have not been taken into account in previous research. To analyze these counteracting effects we link knowledge from environmental and industrial economics with contest theory. The current study provides insights how to incentivize firms to adopt green technologies and which welfare effects need to be accounted for.

To address the concerns just raised above, we consider a Bertrand duopoly game with three stages. In the first stage, the regulator fixes the level of the environmental award. In the second stage, firms decide simultaneously how much to invest in environmental-friendly technologies, and the environmental prize is awarded. Due to the environmental award, consumers see the winner's product as being of higher environmental quality than that of the loser. In the third stage, firms choose simultaneously which market prices to set. Thereafter, consumers make their consumption choices.

Our approach contributes to two strands of the literature: industrial economics and contest theory. The industrial economics literature dealing with eco-labels seems to be one of the most closely related literature to our environmental award approach. These contributions examine optimal policies and corporate strategies for eco-labeling when a labeled product competes against an unlabeled one.[1] Bottega et al. (2009) investigate firms with different cost structures of producing quality. The certifying organization can adopt a policy to maximize total demand for the labeled product or to maximize global quality of the market. The authors show that not necessarily the most efficient[2] firm will label its product and that the label quality depends on the certifiers policy. They find that inefficiencies may occur due to strategic behaviour of the most efficient firms. Ibanez and Grolleau (2008) underline that a green firm only invests in a label if it is sufficiently costly for the polluting firm to invest in the label compared to its green competitor. At the same time negative externality from polluting is reduced. Amacher et al. (2004) consider the production technology to be endogenous. To provide high product quality,

[1] For an overview see e.g. Bonroy and Constantatos (2015) and Yokessa and Marette (2019).

[2] Efficient meaning the firm with the lowest cost of producing quality.

fixed and variable costs are affected. The fixed component is interpreted as audit cost that the firm has to pay to receive the label. The relative cost structure determines firms' investment in green technologies and the quality level of the label. Brécard (2017) models competition among three products, namely an unlabeled good and two labeled goods, one with medium and one with high environmental quality. This paper shows that consumers' misperception due to imperfect information can harm the firm offering the greenest product, as consumers see both eco-labels as a sign of the same environmental quality and so each label as a unique product. However, consumer misperception is not always detrimental to social welfare. In particular, the objectives of the certifier and the nature of consumer information matter. Ghazzai and Lahmandi-Ayed (2021) focus on the informational content of ecolabels. They compare the impact of a partial information label and a complete information label on social welfare where the partial information label requires some minimal labeling criteria to be satisfied and the complete information label to indicate the exact environmental performance of the firm. Their analysis shows that from a social welfare perspective the partial information ecolabel is preferred, but not from the perspective of the green firm. Levels of marginal cost of quality and environmental sensitivity to quality determine which label to prefer from a brown firm's, from consumers' and from an envrionmental perspective.

Summing up, current eco-labeling literature stresses that on the producer side cost structures and abatement technologies and on the consumer side environmental consciousness, information structures and altruism play a crucial role in achieving an efficient outcome. The advantage of our contest approach compared to eco-labeling is that the contest encourages higher investment. This is due to the fact that under labeling only a certain investment threshold has to be reached to hold the label. In contrast, under the contest design, firms should invest as much as to equate the marginal costs and benefits of increasing their winning probability to be awarded.

With the second strand of the literature, contest theory, we try to expand existing policy incentive schemes. The game theoretic approach has the benefit of incorporating negotiations between different entities when deciding about production and technology investment (Zhou and Wang, 2016). Contest theory is rarely applied in environmental context so far. Up to our knowledge there are MacKenzie et al. (2009) who developed a mechanism that distributes emission permits to firms based on a rank-order contest and Bos et al. (2016) who designed a contest that balances two dimensions of inefficiency, namely overproduction of harmful emissions and underprovision of emission abatement efforts. Heyes (1997) and Liston-Heyes (2001) among others use a political contest approach to model an environmental regulation process while accounting for lobbying activities.

The focus of this paper will be on the effects that introducing an environmental contest has on consumer surplus and on social welfare. Here, two opposing trends can be identified: Firms' green investment internalizes part of the environmental externality while product differentiation confers market power on firms. This raises the following questions: Is the positive welfare effect due to reduced externality dominant or the negative welfare effect due to increased pricing power for firms? Which implications do distributional effects between consumers and producers have? Which role do the level of investment cost and environmental externality play?

Our analysis shows that in a covered market where each consumer chooses one unit of one of the products in the market, the positive welfare effect from emission abatement exceeds the negative effect from an increase in firms' market power. But we observe that given high green technology costs relative to low environmental damage, the environmental contest may decrease consumer welfare. Extending the model to an uncovered market, we observe additional quantity effects, as the assumption of unit demand is released: Consumers can buy one unit of the products on the market or none. This reduced demand leads to lower production and in turn to lower environmental damage. At the same time lower demand decreases consumer surplus as utility levels decline. Similiar to the covered market model, particularly under high marginal investment costs and low marginal environmental damage, anti-competitive effects can lead to a loss in consumer surplus. Thus, there are parameter combinations where consumer surplus may decrease under an environmental contest.

