Testing eco-modulation policy incentives: Experimental evidence on extended producer responsibility

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Abstract:

Extended producer responsibility (EPR) is an environmental policy strategy that aims to make producers responsible for the post-consumer stage of their products. Within this policy framework, different types of "eco-modulations" are discussed as alternative incentive strategies to the current basic fee by governmental institutions aiming to improve the sustainability of the eco-design of firms' products. Using a large-scale behavioral experiment with industry professionals (*N* = 377), we systematically examine, under controlled conditions, the effectiveness of different incentive strategies on product eco-design and weight, environmental outcomes, and regulator revenues, as well as the underlying psychological mechanisms driving decision-making. Our results demonstrate, for the first time in this field, that eco-modulations exert a directional effect toward more sustainable eco-designs and a reduction of environmental externalities. In contrast, the current weight-based fee mainly incentivizes producers to reduce the weight of their products. Environmental values have a strong positive effect on eco-design choices; however, EPR policies induce a crowding-out effect, particularly among female participants. Further, we show that, despite being confronted with a revenue decline, eco-modulations appear to improve the cost efficiency of EPR institutions.

Keywords:

Extended producer responsibility, eco-modulations, eco-design, policy instruments,
behavioral lab experiment

JEL Codes:

C91, D23, L51, Q58

1. Introduction

Extended producer responsibility (EPR) is a sustainability policy framework that assigns responsibility for the post-consumer stage of products and packaging to the respective producers (Gui *et al.*, 2016).[1] Producers pay a fee to producer responsibility organizations (PROs), which manage the collection and treatment of waste on behalf of their member producers. The objective is to reduce end-of-life (EoL) costs by enhancing the eco-design of products.

To increase incentives for eco-design, "eco-modulations" are being discussed among academics and policymakers (Pruess and Garrett, 2025; Mayanti and Helo, 2024; Mallick *et al.*, 2024; Lifset *et al.*, 2023; Laubinger *et al.*, 2023; Corsini and Frey, 2023; Pruess, 2023; Laubinger *et al.*, 2021; Sachdeva *et al.*, 2021; Micheaux and Aggeri, 2021; Hogg *et al.*, 2020; Watkins and Gionfra, 2020; Leal Filho *et al.*, 2019; Gui *et al.*, 2018). Currently, eco-modulation measures are primarily conceived in three distinct forms: (1) bonus schemes and (2) penalty schemes, which financially reward or punish producers based on the extent to which their products meet defined eco-design standards; and (3) a more granular differentiation of product categories to better reflect environmental performance.

Although eco-modulation has been introduced in some countries, systematic data on its outcomes remain scarce, despite such data being important for effective policy evaluation. Lifset *et al.* (2023) highlight that a deeper understanding is needed of how producers respond to incentives arising from increased fee granularity and the implementation of bonuses and penalties—an issue that is unlikely to be resolved unless data become more widely accessible. It also remains unclear whether the introduction of eco-modulation can result in a cost-covering and operationally robust system for the PROs (Mallick *et al.*, 2024; Sachdeva *et al.*, 2021; Micheaux and Aggeri, 2021; Hogg *et al.*, 2020).

This paper provides the first causal empirical evidence on the effects of incentives induced by different forms of EPR/eco-modulation policy, assessed from an eco-design, environmental, and PRO perspective. Through a large-scale behavioral experiment in the laboratory involving industry professionals, we address the need for data on the effects of EPR policy modulation. Derived from this, the following two research questions are formulated:

(1) To what extent are different types of EPR/eco-modulation schemes effective in incentivizing producers to enhance the eco-design of their products and reduce EoL costs?

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[1] For brevity, the term "products" refers hereafter to both products and packaging subject to EPR, unless otherwise specified.

(2) To what extent can EPR/eco-modulation schemes provide an efficient system for PROs to internalize EoL costs?

Motivated by the existing data gap, this study responds to the research agenda outlined by Lifset *et al.* (2023, p. 198) to address the challenge of effective incentives for eco-design:

> We see the need for five key components of policy if eco-modulation is to address the challenges described in this article: (1) more and better data collection, (2) incorporation of LCA [life cycle assessments] into definition of objectives and policy evaluation, (3) prioritization of harmonization of components of eco-modulation, especially criteria and fee structures, (4) ex post evaluation of EPR and eco-modulation, and (5) in light of the lack of experience, data, and policy evaluation, treating eco-modulation as an experiment.

To the best of our knowledge, lab experimental methods have not yet been applied in the context of eco-modulation and EPR, despite their potential to contribute to the domains outlined in Lifset *et al.*'s (2023) points (1) to (5): Regarding (1), the experimental method allows for the generation of empirical data on producers' eco-design choices in response to eco-modulation, in contrast to the notoriously difficult process of data collection in real-world field experiment settings. With regard to (2), although LCA cannot be conducted within laboratory experiments, the fee structure of eco-modulation is aligned with estimated EoL costs, reflecting the degree of sustainability of specific product designs. In our experiment, EoL costs are operationalized through the purchase of actual CO_2 certificates linked to participants' product design choices. Concerning (3), the issue is that producers face varying configurations of EPR fee schemes across different markets, which weakens the incentives for implementing eco-design changes. Since our results are independent of specific local cultural, economic, and legal contexts, they can therefore provide a robust empirical basis to inform the harmonization of eco-modulation fee schemes (e.g., across Europe).

In reference to (4), we are able to conduct an *ex post* policy evaluation and assess the impact of eco-modulation using data generated during the experiment. The controlled conditions of lab experiments allow us to identify clear cause-and-effect relationships (Falk and Heckman, 2009). This avoids a common problem of *ex post* EPR studies, as formulated by Pruess and Garrett (2025): the frequent misattribution of causality due to the lack of clearly defined treatment and control groups in the study design. In addition, the experimental method enables the identification of underlying psychological mechanisms and value preferences that drive producers' decision-making, allowing for the development of policy measures that are better tailored to how producers are likely to behave in practice. Furthermore, our experimental approach aligns most directly with the call articulated in Lifset *et al.*'s (2023) point (5).

Our results reveal that eco-modulations exert a directional effect toward more sustainable eco-designs and a reduction of environmental externalities. In contrast, the current weight-based fee mainly incentivizes producers to reduce the weight of their products. Environmental values exert a strong positive influence on eco-design choices. However, EPR policies lead to a crowding-out effect, particularly among female participants. The overall positive impact of eco-modulation nonetheless counterbalances this effect. Further, we show that, despite being confronted with a decline in revenue, eco-modulations appear to improve the cost efficiency of EPR institutions in internalizing EoL costs.

The structure of this paper is as follows: Section 2 provides an overview of the current EPR system, the dominant weight-based fee structure, the design of eco-modulation schemes, and the role of, and challenges faced by, PROs. Section 3 presents how these conditions are operationalized in the experimental design, including the five treatments, and provides a description of the sample of industrial professionals as well as the identification of their value preferences. Based on this design and insights from the literature, we develop hypotheses regarding the expected outcomes. Section 4 reports the results, which are then critically discussed in Section 5 in light of the research questions, as well as with respect to advantages and limitations of the applied experimental method.

2. Theoretical background

2.1 The EPR system

EPR was introduced in the European Union in the early 1990s, and has since been adopted in other regions of the world. The EU Waste Framework Directive (WFD) defines EPR as "a set of measures taken by Member States to ensure that producers of products bear financial, or financial and organisational responsibility for the management of the waste stage of a product's life cycle" (European Parliament, 2018). From a normative perspective, EPR embodies the polluter-pays principle by shifting responsibility for the EoL costs of products from taxpayers to producers (Sachdeva *et al.*, 2021).

According to the OECD (2016), one of the main upstream objectives of EPR is to incentivize producers to design their products in ways that reduce negative environmental impact. It is envisioned that producers will invest in a “design for the environment” approach, also commonly referred to as eco-design. This entails designing products that are (partially) made from recycled materials and feature a high degree of recyclability (OECD, 2016; Gui *et al.*, 2018).

Within collective EPR systems, PROs play a pivotal role as the main entities through which producers fulfill their EPR obligations.[2] Producers that place products on the market are required to contract with a PRO, which organizes the collection and treatment of waste on behalf of its member producers in exchange for a fee. PROs streamline the administration of data and funding while achieving economies of scale in waste collection and processing that individual producers are unlikely to attain on their own (Lifset *et al.*, 2023; Gui *et al.*, 2018). PROs operate at the national level and, depending on national regulations, have varying degrees of freedom in setting the fee structure.