The purpose of our paper is to design an environmental contest within a vertically differentiated market model where we pay particular attention to green investment incentives. Section 2 analyzes a covered market model and section 3 an uncovered one. Section 4 concludes. To solve the model we use backward induction. To begin we first describe firms' incentives to participate in the contest and then characterize the consumer side.

2. Model: covered market

We examine a model of vertical product differentiation as developed by Mussa and Rosen (1978), Shaked and Sutton (1982) and Motta (1993). Consumers are aware of the need to protect the environment. So they regard lower levels of pollution in production and consumption as a positive environmental attribute of the product. This consciousness increases the perceived product quality taking all other characteristics of the goods being equal. If consumers have the choice between goods of different environmental qualities offered for the same price, all consumers prefer the most environmental-friendly good (green consumers), but they differ in their willingness to pay for environmental quality. So, goods can be differentiated according to their perceived environmental quality.

Our model represents a Bertrand duopoly where firms are homogeneous in absence of the contest. Both firms produce goods of environmental quality μ_l that can be interpreted as the minimum standard quality. In this case competition will ensure that prices are equal to marginal cost of production. For simplicity, marginal cost of production are assumed to be zero. Gross profits not accounting for fixed or sunk cost are zero. On the other hand, when products get differentiated in the eyes of consumers with the help of an environmental award (without loss of generality $\mu_w \geq \mu_l$), firms enjoy some degree of market power and will make positive profits. It is in the firms' mutual interest that only one of them gains the award. Thus, identical quality levels are never optimal. Firms prefer to differentiate from their competitor.[3]

In our model we consider a continuum of consumers indexed by θ. The parameter θ represents consumers' marginal valuation for environmental quality. θ is uniformely distributed over $[0, 1]$. To begin with, we consider a covered market, implying that each consumer buys one unit of a good with environmental quality μ_i where $i \in \{l, w\}$. Subscript l denotes the standard quality of the good produced by the firm losing the contest and subscript w the perceived quality of the good produced by the firm winning the contest. Without the environmental award, consumers perceive the goods as two goods of equal quality. They would expect both goods being of standard quality μ_l. However, the environmental contest increases the perceived quality of the good produced by the winning firm to μ_w, where $\mu_w \geq \mu_l$. Thus, consumers expect the quality of the good with the award to be of quality μ_w and the one of the good without the award to be of quality μ_l.

[3] Without the contest deciding about which firm is awarded and which firm profits from a higher perceived product quality, the sub-game would have two pure symmetric Nash-equilibria. Each of the firms wants to be the one offering μ_w. This challenge can be referred to as the "battle of the sexes" game (Bansal, 2008; Ibanez and Grolleau, 2008). The introduction of a contest that assignes which firm is awarded can solve this coordination problem.

The utility function for consumer j with preference θ follows the function described by Mussa and Rosen (1978): $U(y, \theta_j, \mu_i) = y + \theta_j \mu_i$ where y is a composite good and $\theta_j \mu_i$ denotes consumer j's basic willingness to pay for quality μ_i with $i \in \{l, w\}$. Consumers choose their optimal quality by maximizing their utility subject to the budget constraint $y + p_i \leq r$ for $i \in \{l, w\}$. r represents income and is assumed to be large enough to ensure that the market is covered. p_l and p_w denote the market prices for the awarded and the non-awarded good, respectively. r and p_i are measured in terms of y. Therefore, the net utility for consumer j with preference θ_j when consuming one unit of the good with property μ_i is given by the utility function:

$$u(p_i, \mu_i, \theta_j) = r + \theta_j \mu_i - p_i \qquad \text{for } i \in \{l, w\} \tag{1}$$

Consumer j prefers the awarded good to the non-awarded good whenever: $u(p_w, \mu_w, \theta_j) \geq u(p_l, \mu_l, \theta_j)$. The marginal consumer being indifferent between the two quality levels is thus defined by:

$$\tilde{\theta} = \frac{p_w - p_l}{\mu_w - \mu_l}$$

The two firms l and w share the market, where the awarded firm faces a demand of $D_w = 1 - \tilde{\theta}$ and the non-awarded firm of $D_l = \tilde{\theta}$. For simplicity we assume zero marginal cost of production.

2.1 Stage 3: Price game

In the third stage of the game firms simultaneously fix market prices taking technology investments and the level of the environmental award as given. At this stage costs of investment have already been sunk:

$$\max_{p_i} \quad \pi_i = p_i \cdot D_i \qquad \text{for } i \in \{l, w\}$$

Solving the FOCs simultaneously results in market prices of

$$p_w = \frac{2}{3}(\mu_w - \mu_l) \qquad \text{and} \qquad p_l = \frac{1}{3}(\mu_w - \mu_l). \tag{2}$$

It can be seen that the market prices are increasing in the perceived difference in environmental qualities and that the firm winning the contest charges a higher price than the firm losing the contest. The prices lead to market demands of $D_w = \frac{2}{3}$, $D_l = \frac{1}{3}$ and total demand of $D = D_w + D_l = 1$.