2.2 The currently prevalent fee structure and its environmental consequences

In most EPR schemes, fee calculations are based on the product’s material weight (in kilograms) and the category under which it is classified (Gui *et al.*, 2016). Fee categories may be broadly defined, distinguishing, for example, between plastic and glass packaging. Alternatively, they can be more narrowly specified, differentiating between various types of plastics or glass used in packaging. This so-called basic fee scheme provides no financial policy incentive for producers to improve eco-design: A producer that invests in improving the recyclability of its products will not, *ceteris paribus*, benefit from a lower fee paid to a PRO (Lifset *et al.*, 2023). Rather, it reflects a decoupling between the environmental characteristics of the product and the associated fee.

While EPR has been successful in providing necessary funding for municipal waste recycling and in increasing collection rates due to strict targets (Gendell and Stoner, 2022), it remains unclear as to whether the introduction of EPR has had a significant impact on improving eco-design. In addition, its effectiveness in this regard is considered limited due to a lack of incentives within the fee structure (Lifset *et al.*, 2023; Laubinger *et al.*, 2023; Joltreau, 2022; Sachdeva *et al.*, 2021; Røine and Lee, 2006). According to the OECD, the impact of EPR on eco-design is considered to be limited and particularly difficult to distinguish from design changes driven by other factors, such as material and production costs, consumer demand, stakeholder pressure, and legal requirements (OECD, 2016).

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[2] In individual EPR systems, producers themselves are responsible for the waste management of their products (see Pouikli, 2020).

Moreover, by making product weight the main criterion for fee calculation, EPR schemes create incentives for producers to design lighter products (Kripalani *et al.*, 2025). It can be assumed that the product weight reductions observed in recent years are, at least in part, attributable to the influence of EPR incentives, although clear causal relationships cannot be determined (Laubinger *et al.*, 2021; OECD, 2016). As an exception, Joltreau (2022) examined the impact of EPR systems on packaging weight in 25 European countries between 1998 and 2015, and found that EPR incentives had a small but statistically significant effect on reducing packaging waste.

From an environmental standpoint, the consequences of making products more lightweight appear to be ambivalent. Reducing product weight has a positive first-order effect, such as decreasing the consumption of natural resources and the volume of waste sent to landfills. It can also lead to energy savings and reduced transport-related pollution (Meng *et al.*, 2024; Han *et al.*, 2020; Shi and Min, 2013). What may appear to be an improvement in environmental performance can entail disadvantages in terms of recyclability. Lightweight products and packaging may hinder reuse and high-quality recycling due to limited durability, poor sortability, and material complexity (Sachdeva *et al.*, 2021; Leal Filho *et al.*, 2019; Zero Waste Europe, 2017). In contrast, sturdy and durable designs may offer better potential for closing material loops within a circular economy (Maitre-Ekern, 2021; Alev *et al.*, 2020).

2.3 The introduction of eco-modulations

Eco-modulations represent a modification and differentiation of the prevalent EPR fee structure. They aim to make products with low EoL costs less expensive, and those with high EoL costs more costly, for producers. Policymakers in various countries are considering how to design and implement eco-modulation. It is plausible that producers will alter their product designs in response to eco-modulation, depending on the details of eco-modulation schemes in EPR systems (Lifset *et al.*, 2023).

The revised WFD encourages Member States to apply eco-modulation in their EPR schemes (European Parliament, 2018). France was one of the first countries in Europe to implement an eco-modulation system, and many other countries have since adopted eco-modulation for a range of products (Mallick *et al.*, 2024). Nevertheless, according to a report by the European Commission, the general lack of information on the effectiveness of existing eco-modulation initiatives and their policy evaluations suggests that eco-modulation should be approached as a series of experiments (Hogg *et al.*, 2020).

Typically, eco-modulations follow three main approaches (Mallick *et al.*, 2024; Lifset *et al.*, 2023; Sachdeva *et al.*, 2021; Laubinger *et al.*, 2021; OECD, 2016): (1) bonus schemes, (2) penalty schemes, and (3) increased granularity schemes. In bonus schemes, which center on a basic fee per unit, a bonus is granted if a defined eco-design criterion is met. If the criterion is not met, the producer pays the basic fee. Penalty schemes operate similarly, but in a reverse manner: On the basis of a basic fee per unit, a penalty is imposed if a defined criterion is not met. If the criterion is met, the producer pays the basic fee. The criteria are used to link bonuses or penalties to the product's eco-design, and can target various objectives. These may include recyclability, the reduction of hazardous or problematic substances, the use of recycled content or sustainably sourced renewable resources, as well as characteristics that support longer product lifespans, such as durability, reusability, and repairability (Mallick *et al.*, 2024). Bonuses and penalties can be applied either as an absolute amount or as a percentage of the basic fee (Lifset *et al.*, 2023). The size of eco-modulation varies across EPR systems. While many countries apply relatively modest differentiation (e.g., ±5–30%), some, such as France and Portugal, have introduced bonuses and penalties of up to 100%, effectively doubling or halving the basic fee (Sachdeva *et al.*, 2021; Laubinger *et al.*, 2021).

The granularity approach involves the narrowing and differentiation of product categories. Product category families are divided into sub-categories, with each sub-category being assigned a specific fee level. For example, within the broader category of plastics used in packaging, a distinction can be made between EPS (expanded polystyrene), HDPE (high-density polyethylene), PET (polyethylene terephthalate), PEX (cross-linked polyethylene), PP (polypropylene), PU (polyurethane), and PVC (polyvinyl chloride), or even sub-types of these plastics (Meng *et al.*, 2024). The underlying idea is that the fee level for each sub-category reflects its corresponding EoL costs. Accordingly, sub-categories associated with higher EoL costs are subject to higher fees, while those with lower EoL costs are charged lower fees.

2.4 The producer responsibility organization perspective

PROs should set fees in an EPR system—including eco-modulation—in a way that reflects the EoL costs of products. These costs comprise both (1) the operational costs of waste management and (2) the negative externalities that are not reflected in market prices. To ensure a more objective identification of negative externalities, it is advisable to use LCA-based evaluations of environmental impacts. If the objectives set in EPR systems fully and efficiently address the underlying externalities, then passing the cost of meeting these objectives on to producers should lead to an adequate internalization of the social costs through the fees they pay (Lifset *et al.*, 2023).

From the perspective of regulatory authorities, eco-modulation might appear straightforward to implement, but this comes at the expense of the implementation burden being shifted to the PROs. The introduction of eco-modulation has raised concerns regarding the financial stability of the PROs (Mallick *et al.*, 2024; Sachdeva *et al.*, 2021; Hogg *et al.*, 2020). If a significant number of producers adopt improved eco-designs and consequently pay reduced fees, the resulting revenues of PROs are expected to decline. This may hinder PROs from adequately internalizing EoL costs and covering their operational expenses. The increased administrative costs associated with the introduction of eco-modulation may further amplify this effect (Mallick *et al.*, 2024; Micheaux and Aggeri, 2021).

Furthermore, PROs face restrictions under the WFD, which emphasizes the need for cost-efficient and lean institutional structures. Article 8a(4c) states that financial contributions (i.e., the fees levied by PROs): “do not exceed the costs that are necessary to provide waste management services in a cost-efficient way. Such costs shall be established in a transparent way between the actors concerned” (European Parliament, 2018). This does not mean that each producer pays a fee that corresponds exactly to the EoL costs of their specific product. Rather, it is essential that the system as a whole, on average, recovers the actual total costs (Hogg *et al.*, 2020).

However, this provision of the WFD limits the overall revenues that a PRO may generate and also constrains the size of eco-modulation, consequently reducing the potential incentive impact for eco-design (Lifset *et al.*, 2023). These issues raise the question of whether an eco-modulation fee system constitutes an improvement over the conventional weight-based fee system, considering the concerns and regulatory constraints identified from the perspective of PROs.

3. Experimental design and research hypotheses

Our study was approved by the Ethics Committee of the Faculty of Business Administration at TU Bergakademie Freiberg (Project ID 2024-07), and pre-registered at the American Economic Association’s Registry for Randomized Controlled Trials (RCT ID: AEARCTR-0015781).

3.1 The basic experimental setup

In our experiment, participants assume the role of a company manager tasked with designing the company’s main product. Each product design involves two decisions: the eco-design level and the product weight. Eco-design levels range from 1 (lowest sustainability) to 3 (highest

	Weight		
Eco-design	**1 kg**	**2 kg**	**3 kg**
1	A	B	C
2	D	E	F
3	G	H	I

Figure 1: Product designs A-I

Notes: This figure illustrates the nine possible product designs (A–I) resulting from the combination of eco-design level and product weight. Eco-design levels (left y-axis) range from 1 (least sustainable) to 3 (most sustainable), while product weight (top x-axis) ranges from 1 kg (lightest) to 3 kg (heaviest).

sustainability). Weight levels also range from 1 (1 kg, lightest) to 3 (3 kg, heaviest). The combination of these levels results in nine unique product designs labelled A to I (see Figure 1). For example, product H has an eco-design level of 3 (highest sustainability) and a weight level of 2 (2 kg).

Each product design comprises a specific monetary profit for the manager and a negative environmental impact on society. On the one hand, higher eco-design levels yield lower profits, reflecting assumed higher production costs associated with more sustainable designs (Han *et al.*, 2020; Raz *et al.*, 2013; Frota Neto *et al.*, 2008). As a simplification, the weight of the product has no direct effect on profit due to the assumption that increased production costs associated with advanced lightweight technologies offset the material cost savings (König *et al.*, 2024; Delogu *et al.*, 2018). On the other hand, higher eco-design levels lead to a lower negative environmental impact on society.

Environmental impacts vary with product design but are held constant across all treatments—that is, every specific product design A–I induces the same negative environmental impact across treatments. Negative environmental impact is operationalized through the actual purchase of gold standard-certified CO_2 certificates by the experimenters after the experiment. The purchase of CO_2 certificates leads to an effective reduction in CO_2 emissions, as the purchased certificates are “retired” from the market. The purchased certificates are thus permanently removed from trading, and no other entity can use them. This corresponds to an effective reduction in CO_2 emissions. In the experiment, we model the environmental impact as CO_2 reduction resulting from a specific product design choice to make the experimental instructions easier to understand for the participants. Our framing is a linear transformation of negative environmental impacts, such that an additional omission to reduce CO_2 in the experiment corresponds to an additional negative environmental impact in reality.

Climate project 1

	Weight		
Eco-design	**1 kg**	**2 kg**	**3 kg**
1	86.96	43.48	0
2	130.44	86.96	43.48
3	173.92	130.44	86.96

Climate project 2

	Weight		
Eco-design	**1 kg**	**2 kg**	**3 kg**
1	0	43.48	86.96
2	43.48	86.96	130.44
3	86.96	130.44	173.92

Figure 2: CO_2 reduction in kg in climate projects 1 (left) and 2 (right) in the experiment

Notes: The left table in this figure illustrates the CO_2 reduction achieved in climate protection project 1 across the nine product designs (A–I), which result from the combination of eco-design level and product weight. The right table shows the corresponding CO_2 reduction for climate protection project 2. In both tables, eco-design levels (left y-axis) range from 1 (least sustainable) to 3 (most sustainable), while product weight (top x-axis) ranges from 1 kg (lightest) to 3 kg (heaviest).

Certificates are acquired in two distinct climate protection projects provided by a non-profit organization. Climate protection project 1 promotes resource efficiency and energy savings, and centers on first-order environmental consequences. Climate protection project 2 facilitates a circular economy and represents the environmental consequences of product recyclability. In both climate protection projects, experimental participants' decision to select higher levels of eco-design results in the purchase of more CO_2 certificates. The weight choice affects the two climate projects differently, reflecting the environmental ambivalence associated with product weight: In climate project 1, a lower product weight leads to the purchase of more CO_2 certificates, whereas in climate project 2, it results in fewer certificates being purchased. Hence, in our experiment, total CO_2 reduction, based on the certificates acquired in both climate projects, depends solely on the chosen eco-design level.

In both climate projects, CO_2 certificates are priced at €23 per ton of CO_2. Based on the participants' design choice, an amount between €0 and €4 is used to purchase CO_2 certificates in each climate protection project. At a rate of €0.023 per kilogram, this corresponds to a minimum of 0 kg and a maximum of approximately 173.92 kg of CO_2 reduction per project and participant. In Figure 2, we show the CO_2 reduction resulting from each specific product design. Information about both climate projects was provided to participants prior to their product design decision as part of the experimental instructions. Participants were also notified that around 134 kg of CO_2 corresponds to the average emissions caused by one European in a single week (Friedlingstein *et al.*, 2025). Taken together, the operationalization of negative environmental impact in our experimental design comprises a substantial CO_2 reduction.

Treatment 2	Weight		
Eco-design	1 kg	2 kg	3 kg
1	11	9	7
2	9	7	5
3	7	5	3

Treatment 5	Weight		
Eco-design	1 kg	2 kg	3 kg
1	7	7	7
2	7	7	7
3	7	7	7

Treatment 1	Weight		
Eco-design	1 kg	2 kg	3 kg
1	12	12	12
2	10	10	10
3	8	8	8

Treatment 3	Weight		
Eco-design	1 kg	2 kg	3 kg
1	8	8	8
2	6	6	6
3	7	7	7

Treatment 4	Weight		
Eco-design	1 kg	2 kg	3 kg
1	8	8	8
2	6	6	6
3	7	7	7

Figure 3: Experiment participants' profit in euros

Notes: This figure shows participants' profit (in euros) for each product design, resulting from the combination of eco-design level and product weight, across treatments 1–5. The central table displays profit in treatment 1 (unregulated market). The remaining tables correspond to treatments 2–5: top-left (weight-based), bottom-left (bonus eco-modulation), bottom-right (penalty eco-modulation), and top-right (granular eco-modulation). Across all five tables, eco-design levels (left y-axis) range from 1 (least sustainable) to 3 (most sustainable), while product weight (top x-axis) ranges from 1 kg (lightest) to 3 kg (heaviest).

In the following, we describe our five experimental treatments, each of which systematically varies managers' incentives for more sustainable product designs. Thereby, every treatment maps a currently used or debated EPR/eco-modulation policy incentive scheme described above. The fees in the experiment are levied by a PRO, which is represented by the experimenters. Specific profit values for the participants in each treatment are depicted in Figure 3.

Treatment 1 (T1): *Unregulated market.* T1 serves as our baseline scenario, representing an unregulated market environment without an EPR fee system. Participants' profits depend solely on their chosen level of eco-design.

Treatment 2 (T2): *Weight-based scheme.* T2 maps the status quo of the dominant EPR practices. Building on T1, it introduces a linearly progressive fee structure based on product weight, thereby making more lightweight product designs financially more attractive. A small fee (€1) is applied to product weight 1 (1 kg), a mid-size fee (€3) to product weight 2 (2 kg), and a high fee (€5) to product weight 3 (3 kg). Consequently, the profit depends on the chosen products' level of eco-design and weight.

Treatment 3 (T3): *Bonus eco-modulation.* T3 implements an eco-modulation scheme using a bonus approach based on an eco-design criterion. Building on T1, a basic fee (€4) is charged when participants choose eco-design levels 1 or 2. If eco-design level 3—representing the most sustainable option—is chosen, the eco-design criterion is met, and a fee reduction of 75% (to

€1) is granted as a reward. Despite representing a substantial double-digit fee reduction, the bonus remains relatively conservative, as a full 100% reduction—already implemented in some countries—is not applied in our experiment.

Treatment 4 (T4): *Penalty eco-modulation.* T4 represents an eco-modulation penalty approach. For reasons of comparability, the underlying monetary incentive structure is identical to T3, except for the framing. The basic fee (€1) applies to eco-design level 3, where the eco-design criterion is met. When eco-modulation level 1 or level 2 is chosen, a penalty is imposed that increases the fee (to €4). Hence, the most sustainable eco-design level generates a profit that is identical to the bonus under T3. Similarly, when managers decide on a product design with an eco-design level of 1 or 2, the induced penalty yields a profit as the basic fee in T3.

Treatment 5 (T5): *Granular eco-modulation.* T5 introduces a granular eco-modulation scheme in which all three eco-design levels are treated as distinct product sub-categories. A linearly progressive fee structure is imposed, with the fee increasing as the sustainability of the products' eco-design decreases. A small fee (€1) is applied to eco-design level 3, a mid-sized fee (€3) to eco-design level 2, and a high fee (€5) to eco-design level 1. This also compensates for the higher production costs associated with more sustainable eco-design levels.