2.2 Stage 2: Investment game

Anticipating these market prices, the firms decide in the second stage how much to invest in environmental-friendly technologies. The investment levels are denoted by x_1 and x_2.[4] In the investment stage, each firm incurs cost of investment, cx_1 and cx_2 respectively. Constant unit production costs are incurred. Without loss of generality, we take these costs to be zero (cf. Motta, 1993).

In the investment stage, firms maximize their expected profits from winning and losing the contest while taking the investment cost into account. Therefore, the potential profits from winning and losing the contest are weighted with the respective probability. For our incentive mechanism we assume that the probability of winning the environmental award is derived according to a Tullock contest success function, meaning that a player's probability of winning the contest is a function of that player's effort (investment) over the sum of efforts (aggregate investment) (Skaperdas, 1996). Thus, a firm can increase its probability of winning the award (ceteris paribus) by increasing investment, but only wins with certainty when the outcome is uncontested. This lottery or imperfectly discriminating auction design is often used to model a noisy decision-making context where the player exerting the highest effort is more likely to succeed, but not necesssarily succeeeds. Firms' optimization problems then are:

$$\begin{aligned}
\underset{x_1}{max} \quad E[\pi_1] &= p_w \cdot D_w \cdot \frac{x_1}{x_1 + x_2} + p_l \cdot D_l \cdot \frac{x_2}{x_1 + x_2} - cx_1 \\
\underset{x_2}{max} \quad E[\pi_2] &= p_w \cdot D_w \cdot \frac{x_2}{x_1 + x_2} + p_l \cdot D_l \cdot \frac{x_1}{x_1 + x_2} - cx_2
\end{aligned}$$

This mechanism motivates firms to invest in green technologies. Firms' optimal investment levels need to satisfy the following condition:

$$x_1 = x_2 = \frac{\mu_w - \mu_l}{12c} \tag{3}$$

Up to this stage of the game (stages one and two) the firms are symmetric in their decision-making. Now the contest offers firms the possibility to differentiate themselves and to enjoy some degree of market power. In absence of the contest, the symmetric firms would end up in a homogeneous Bertrand duopoly: Both firms would be active sharing equally the market, prices would be cut to marginal cost of production and no positive profits would be realized.

Equation (3) shows that an increase in the perceived quality difference leads to an increase in investment. This stresses the positive investment incentive provided by the contest.

[4]In this stage of the game the firms are labelled $i \in \{1, 2\}$. This is the case as it is still undecided which firm will win and which will lose the contest.

Additionally, when deciding about their investment level, firms face two opposing effects: An increase in the investment level leads to an increase in the winning probability and at the same time to an increase in cost.[5]

2.3 Stage 1: Level of the environmental award

In the first stage the social planner defines the parameter of the contest, namely the perceived quality of the awarded good. To set μ_w the regulator takes the sum of consumer surplus, firms' profits and the social benefit of environmental quality into account.[6] We assume a paternalistic regulator. This implies that the decision about the level of the environmental award is based on the real environmental qualities of the goods (μ_l, μ_l) and not on the perceived ones (μ_l, μ_w) (Salanié and Treich, 2009).[7] Under the latter approach, a populist regulator would have one further incentive to increase μ_w in order to increase consumer surplus (in addition to incentivizing green investment). To preclude this additional motivation and to focus on how to incentivize green investment, we concentrate on the assumption of a paternalistic regulator. Then social welfare is described by:

$$\begin{aligned} \underset{\mu_w}{max} \quad W = & \int_0^{\tilde{\theta}} (r + \theta\mu_l - p_l)\ d\theta + \int_{\tilde{\theta}}^1 (r + \theta\mu_l - p_w)\ d\theta + p_l \cdot D_l + p_w \cdot D_w - c \cdot (x_1 + x_2) \\ & - \delta \cdot (E - x_1 - x_2)^2 \\ = & \ r + \frac{6c^2 \cdot (4\mu_l - \mu_w - 6\delta) - \delta \cdot (\mu_w - \mu_l)^2 + 12c\delta \cdot (\mu_w - \mu_l)}{36c^2} \end{aligned} \tag{4}$$

The term $\delta \cdot (E - x_1 - x_2)^2$ represents the environmental externality, where δ captures the marginal environmental damage. δ measures the effect of a marginal increase in environmental degradation monetarily. We assume that the sum of green investment is used to internalize environmental damage, so that total investment reduces environmental degradation. Consumers and firms do not account for this positive effect, only the regulator does when maximizing social welfare in the first stage of the game. Further, one unit of output generates one unit of emissions. So total emissions without climate action $E = D = 1$ are reduced by the sum of green investment. We assume that the environmental externality is strictly increasing and convex in total environmental damage.

[5] Due to the nature of the environmental externality described in stage one (cf. equation (4)), the sum of investment levels must not exceed the value of total output, where $D = D_w + D_l$. Therefore, marginal cost of investment c need to fulfil the following requirement: $c \geq \frac{\mu_w - \mu_l}{6}$.

[6] We neglect the cost of the contest program.

[7] Salanié and Treich (2009), studying the consumer misperception of eco-labels, distinguish between a paternalistic regulator who considers real environmental qualities and a populist regulator who considers perceived environmental qualities to maximize consumer surplus.