3.2 Important features of our experimental design

In designing the experiment, we aimed to carefully balance an adequate degree of realism and adherence to high experimental standards. In the following, we outline five features of our experiment that we deem important for ensuring the internal and external validity of our results.

(1) All incentives in this experiment were real: Based on the specific decisions of participants, they received actual monetary payments, and real CO_2 emission externalities were realized (Figure 2 in Appendix B shows the official certificates of climate protection projects 1 and 2). Hence, participants made consequential choices, perceived their decisions as meaningful, and experienced genuine emotions. This setting allowed us to elicit decisions that closely reflected participants' true preferences (Falk and Heckman, 2009).

(2) To enhance comparability of across treatments, each treatment allocated a total of €14 in each product design (i.e., in each cell in Figure 1) based on participants' decision among: (a) participants (profit), (b) a PRO (collected fee), and (c) climate protection project 1 and 2 (resulting amount for CO_2 certificate purchase).

(3) Accordingly**,** the average monetary incentive amounted to €10 in T1, compared to €7 in T2–T5. Nevertheless, to ensure equal average monetary incentives across treatments, profits were shown in coins during the experiment (see Figure 1 in Appendix A). Participants received their profits in euros after the experiment. An exchange rate variation across treatments ensured equal average monetary incentives (105 coins), referring to *money illusion*—a cognitive phenomenon in which individuals respond to nominal, rather than real, monetary values (Shafir *et al.*, 1997). The exchange rate from coins to euros was set at 1.0:10.5 in T1, and at 1:15 in T2–T5. This ensured comparability of incentives across treatments, and enabled testing of the incentive *architecture* of each EPR policy.

(4) The average fee (€3) collected by the PRO was held constant across T2–T5 to ensure comparability across treatments. Compared to T1 (unregulated market), this resulted in a 30% reduction in average profit in T2–T5. Assuming that the EPR fee accounts for 1–3% of the product price[3] and the net profit margin lies between 5% and 10%,[4] this appears to be a plausible operationalization of the fee structure. The aggregate fees collected from participants in each treatment constituted the PRO's revenue.

(5) The EoL costs of product designs were represented by the total amount *not used* for purchasing CO_2 certificates across both climate protection projects, plus an additional €1 to account for the assumption that environmentally neutral production is unattainable due to inherent negative externalities (Rothenberg, 2023) (see Figure 4). For T2, the weight-based fee was reduced without being associated with a corresponding decrease in EoL costs. In the bonus and the penalty eco-modulation schemes (T3 and T4), the fee was aligned with the EoL costs for eco-design level 3. For eco-design level 2, the fee slightly exceeded the corresponding EoL costs, whereas at level 1 there was a slight deficit in the fee to EoL costs ratio. In T5, the granular fee was, by design, fully aligned with the corresponding EoL costs for each eco-design level. Moreover, in T2–T5, the average EoL costs (€3) equaled the average PRO revenue, thereby satisfying the requirement of Article 8a(4c) of the WFD (European Parliament, 2018): Based on the *ex ante* assumption of equal outcome probabilities, each EPR system in the experiment could cost-efficiently recover the total EoL costs.

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[3] This is difficult to estimate; for example, Joltreau (2022) calculated the average EPR fees for a 1.5-liter PET water bottle of 2.7%. For batteries, an EPR fee amounting to 2% of the product price also appears to be a realistic estimate (Sachdeva *et al.* (2021). According to Hogg *et al.* (2020), the EPR fee for technical devices is estimated to range between slightly less than 1% and 2% of the product price (e.g., fridge, vacuum cleaner).

[4] According to Houalla and Portese (2023), the average net profit margin of non-financial companies in Europe lies around 8%.

	Weight		
Eco-design	**1 kg**	**2 kg**	**3 kg**
1	5	5	5
2	3	3	3
3	1	1	1

Figure 4: EoL costs operationalized in the experiment

Notes: This figure illustrates the EoL costs of each product design, which result from the combination of eco-design level and product weight. Eco-design levels (left y-axis) range from 1 (least sustainable) to 3 (most sustainable), while product weight (top x-axis) ranges from 1 kg (lightest) to 3 kg (heaviest).

Based on the operationalization of EoL costs and CO_2 reduction, two key variables can be calculated to assess the introduced EPR fee systems from an institutional/PRO perspective: (1) the amount of EoL costs that must be reduced per €1 of PRO revenue, as an indicator of whether PROs have sufficient resources to offset negative environmental externalities. A value of €1 indicates that EoL costs and PRO revenue are balanced—that is, that sufficient monetary funds are available to cover the system's EoL costs. The condition set out in WFD Article 8a(4c) would potentially be fulfilled. (2) The achieved CO_2 reduction in kg per €1 of PRO revenue, as an indicator of the efficiency of eco-modulation to reduce producers' environmental externalities through eco-design improvements relative to the revenue generated. We analyze both key variables in our results section.

3.3 Additional measures

To collect additional information on individual differences in participants' pro-sociality, after the main experiment[5] we administered a questionnaire on participants' personal values (Schwartz, 2012). Schwartz (2012) assumes that individuals possess a set of values that establishes their preference patterns and can shape their decisions. Based on preliminary social sciences research, a distinction is made between ten basic or low-level values, which are grouped into four higher-order value domains: self-transcendence (universalism and benevolence), self-enhancement (achievement, power, and hedonism), conservation (tradition, conformity, and security), and openness to change (stimulation, self-direction, and hedonism). Previous studies have shown that people's Schwartz values are associated with decisions in the social domain (Czupryna and Schaff, 2024; Lönnqvist *et al.*, 2013; Ahmad *et al.*, 2020). In particular, the distinct value of universalism—combining two subtypes of concern: (1) for the welfare and

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[5] Following the strict conventions of experimental economics, we collected participants' product design decisions first to ensure that these were not biased by any previously elicited measure.

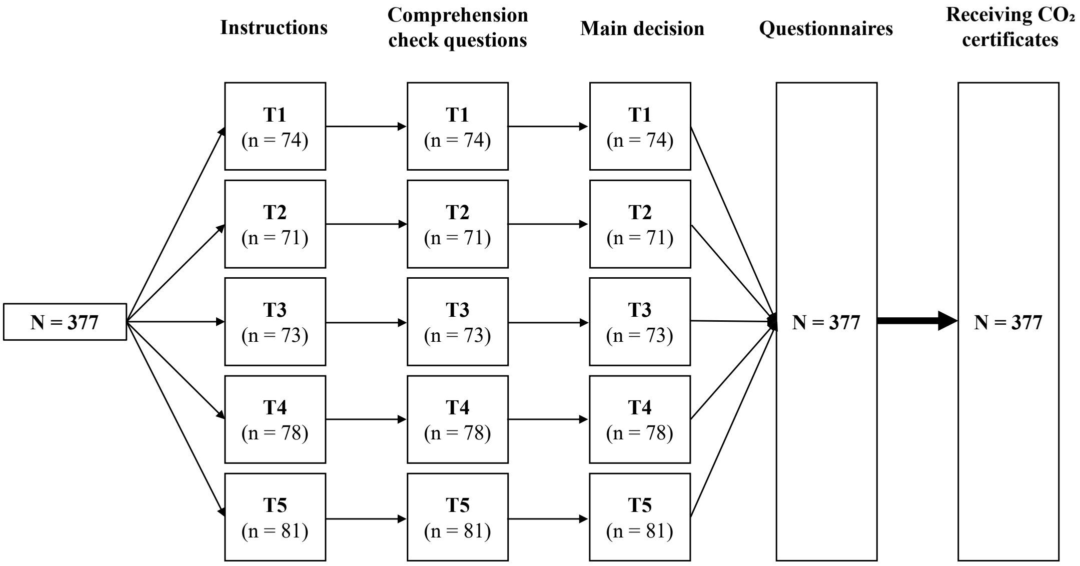

Figure 5: Procedure of the experiment

Notes: This figure illustrates the stages of the experiment. First, participants were randomly assigned to one of the five treatments (T1–T5), and read the corresponding treatment-specific instructions. T1 represents the unregulated market, T2 the weight-based scheme, T3 the bonus eco-modulation, T4 the penalty eco-modulation, and T5 the granular eco-modulation. Second, participants completed treatment-specific comprehension check questions. Third, they made their decision regarding the product design. Fourth, they filled out questionnaires covering personal values, socio-economic data, and their preference for climate protection project 1 or 2. Finally, participants received a confirmation of the CO_2 certificate purchase in climate projects 1 and 2.

tolerance of those in the larger society and world (UNC + UNT), and (2) especially relevant in this context, for nature (UNN)—has been demonstrably associated with a higher willingness to protect or facilitate environmental goods (Primc *et al.*, 2021; Grankvist *et al.*, 2019; Prati *et al.*, 2018; Katz-Gerro *et al.*, 2017). To control for participants' socio-economic background, we collected data on their gender, age, education level, and income. In addition, we asked whether participants had a preference for climate project 1 or 2, to control for the fact that such preference could explain treatment differences.

3.4 Participants and procedures

A total of 377 participants[6] were recruited for the experiment via the online platform Prolific. Table 1 displays the number of participants in each treatment and their basic demographic

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[6] In our literature search, we did not find any comparable studies from which reference values could have been derived for the sample size calculation. Therefore, we based our estimation on standard statistical assumptions. Specifically, we assumed a medium effect size (Cohen's $d = 0.5$) and aimed for statistical power of 0.80, following the conventional classification by Cohen (1988). The calculation indicated that a sample size of 64 participants per treatment group would be sufficient to detect effects of this magnitude. This requirement was marginally exceeded in the present study. Since some participants—for example, due to technical reasons—dropped out of the experiment, a slight imbalance in the sample size per treatment was unavoidable.

Table 1: Sample

Treatment	*N*	Male (%)	Female (%)	Mean age
T1	74	43.24	56.76	41.88
T2	71	53.52	46.48	42.24
T3	73	47.95	52.05	38.91
T4	78	51.28	48.72	39.54
T5	81	53.09	46.91	40.61
Total	377	49.87	50.13	40.61

Notes: This table depicts the demographic characteristics of participants across treatments 1–5 and overall. T1 represents the unregulated market, T2 the weight-based scheme, T3 the bonus eco-modulation, T4 the penalty eco-modulation, and T5 the granular eco-modulation. Columns report the number of participants (*N*), gender distribution (male and female, in %), and mean age (in years). The bottom row reports aggregated values from the overall sample.

characteristics. Gender distribution and participants' age were balanced across treatments. All subjects were industrial professionals with management experience: 42.97% reported having (current or past) decision-making responsibilities in operations/production, 34.48% in research and development, 32.36% in business strategy, and 25% in supply chain/logistics. These areas exhibit thematic proximity to topics related to EPR.

Participants were randomly assigned to the five treatments based on the order of their enrollment on Prolific, with each successive participant allocated to the next treatment in the rotating sequence (e.g., the first participant was assigned to T1, the second to T2, etc.) (see Figure 5). Instructions were presented onscreen (see Appendix A). Before making their decisions, participants were required to complete five treatment-specific comprehension check questions (see Appendix A) to ensure they had understood the experimental instructions (Peer *et al.*, 2022). Only if participants answered all the questions correctly could they start the experiments. After making the experimental decision, the participants completed the questionnaires. On average, participants earned €8.44 for about 20 minutes of participation. In addition, participants received official certificates confirming the reduction of CO_2 resulting from their decisions during the experiment (see Figure B in Appendix 2).

3.5 Research hypotheses

Based on the theoretical literature and the provided incentive structures, five hypotheses are formulated. First, we compare the baseline (T1, *unregulated market*) with the weight-based scheme (T2, *weight-based scheme*), as well as with the bonus (T3, *bonus scheme*) and penalty (T4, *penalty scheme*) schemes, in terms of eco-design and CO_2 reduction. Subsequently, we compare the different eco-modulation schemes (T3, T4, and T5, *granular scheme*). Finally, we predict the development of PRO revenue, the amount of EoL costs that must be reduced per €1 of PRO revenue, and the achieved CO_2 reduction in kg per €1 of PRO revenue.

Hypothesis 1 (H1, effectiveness of weight-based incentive scheme): *T1 vs. T2*: *The weight-based scheme does not lead to a significantly better eco-design compared to the unregulated market scenario.*

In T2, keeping everything else constant, compared to T1, participants have an additional monetary incentive to select lighter product weights to minimize fees and increase profits. This will not improve total CO_2 reduction in T2 compared to T1.

Hypothesis 2 (H2, effectiveness of bonus and penalty incentive schemes): *T1 vs. T3 and T4: The bonus and the penalty schemes lead to a significantly better eco-design, respectively, compared to the unregulated market scenario.*

The presence of monetary incentives for improving eco-design in the form of a bonus (T3) and a penalty (T4) is predicted to shift the behavior of participants toward more sustainable eco-designs. This is based on previous studies, which have shown that monetary bonuses and penalties elicit pro-social and pro-environmental behavior (Lazear, 2000; Vollaard and van Soest, 2024; Kroker and Lange, 2024). This will improve total CO_2 reduction in T3 and T4 compared to T1. This hypothesis also implies transitivity: Bonus/penalty systems are expected to outperform the weight-based approach in T2.

Hypothesis 3 (H3, effectiveness of bonus vs. penalty incentive schemes): *T3 vs. T4: The penalty-based eco-modulation leads to a significantly better eco-design compared to the bonus-based modulation.*

This hypothesis is grounded in the behavioral phenomenon of loss aversion—a core element in prospect theory (Kahneman and Tversky, 1979). It describes that the psychological pain experienced from losses outweighs the pleasure gained from equivalent gains. Many studies have confirmed the substantial influence of loss aversion in field and laboratory decision-making experiments within the context of the circular economy and sustainability (Faccioli *et al.*, 2019; Nabi *et al.*, 2018; Grazzini *et al.*, 2018; Bull, 2012; Morton *et al.*, 2011; White *et al.*, 2011; Abdellaoui *et al.*, 2007). According to Homar and Cvelbar (2021), policymakers should incentivize pro-environmental behavior by framing the consequences of environmental decisions as losses rather than gains. In our experiment, the bonus in T3 is framed as a gain, whereas the penalty in T4 is framed as a loss—while actually both treatments' incentive structures are identical (see Figure 3). This will improve total CO_2 reduction in T4 compared to T3.

Hypothesis 4 (H4, effectiveness of granular incentive scheme): *T3 and T4 vs. T5: The granular eco-modulation leads to a significantly better eco-design compared to the bonus and the penalty modulations.*

In T5, the fee structure fully compensates for the higher production costs associated with more sustainable eco-designs—that is, there is no financial disadvantage linked to higher eco-design levels. Participants with even moderate concern for nature choose the most sustainable eco-design level, as it involves no personal cost (Primc *et al.*, 2021; Grankvist *et al.*, 2019; Prati *et al.*, 2018; Katz-Gerro *et al.*, 2017). This is in line with numerous studies showing that human decision-making—particularly with regard to environmental or common goods—is strongly influenced by pro-social and pro-environmental preferences (Falk *et al.*, 2018; Carlsson and Johansson-Stenman, 2000; Fehr and Schmidt, 1999). In addition, it is plausible that participants have image concerns, as depicted in numerous studies showing that image concerns can play an important role in decision-making, especially in environmental contexts (Sexton and Sexton, 2014; Delmas and Lessem, 2014). Image concerns refer to individuals' awareness of their social reputation and the utility they gain from being perceived as pro-social by others (Ariely *et al.*, 2009).[7] In T5 of our experiment, participants can demonstrate socially desirable behavior (e.g., toward the experimenters) by choosing a high eco-design, thereby building a positive social reputation and deriving utility from it, without suffering any monetary costs. Taken together, this will improve total CO_2 reduction in T5 compared to T3 and T4. Due to transitivity, the granular eco-modulation is expected to outperform the unregulated market and the weight-based approach in T1 and T2.

Hypothesis 5 (H5, institutional perspective): T2 *vs. T3, T4, and T5: The eco-modulation schemes, despite leading to a decline in PRO revenue, lead to a more balanced relation of EoL costs and PRO revenue, and to a significantly higher CO_2 reduction in kg per €1 of PRO revenue compared to the weight-based scheme.*

If H1–H4 hold, the eco-modulation schemes lead to more sustainable eco-designs. This implies that participants in the eco-modulation schemes pay reduced fees. Since PRO revenue equals the fees actually paid, PRO revenue will decline. However, the eco-modulation schemes make fees closely aligned with the actual EoL costs—that is, lower fees and, consequently, reduced PRO revenue corresponding to lower EoL costs. In T5 (granular scheme), PRO revenue is, by

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[7] In the Schwartz (2012) value model, image concerns are represented by the values of conformism (restraining actions, inclinations, and impulses likely to upset or harm others and violate social expectations or norms) and face (maintaining one's public image and avoiding humiliation).

design, fully aligned with the corresponding EoL costs, whereas in T3 (bonus scheme) and T4 (penalty scheme), only small differences exist for eco-design levels 1 and 2. By contrast, in T2 (weight-based scheme), lower fees and, consequently, a reduced PRO revenue for lighter products do not correspond to lower EoL costs. In addition, regarding CO_2 reduction, eco-modulation fees are based on eco-design, whereby more sustainable eco-designs with a higher total CO_2 reduction are incentivized. In contrast, the weight-based scheme is centered on product weight, whereby lighter products do not result in higher total CO_2 reduction.