Solving the first-oder condition with respect to μ_w gives the optimal level of the environmental award being equal to

$$\mu_w^* = \frac{6c\delta + \delta\mu_l - 3c^2}{\delta}. \tag{5}$$

For $0 < c < 2\delta$,[8] $\delta > 0$, $\mu_l > 0$, we see that μ_w^* reacts positively to a marginal increase in the standard environmental quality μ_l and positively to an increase in marginal environmental damage δ. For $0 < c < \delta$ the optimal award level increases in c and for $\delta < c < 2\delta$ decreases in c. In equilibrium, market prices, demand, investment, rents and welfare are characterized by the following conditions for $0 < c < 2\delta$:[9]

$$\begin{aligned}
p_w^* &= 2c \cdot (2 - \frac{c}{\delta}) = 2 \cdot p_l^* \qquad \text{and} \qquad p_l^* = c \cdot (2 - \frac{c}{\delta}) \\
D_w^* &= \frac{2}{3} = 2 \cdot D_l^* \qquad \text{and} \qquad D_l^* = \frac{1}{3} \\
x_1^* &= x_2^* = \frac{1}{2} - \frac{c}{4\delta} \\
CS^* &= \int_0^{\tilde{\theta}} (r + \theta\mu_l - p_l^*)\ d\theta + \int_{\tilde{\theta}}^1 (r + \theta\mu_l - p_w^*)\ d\theta - \delta(1 - x_1^* - x_2^*)^2 \\
&= r + \frac{1}{2}\mu_l + \frac{17c^2}{12d} - \frac{10}{3}c \\
PS^* &= p_l^* \cdot D_l^* + p_w^* \cdot D_w^* - c \cdot (x_1^* + x_2^*) = \frac{7c(2\delta - c)}{6\delta} \\
W^* &= r + \frac{1}{4} \cdot \left(\frac{c^2}{\delta} + 2\mu_l - 4c \right)
\end{aligned}$$

Notice that, while both firms make the same investments, the winner of the award sets a higher price, has a higher market share, and thus makes more profits.

2.4 Incidence

In the following we analyze how the environmental contest affects the distribution of rents. To do so we compare the contest outcome with the one without climate action (Laisser-faire equilibrium). The Laisser-faire equilibrium results in homogeneous goods, in prices equal to marginal production cost of zero and in zero abatement of the environmental damage. Breaking down the effects of introducing an environmental contest in changes

[8] This condition is derived from the condition for the sum of optimal green investment in the investment stage where $x_1 + x_2 < D = 1 \leftrightarrow \frac{\mu_w - \mu_l}{6c} < 1$.

[9] Consumer surplus is determined by the utility consumers derive from consumption and substracting the harmful effect of environmental pollution on consumers.

in consumer and producer surplus yields:

$$\begin{aligned} \Delta CS = CS - CS^{LF} &= \delta + \frac{17c^2}{12\delta} - \frac{10}{3}c\,, \quad \text{where} \\ \Delta CS \quad > \quad 0 \quad &\text{for} \quad \delta > 0,\ 0 < c < \frac{6}{17}\delta \quad \text{and} \\ \Delta CS \quad < \quad 0 \quad &\text{for} \quad \delta > 0,\ \frac{6}{17}\delta < c < 2\delta. \end{aligned} \tag{6}$$

$$\Delta PS = PS - PS^{LF} = \frac{7c(2\delta - c)}{6\delta} \quad > \quad 0 \quad \text{for} \quad 0 < c < 2\delta \tag{7}$$

$$\begin{aligned} \Delta CS - \Delta PS &= \delta + \frac{31c^2}{12\delta} - \frac{17}{3}c\,, \quad \text{where} \\ \Delta CS - \Delta PS \quad > \quad 0 \quad &\text{for} \quad \delta > 0,\ 0 < c < \frac{6}{31}\delta \quad \text{and} \\ \Delta CS - \Delta PS \quad < \quad 0 \quad &\text{for} \quad \delta > 0,\ \frac{6}{31}\delta < c < \frac{6}{17}\delta. \end{aligned} \tag{8}$$

$$\Delta CS + \Delta PS = \Delta W = \frac{(c - 2\delta)^2}{4\delta} \quad > \quad 0 \quad \text{for} \quad \delta > 0,\ \frac{6}{17}\delta < c < 2\delta \tag{9}$$

Equations (6) to (9) underline that the ratio of marginal investment cost relatively to the level of marginal environmental damage plays a decisive role: First, at low marginal cost with $0 < c < \frac{6}{31}\delta$, consumers and producers benefit from introducing an environmental contest ($\Delta CS > 0$). Consumers gain from internalizing the environmental externality and producers from the obtained pricing power. Given this parameter constellation, the consumer side profits more from the contest design compared to the producer side ($\Delta CS - \Delta PS > 0$). Second, at medium marginal cost with $\frac{6}{31}\delta < c < \frac{6}{17}\delta$, the award design is still advantageous for consumers and producers ($\Delta CS > 0$). Here, the gain of rent for producers exceeds the gain of rent for consumers ($\Delta CS - \Delta PS < 0$). Third, at high marginal cost with $\frac{6}{17}\delta < c < 2\delta$, we observe that the contest mechanism results in a redistribution of rents from consumers to producers (distributive effect). The contest harms consumers ($\Delta CS < 0$), whereas producers keep benefiting, but the gain in producer surplus more than offsets the loss in consumer surplus ($\Delta CS + \Delta PS > 0$). So, we can construct parameter constellations of c and δ where implementing an environmental award decreases consumer surplus. In conclusion, the cost level determines whether implementing an environmental contest is beneficial for consumers or not.