4. Results

This section presents the empirical results of the experiment. We begin with robustness checks to ensure comparability of participants across treatments. Then, we test H1–H4 on eco-design and product weight. Subsequently, we report how the moderator variables influence eco-design choice, and then analyze CO_2 reduction in total and in climate projects 1 and 2. Finally, we examine H5, focusing on PRO revenue, the amount of EoL costs that must be reduced per €1 of PRO revenue to meet legal requirements, and CO_2 reduction in kg per €1 of PRO revenue.

4.1 Robustness checks

First, to assess the balance of background characteristics across treatments, we conducted robustness checks on key moderators: gender, age, UNN, conformism, face, preference for climate project 1 or 2, monthly income, education level, and mistakes in the comprehension check questions.

Using the chi-squared test and Fisher–Pitman permutation test, the robustness checks demonstrate no systematic imbalances across treatments (all $p \geq 0.09$; see Tables 1 and 2 in Appendix C). The only exception, based on the chi-squared test, is a statistically significant difference in income distribution ($\chi^2(4) = 10.33$, $p = 0.04$) between T3 and T5. This minor deviation is noted, but does not induce fundamental imbalances across treatment samples—as shown by regression analysis (see below).

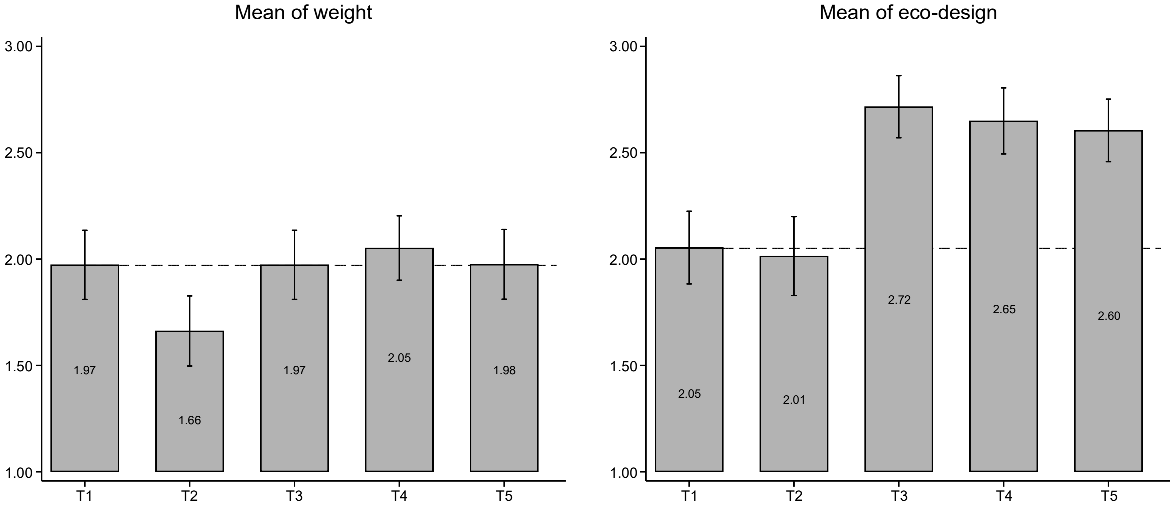

Figure 6: CO_2 reduction in the experiment

Notes: On the left, the mean weight is shown for T1–T5 on the x-axis, ranging from 1.00 to 3.00 on the y-axis. On the right, the mean eco-design score is shown for T1–T5 on the x-axis, ranging from 1.00 to 3.00 on the y-axis. Horizontal lines indicate the mean value of T1. T1 represents the unregulated market, T2 the weight-based scheme, T3 the bonus eco-modulation, T4 the penalty eco-modulation, and T5 the granular eco-modulation.

4.2 Effectiveness of the weight-based incentive scheme (H1)

We find no significant difference in the mean eco-design between T1 (2.05, *SD* = 0.74, CI: 1.88, 2.23) and T2 (2.01, *SD* = 0.78, CI: 1.83, 2.20, *d* = 0.05, *p* = 0.83, Fisher–Pitman permutation test for two independent samples, two-sided)[8] (see Figure 6). However, the product weight is

significantly lower in T2 (1.66, *SD* = 0.70, CI: 1.50, 1.83) compared to in T1 (1.97, *SD* = 0.70, CI: 1.81, 2.14, *d* = 0.45, *p* = 0.01) (see Figure 6). These findings support H1. Thus:

Result 1: *The weight-based scheme, compared to the unregulated market scenario, leads not to a significantly better eco-design and higher total CO_2 reductions, but rather to lighter products.*

4.3 Effectiveness of bonus and penalty incentive schemes (H2 and H3)

We find a significantly higher mean eco-design in T3 (2.72, *SD* = 0.63, CI: 2.57, 2.86) compared to in T1 (2.05, *SD* = 0.74, CI: 1.88, 2.23, *d* = 0.96, *p* < 0.001). Similarly, eco-design in T4 (2.65, *SD* = 0.68, CI: 2.50, 2.81) significantly outperforms eco-design in T1 (*d* = 0.85, *p* < 0.001) (see Figure 6). Furthermore, compared to T1, the mean product weight is not significantly different in T3 (1.97, *SD* = 0.70, CI: 1.81, 2.14, *d* = 0.00, *p* = 1.00) or T4 (2.05, *SD* =

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[8] In the following, we report two-sided non-parametric Fisher–Pitman permutation tests for two independent samples (Siegel and Castellan, 1988), Cohen's *d* for effect sizes, and 95% confidence intervals, unless otherwise indicated.

0.67, CI: 1.90, 2.20, *d* = 0.11, *p* = 0.56) (see Figure 6). Additional evidence suggests that T3 and T4 are more effective with regard to eco-design relative to T2. These findings lend support to H2. In summary:

Result 2: *The bonus and the penalty schemes, compared to the unregulated market scenario, lead to a significantly better eco-design and significantly higher total CO_2 reductions.*

Comparing T3 and T4 (H3), we find that the mean eco-design is lower in T4 than in T3, albeit not significantly different (*d* = 0.10, *p* = 0.62). These findings do not confirm H3. Thus:

Result 3: *The penalty-based eco-modulation does not lead to a significantly better eco-design compared to the bonus-based modulation.*

4.4 Effectiveness of the granular scheme (H4)

We find that the mean eco-design in T5 (2.60, *SD* = 0.66, CI: 2.46, 2.75) is slightly lower than in T3 (*d* = 0.17, *p* = 0.35). In addition, T5 shows a slightly lower mean eco-design compared to T4 (*d* = 0.07, *p* = 0.74). Compared to T1, the mean product weight is not significantly different in T5 (1.98, *SD* = 0.74, CI: 1.81, 2.14, *d* = 0.00, *p* = 1.000). Despite showing no advantage over T3 and T4, T5 still outperforms both the weight-based fee scheme (T2), and the unregulated market (T1). These findings do not confirm Hypothesis 4. Thus:

Result 4: *The granular eco-modulation does not lead to a significantly better eco-design compared to the bonus or the penalty modulations.*

Before we turn to the results for H5 (see subsection 4.7), we assess the influence of moderator variables on eco-design choice and effective CO_2 reduction across treatments.

4.5 Influence of the moderator variables

In the following, we run regression analyses to examine the robustness of our non-parametric findings and the potential influence of moderator variables on eco-design—that is, participants' demographic background and personal values.

Model (1) in Table 2, consistent with the permutation tests, shows that the eco-modulation fee systems (T3–T5)—and not the weight-based fee (T2)—have a positive and statistically significant effect on eco-design. Results are robust when controlling for covariates. Models (2)–(6) reveal that neither gender nor age consistently influences eco-design. Model (3) includes participants' concern for nature (UNN). UNN reveals a significant positive effect on eco-design, indicating that individuals with higher environmental values are more likely to make more sustainable eco-design choices.

Table 2: Regression model: Moderators

	Dependent variable: Eco-design					
	All				Male	Female
Variables	(1)	(2)	(3)	(4)	(5)	(6)
T2	-0.040	-0.029	-0.052	-0.046	-0.093	-0.026
	(0.127)	(0.127)	(0.123)	(0.129)	(0.202)	(0.162)
T3	0.662***	0.654***	0.641***	0.704***	0.698***	0.697***
	(0.113)	(0.114)	(0.111)	(0.116)	(0.173)	(0.160)
T4	0.600***	0.598***	0.599***	0.618***	0.359*	0.869***
	(0.115)	(0.114)	(0.109)	(0.117)	(0.185)	(0.133)
T5	0.551***	0.555***	0.530***	0.625***	0.483***	0.764***
	(0.113)	(0.113)	(0.111)	(0.117)	(0.185)	(0.146)
Gender		0.092	0.066	0.075		
		(0.073)	(0.071)	(0.071)		
Age		-0.004	-0.006**	-0.006*	-0.005	-0.005
		(0.003)	(0.003)	(0.003)	(0.005)	(0.004)
UNN			0.165***	0.310***	0.155	0.395***
			(0.046)	(0.081)	(0.175)	(0.085)
T2 × UNN				-0.067	0.093	-0.148
				(0.138)	(0.248)	(0.155)
T3 × UNN				-0.260**	-0.083	-0.318**
				(0.113)	(0.193)	(0.159)
T4 × UNN				-0.067	0.196	-0.296**
				(0.147)	(0.229)	(0.133)
T5 × UNN				-0.323**	-0.162	-0.423***
				(0.128)	(0.241)	(0.152)
Constant	2.054***	2.173***	2.231***	2.190***	2.247***	2.146***
	(0.086)	(0.162)	(0.159)	(0.162)	(0.243)	(0.187)
Observations	377	377	377	377	188	189
Prob > F	0.000	0.000	0.000	0.000	0.000	0.000
R^2	0.161	0.169	0.198	0.216	0.164	0.310

Notes: The table reports OLS regression results for the dependent variable eco-design. The reported values are estimated regression coefficients; robust standard errors are shown in parentheses. T1, representing the unregulated market, serves as the reference category. Regarding variables, T2 represents the weight-based scheme, T3 the bonus eco-modulation, T4 the penalty eco-modulation, and T5 the granular eco-modulation. UNN denotes participants' concern for nature. Interaction terms (T2 × UNN to T5 × UNN) test whether the treatment effects on *eco-design* vary with participants' concern for nature. Model (1) includes only treatment dummies, while models (2)–(4) add gender, age, and UNN, as well as the interactions between UNN and T2–T5. Models (5) and (6) show results for male and female participants, respectively.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$

Model (4) extends the analysis by including interaction terms between treatments (T2–T5) and UNN. First, it shows that UNN has a strong and significant positive effect on eco-design in T1. However, the model also shows that the influence of UNN weakens following EPR policy introduction, significantly in T3 (bonus scheme), and even stronger in T5 (granular scheme),

where the influence of UNN on eco-design reverses and even becomes negative (total effect of UNN amounts to $b = 0.310 – 0.323 = –0.013$).

To further explore the effects of UNN on participants' eco-design choice, we separate our analysis according to participants' gender. Females have been found to have generally higher universalism values, and a higher concern for environmental protection, compared to males

(Schwartz and Rubel-Lifschitz, 2009; Schwartz and Rubel, 2005; Zelezny *et al.*, 2000). Accordingly, in Model (5) [6], we restrict the analysis of Model (4) to male [female] participants. Model (5) shows that UNN has no statistically significant association with eco-design for male participants across treatments. Conversely, the model for females (Model (6)) shows that UNN positively predicts eco-design choice in T1, but this effect is weakened under the EPR/eco-modulation policy. Strikingly, in T5, UNN negatively predicts eco-design choice, as the total effect of UNN amounts to $b = 0.395 - 0.423 = -0.028$.

Comparing females to males further indicates that the bonus scheme (T3) has an almost equally strong positive effect on eco-design choice for both genders. In contrast, the penalty scheme (T4) shows the strongest effect on eco-design for females, but the effect is lowest for male participants. In addition, the granular scheme (T5) shows a substantially stronger effect among females compared to males. These results provide evidence that eco-modulation is more effective for female participants, despite the negative influence of UNN. Even though UNN operates differently across genders in our sample, higher average female UNN values do not reach statistical significance (see Table 3 in Appendix C). Therefore:

Result 5: *Environmental values have a strong positive effect on eco-design decisions. This effect weakens, and partly reverses, under the EPR schemes, particularly the eco-modulation schemes. These effects are more pronounced among female participants, showing that, generally, eco-modulation is more effective for females. The bonus scheme has similar positive effects for both males and females.*

4.6 Implications for CO_2 reduction

In terms of environmental externalities, we find that, in comparison to T1 (178.62, *SD* = 64.20, CI: 163.75, 193.49), the mean total CO_2 reduction in kg—as a direct consequence of eco-design choice—is only 1.99% lower in T2 (175.14, *SD* = 68.14, CI: 159.02, 191.27, *d* = 0.05, *p* = 0.67) (see Figure 7). However, comparing the reduction across climate projects 1 and 2 reveals a more nuanced pattern: for climate project 1, the mean CO_2 reduction is 13.02% higher in T2 (102.27, *SD* = 40.99, CI: 92.57, 111.97) than in T1 (90.49, *SD* = 45.95, CI: 79.84, 101.13, *d* = 0.27, *p* = 0.09). In contrast, for climate project 2, the mean CO_2 reduction is 17.33% lower in T2 (72.87, *SD* = 49.72, CI: 61.11, 84.64) than in T1 (88.14, *SD* = 42.56, CI: 78.27, 97.99, *d* = 0.33, *p* = 0.058).

In terms of the eco-modulation schemes, we find highly significant differences. Compared to T1, the mean total CO_2 reduction is 32.24% higher in T3 (236.20, *SD* = 54.85, CI: 223.49,

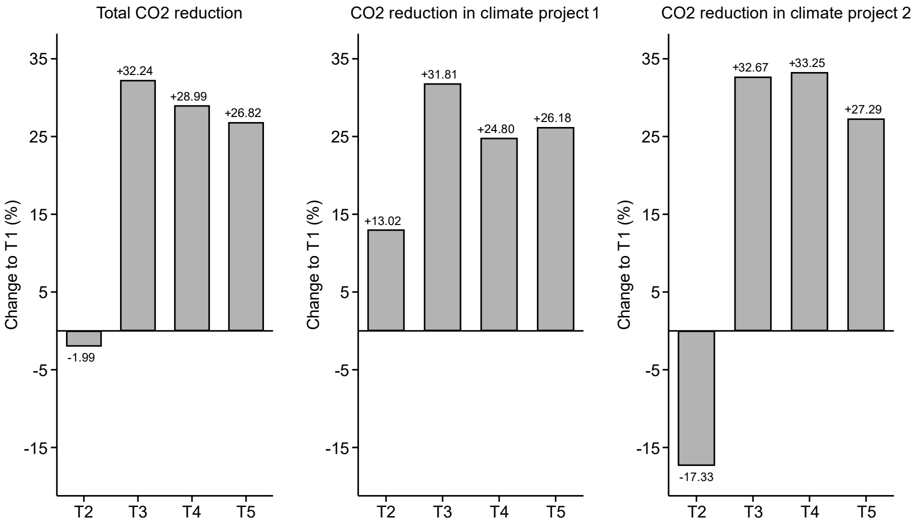

Figure 7: Total CO_2 reduction, and CO_2 reduction in climate projects 1 and 2

Notes: On the left, the relative percentage change in total CO_2 reduction compared to T1 is shown for T2–T5 on the x-axis, ranging from –15 to +35 on the y-axis. In the middle, the relative percentage change in CO_2 reduction in climate project 1 relative to T1 is shown for T2–T5 (x-axis), ranging from –15 to +35 on the y-axis. On the right, the relative percentage change in CO_2 reduction in climate project 2 relative to T1 is shown for T2–T5 (x-axis), ranging from –15 to +35 on the y-axis. T1 represents the unregulated market, T2 the weight-based scheme, T3 the bonus eco-modulation, T4 the penalty eco-modulation, and T5 the granular eco-modulation.