3. Model: uncovered market

We now relax the assumption of a covered market. All other assumptions and specifications from the section before are maintained. The modification implies that each consumer consumes at most one unit of the product. The net utility of consumer j with a marginal valuation for environmental quality of θ_j buying a product of firm i with quality μ_i is then described by

$$u\left(p_i, \mu_i, \theta_j\right) = \max\left[0,\; r + \;\theta_j \mu_i - p_i\right] \qquad \text{for } i \in \{l, w\}. \tag{10}$$

In the uncovered market model we can find a consumer who devotes the whole income r for buying the composite good y while enjoying utility r if $u\left(p_w, \mu_w, \theta_j\right) < u\left(p_l, \mu_l, \theta_j\right) \leq r$. This consumer will consume neither the awarded nor the non-awarded good. Thus, not all consumers necessarily buy one unit of a good. The marginal consumer being indifferent between not buying and buying the standard quality good is decribed by $\underline{\theta} = \frac{p_l - r}{\mu_l}$ whereas the marginal consumer being indifferent between buying the standard quality good and the awarded good is characterized by $\overline{\theta} = \frac{p_w - p_l}{\mu_w - \mu_l}$. Therefore, firms' demand functions are $D_w = 1 - \overline{\theta}$ and $D_l = \overline{\theta} - \underline{\theta}$. The share of consumers not buying is $\underline{\theta}$, meaning that total demand of the products may be impacted by the policy design. If e.g., environmental policy increases the equilibrium price p_l, then ceteris paribus, more consumers do not buy any good. Consequently, environmental policy and relocation decisions can have quantity effects under this setting. This is reflected in two opposing effects: a positive welfare effect as a lower production level leads to a lower agggregate level of environmental damage and a negative welfare effect as consumer surplus declines due to lower market coverage and lower aggregate utility. As in the section before, to find the optimal level of the environmental award the three-stage game is solved by backward induction.

3.1 Stage 3: Price game

In the last stage of the game firms compete à la Bertrand. They simultaneously fix prices given green technology investment and the level of the environmental award:

$$\underset{p_i}{max} \quad \pi_i = p_i \cdot D_i \qquad \text{for } i \in \{l, w\}$$

leading to market prices of

$$p_w = 2\mu_w \cdot \frac{\mu_w - \mu_l}{4\mu_w - \mu_l} \qquad \text{and} \qquad p_l = \mu_l \cdot \frac{\mu_w - \mu_l}{4\mu_w - \mu_l}. \tag{11}$$

The market prices underline that the winning firm can charge a multiple of the price of the losing firm. The prices are an increasing function in the perceived difference in environmental product qualities. Then market demands are $D_w = \frac{2\mu_w}{4\mu_w - \mu_l}$, $D_l = \frac{\mu_w}{4\mu_w - \mu_l}$ and $D = D_w + D_l = \frac{3\mu_w}{4\mu_w - \mu_l}$.

3.2 Stage 2: Investment game

In the next stage the competitors choose the amount of environmental-friendly technology investment where the expected profits from winning and losing the contest are considered:

$$\begin{aligned} \max_{x_1} \quad & E[\pi_1] = p_w \cdot D_w \cdot \frac{x_1}{x_1 + x_2} + p_l \cdot D_l \cdot \frac{x_2}{x_1 + x_2} - cx_1 \\ \max_{x_2} \quad & E[\pi_2] = p_w \cdot D_w \cdot \frac{x_2}{x_1 + x_2} + p_l \cdot D_l \cdot \frac{x_1}{x_1 + x_2} - cx_2 \end{aligned}$$

The FOCs yield the optimality conditions for green investment:

$$x_1 = x_2 = \frac{\mu_w \cdot (\mu_w - \mu_l)}{4c \cdot (4\mu_w - \mu_l)}. \tag{12}$$

We observe that the level of investment is rising with an increase in the perceived quality difference and also with an increase in the perceived quality of the awarded good μ_w.[10]

3.3 Stage 1: Level of the environmental award

The first stage determines the level of the environmental award by maximizing social welfare assuming a paternalistic regulator:

$$\begin{aligned} \max_{\mu_w} \quad W = & \int_{\underline{\theta}}^{\overline{\theta}} (r + \theta\mu_l - p_l)\, d\theta + \int_{\overline{\theta}}^{1} (r + \theta\mu_l - p_w)\, d\theta + p_l \cdot D_l + p_w \cdot D_w - c \cdot (x_1 + x_2) \\ & - \delta \cdot (E - x_1 - x_2)^2 \\ = & \; r - \frac{\mu_w \cdot [\delta\mu_w(\mu_w - \mu_l)^2 + 12c\delta\mu_w(-\mu_w + \mu_l) + 2c^2(18\delta\mu_w + 4\mu_w^2 - 20\mu_w\mu_l + 7\mu_l^2)]}{4c^2 \cdot (-4\mu_w + \mu_l)^2} \end{aligned} \tag{13}$$

[10]Due to the characteristics of the environmental externality (cf. (13)), marginal investment cost must satisfy the following condition: $c \geq \frac{(\mu_w - \mu_l)}{6}$.

Again, one unit of output generates one unit of emissions, hence $E = D$. Building the FOC, there exist four potential candidates for the equilibrium value of the award. Using a numerical approach, the only meaningful μ_w^* is identified.[11] When substituting this equilibrium level back into (11), (12) and (13) we obtain the equilibrium values for the market prices, for green technology investment and for social welfare. Due to their length we do not provide the expressions for these equilibrium values. Instead the next section presents a numerical analysis to understand the correlations between the model parameters.

3.4 Incidence

This section assesses whether introducing a contest can be beneficial for consumers, producers and for total social welfare. Therefore, we analyze how changes in the exogeneous model parameters c, δ and μ_l influence equilibrium outcomes. To demonstrate we run a numerical analysis on consumer surplus, producer surplus and on total welfare. Table 3.1 provides a description of the respective model parameters. Numerics 1 examines the effect of the standard quality parameter on equilibrium outcomes while numerics 2 investigates the impact of marginal green investment cost and numerics 3 the impact of marginal environmental damage on equilibrium outcomes.[12]

Table 3.1: Numerical analysis

	Numerics	Fixed parameters
NUM 1	Level of standard quality μ_l	$c = 1 \quad \delta = 1 \quad r = 0$
NUM 2	Cost of green technology investment c	$\delta = 1 \quad \mu_l = 1 \quad r = 0$
NUM 3	Level of environmental externality δ	$c = 1 \quad \mu_l = 1 \quad r = 0$

To evaluate the effectiveness of implementing an environmental contest, we consider the difference in equilibrium outcomes between a policy using an environmental contest and a policy without climate action (Laisser-faire).

Firstly, figure 3.1 examines the difference in consumer surplus between an environmental contest and a laisser-faire design ($CS^* - CS^{LF}$). With increasing standard quality (parameter constellations from NUM 1), the difference in consumer surplus decreases. This is due to a decline in green investment when raising μ_l. Consequently, less environmental damage is internalized, leading to a decrease in consumer surplus under the contest design. So the difference $CS^* - CS^{LF}$ becomes more negative as CS^* declines. When

[11]Due to its length the expression for μ_w^* is not shown in the paper.

[12]The parameter constellations and graphical illustrations are in line with the model restrictions for c and $\mu_w > \mu_l$.

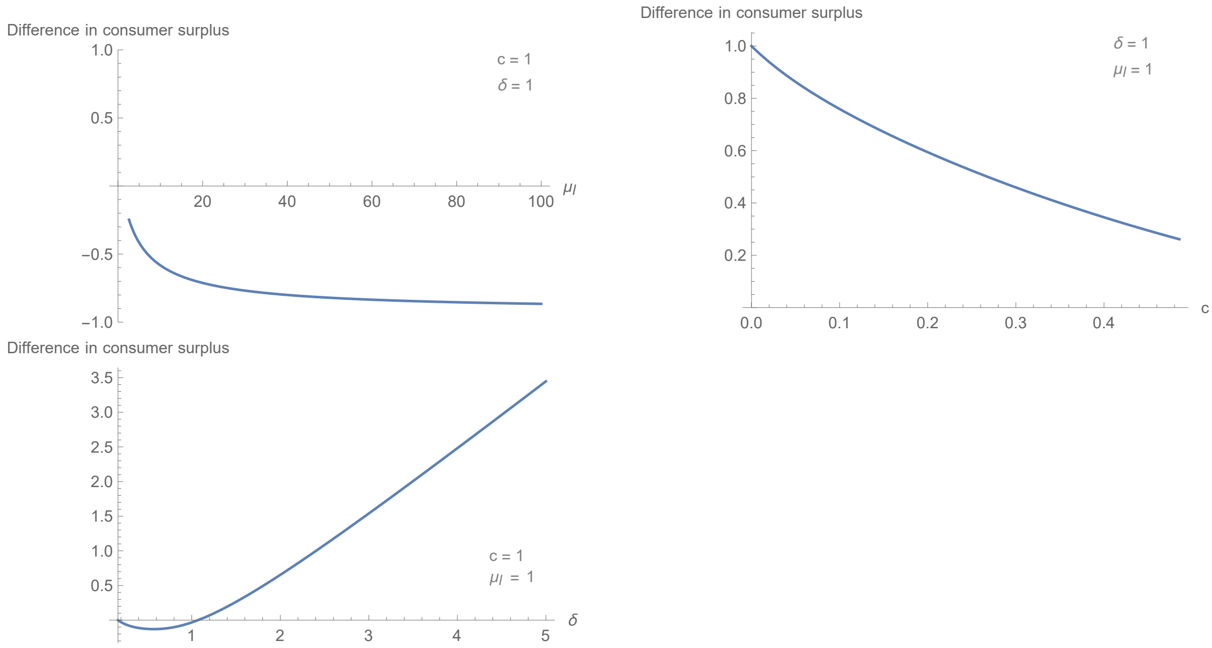

Figure 3.1: Difference in consumer surplus between a contest-designed and a laisser-faire equilibrium.

increasing marginal investment cost (NUM 2), we observe a decline in the difference in consumer surplus. This implies that the advantage of the contest mechanism vanishes as the cost for technology investment rise. With increasing marginal environmental damage (NUM 3) the difference in consumer surplus levels increases, meaning that the advantage of a contest design increases. The merit of the contest design can be attributed to compensating the environmental externality. But NUM 3 also underlines that there exist parameter constellations where implementing an environmental contest is detrimental to consumers: under high marginal green investment cost relative to low marginal environmental degradation. In this case the social planner would set $\mu_w = \mu_l$ and not use the contest.

Secondly, figure 3.2 shows that firms profit from introducing an environmental contest, as $PS^* - PS^{LF} > 0$ and strictly increasing for changes in c, d and μ_l. Due to the contest firms can exert some market power which is reflected in positive rents.

Lastly, combining effects on consumer and producer surplus, figure 3.3 examines the welfare difference of an environmental contest and a laisser-faire design $(W^* - W^{LF})$. We observe that the difference in welfare is always positive: The potentially negative effect on consumer surplus is more than offset by the increase in producer surplus. We find a redistribution of rents from consumers to producers.

To sum up: In the uncovered market model we identify four different welfare effects: Firstly, due to the perceived differentiation of products firms get pricing power which

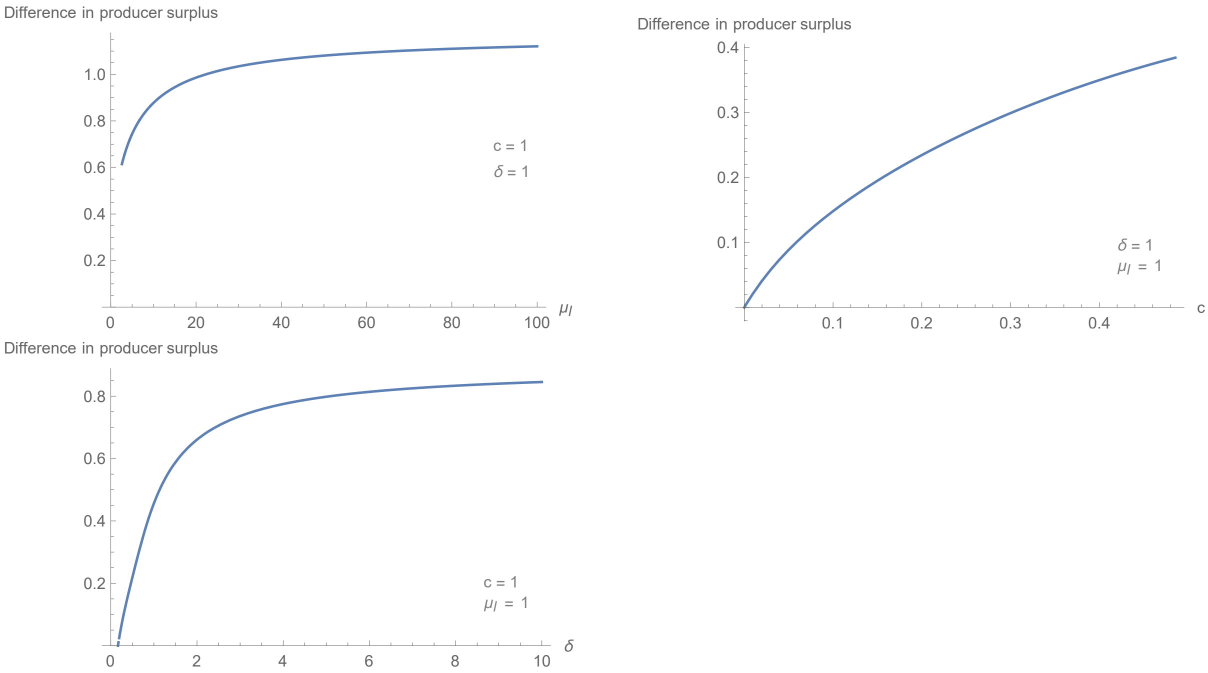

Figure 3.2: Difference in producer surplus between a contest-designed and a laisser-faire equilibrium.

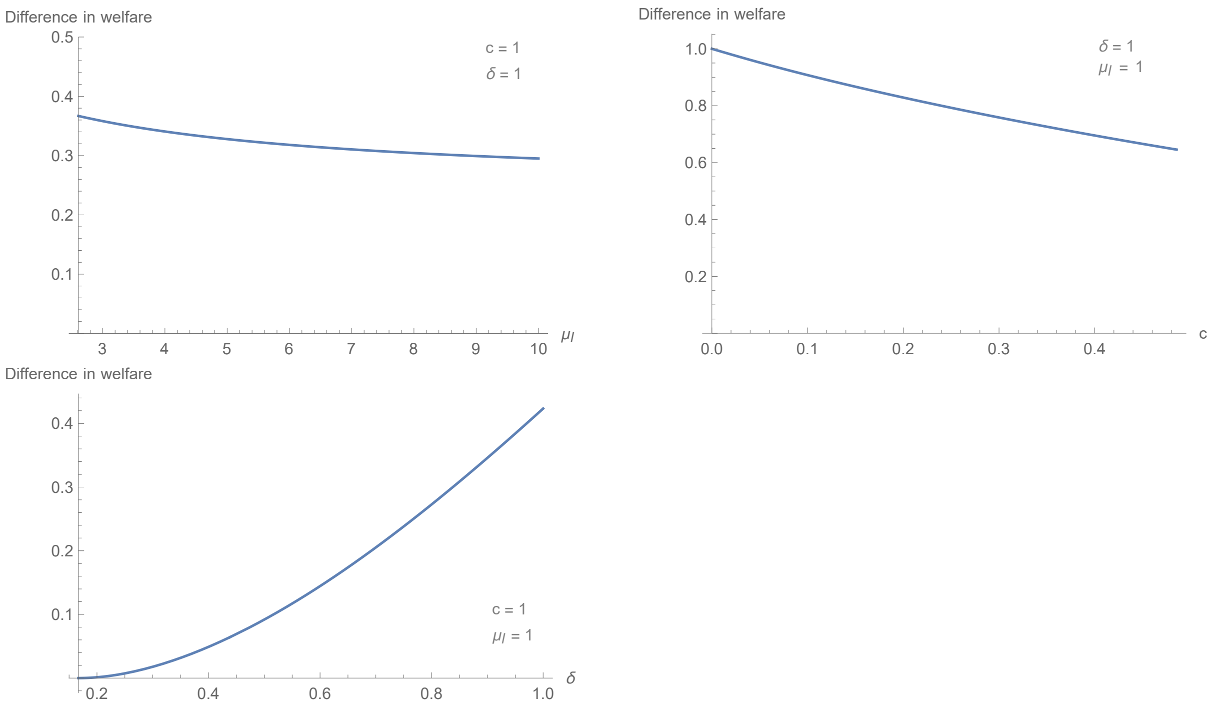

Figure 3.3: Difference in total welfare between a contest-designed and a laisser-faire equilibrium.

influences welfare negatively. Secondly, green investment contributes to limit and reduce environmental damage and consequently has a positive welfare impact. These two effects are also present in the covered market model. However, in the uncovered market model two additional effects (quantity effects) occur, as demand is no longer equal to unity: Thirdly, the externality due to emissions is reduced as a lower production level is realized, having a positive welfare effect. Fourthly, the lower market coverage leads to lower aggregate consumer utility so that consumer surplus shrinks. Considering these opposing effects, it is possible to find parameter constellations where the positive effects on consumer surplus dominate, respectively where the negative effects dominate. This implies that introducing an environmental contest is not necessarily beneficial for consumers.

4. Conclusion

In addition to the well-known policy instruments for limiting greenhouse gas emissions such as subsidies, emission trading or taxation, this paper proposes an environmental contest as a further potential instrument to control emissions. The advantage of designing an environmental contest is that firms have an incentive to take part in the contest, as gaining the award leads to product differentiation, which in turn leads to increased profits. Furthermore, firms do not have to disclose confidential, internal data to implement the mechanism. Only the documentation of a firm's green investment activities is required.

Our article provides theoretical insights whether implementing an environmental contest is beneficial for social welfare. In a covered market where every consumer purchases one unit of the good, the positive welfare effect from emission abatement outweighs the negative effect from an increase in firms' market power. In the uncovered market, additional quantity effects arise. It is not every consumer anymore who buys one unit of the good so that total demand declines compared to the covered market. Lower demand results in lower production, while lower production results in lower environmental harm. At the same time lower demand leads to lower consumer surplus as utility levels decline. In the covered as well as in the uncovered market model, we can identify parameter constellations where implementing the contest reduces consumer surplus. This is particularly the case when marginal green investment costs are high while marginal environmental damage is relatively low. Depending on the model parameters, introducing an environmental contest can harm consumers.

Furthermore, compared to a Laisser-faire outcome, a redistribution of wealth between consumers and producers takes place. Under the contest design, companies can set higher prices and generate positive profits. This is only possible at the expense of consumers, who have to buy the goods at higher prices. Thus, we observe a redistribution of rents from consumers to producers. Therefore, the legislator should also keep distributive justice in mind.

To generalize the results, it would be worthwhile to extend the model to more than two firms and allow several firms to get an award for their environmental action. But as Gabszewicz and Thisse (1980) describe only a limited number of firms can be active in a vertically differentiated quality model. Studying how dynamic structures and additional periods affect outcomes would be possible extensions. It would also be interesting to compare the welfare effects of a contest with those of an eco-label in order to derive a concrete policy recommendation.

Finally, it should be stressed that environmental contests should not be seen as a substitute for successful environmental and industrial policy, but rather as a complement and as an incentive mechanism to motivate firms to increase green investment.

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