248.91, $d = 0.96$, $p < 0.001$), 28.99% higher in T4 (230.39, *SD* = 59.46, CI: 216.89, 243.88, $d = 0.84$, $p < 0.001$), and 26.82% higher in T5 (226.53, *SD* = 57.81, CI: 213.74, 239.31, $d = 0.79$, $p < 0.001$). Between the eco-modulations, no remarkable differences can be observed in pairwise comparisons (all $d \leq 0.17$, all $p \geq 0.23$). Thus:

Result 6: *In comparison to the unregulated market treatment, the weight-based scheme does not lead to a significant improvement in total CO_2 reduction, but results in a lower CO_2 reduction in climate project 2. All eco-modulation schemes lead to significantly higher total CO_2 reduction.*

4.7 Institutional perspective (H5)

To analyze the institutional/PRO perspective, T1 is excluded, since no PRO is involved in an unregulated market. Compared to T2 (2.41, *SD* = 1.41, CI: 2.07, 2.74), we find that PRO revenue is significantly lower in T3 (1.57, *SD* = 1.83, CI: 1.29, 1.84, $d = 0.65$, $p < 001$), T4 (1.70, *SD* = 1.28, CI: 1.41, 1.99, $d = 0.53$, $p = 0.002$), and T5 (1.79, *SD* = 1.33, CI: 1.50, 2.08, $d = 0.45$, $p = 0.009$). Pairwise comparisons of PRO revenues from T3–T5 reveal no significant differences (all $d \leq 0.18$, all $p \geq 0.30$) (see Figure 8).

Concerning the balance of EoL costs and PRO revenue, we find that in T2, €1.92 of EoL costs (*SD*: 1.68, CI: 1.52, 2.32) must be reduced per €1 of PRO revenue. By contrast, €1 of EoL costs must be reduced per €1 of PRO revenue in T3 (*SD* = 0.11, CI: 0.97, 1.03), T4 (*SD* = 0.12, CI:

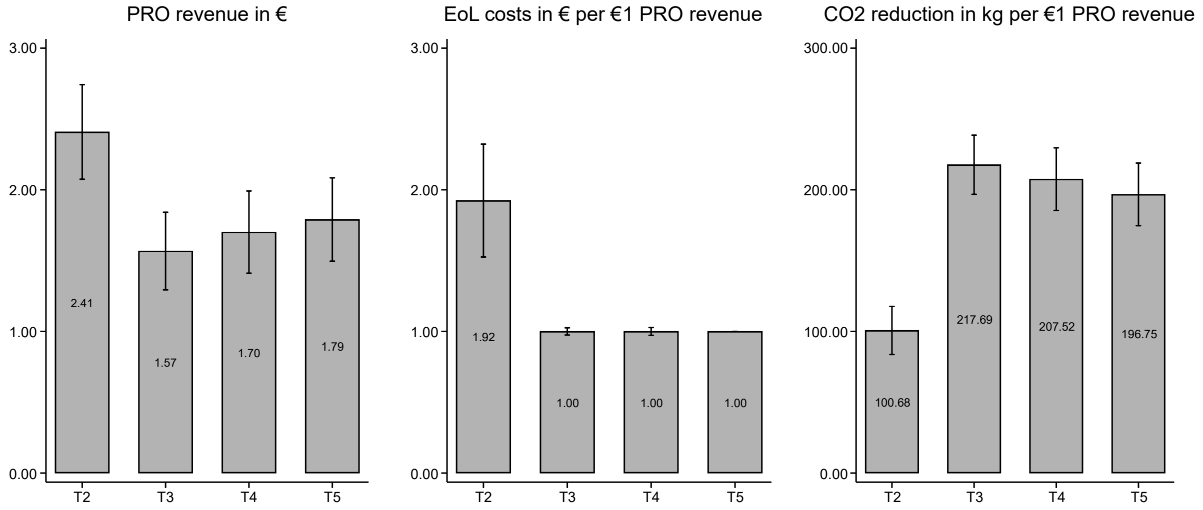

Figure 8: PRO / institutional perspective

Notes: On the left, the mean PRO revenue is displayed for T2–T5 on the x-axis, ranging from €0 to €3 on the y-axis. In the middle, the mean EoL costs per €1 of PRO revenue are shown for T2–T5 (x-axis), also ranging from €0 to €3 (y-axis). On the right, the mean CO_2 reduction in kilograms per €1 of PRO revenue is depicted for T2–T5 (x-axis), ranging from 0 kg to 300 kg (y-axis). T2 represents the weight-based scheme, T3 the bonus eco-modulation, T4 the penalty eco-modulation, and T5 the granular eco-modulation.

0.97, 1.03), and T5 (*SD* = 0.00, CI: 1.00, 1.00) by experimental design. The differences relative to T2 are statistically significant for T3 ($d = 0.78$, $p < 0.001$), T4 ($d = 0.79$, $p < 0.001$), and T5 ($d = 0.80$, $p < 0.001$).

Furthermore, compared to T2 (100.68, *SD* = 71.71, CI: 83.70, 117.65), the achieved CO_2 reduction per €1 of PRO revenue is significantly higher in T3 (217.69, *SD* = 90.14, CI: 196.81, 238.58, $d = 1.43$, $p < 0.001$), T4 (207.52, *SD* = 97.39, CI: 185.41, 229.62, $d = 1.24$, $p < 0.001$), and T5 (196.75, *SD* = 99.99, CI: 174.64, 218.86, $d = 1.09$, $p < 0.001$). The achieved CO_2 reduction per €1 of PRO revenue is slightly higher in T3 compared to T5 ($d = 0.21$, $p = 0.17$). The difference between T3 and T4 ($d = 0.11$, $p = 0.55$) and between T4 and T5 ($d = 0.11$, $p = 0.48$) is negligible. These findings confirm H5. In summary:

Result 7: *The eco-modulation schemes, despite leading to a decline in PRO revenue, lead to a greater balance between EoL costs and PRO revenue, and to a significantly higher CO_2 reduction in kg per €1 of PRO revenue compared to the weight-based scheme.*

5. Discussion

Summary

We started from the research agenda outlined by Lifset *et al.* (2023) that emphasized, *inter alia*, that effective eco-modulation policy requires an experimental approach to policymaking, improved data collection, systematic *ex post* evaluation, and harmonized criteria and fee structures. This paper provides the first causal empirical evidence on the impact of incentives induced by EPR/eco-modulation fee schemes, assessed from an eco-design, environmental, and PRO perspective. Our behavioral experiment with industrial professionals is also the first to demonstrate that eco-modulation schemes exert a directional effect toward more sustainable eco-design, and a reduction of environmental externalities. In contrast, the weight-based fee scheme does not foster more sustainable eco-design, but rather leads to lighter products. Decision-makers' personal environmental values have a strong positive effect on eco-design choices; however, this effect weakens—and partly reverses—under the EPR schemes, particularly under eco-modulation, and is noted to be stronger among female participants. Although eco-modulation schemes reduce overall PRO revenue, they lead to a more balanced relation between EoL costs and revenues, and achieve a more efficient reduction of environmental externalities relative to the revenue generated.

Effectiveness of eco-modulation incentive schemes

Our results reveal that eco-modulation schemes effectively promote improvements in eco-design choices even under conservative experimental conditions: In our between-subjects experiment (i.e., where participants only experienced one experimental treatment), the eco-modulation schemes induced, on average, monetary deteriorations for the participants compared to the unregulated market treatment, whereas average profit levels were held constant relative to the weight-based fee scheme. Even receiving a bonus for choosing eco-design level 3 in the bonus scheme did not constitute an actual monetary improvement compared to the unregulated market, but merely resulted in a smaller deterioration in profit than if a less sustainable eco-design had been chosen.[9] In addition, in real-world EPR systems, eco-modulations can reach up to ±100% relative to the base fee, whereas in our experiment, this fee size was not fully exhausted (Sachdeva *et al.*, 2021; Laubinger *et al.*, 2021). These outcomes suggest that the effects found in this study are likely to be conservative estimates of the potential impact of such schemes. If we were to relax the strict constraints required to achieve experimental comparability (e.g., by including an actual additional bonus for choosing more sustainable eco-designs), it is plausible that the observed effects would be stronger.

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[9] Note that this has potentially important implications regarding the PRO budget, because no additional funds for bonus payments are required when eco-design goals are met.

Regarding the effectiveness of specific eco-modulation in promoting more sustainable eco-design choices, it is surprising that the granular fee scheme (T5) does not perform best, even though its fee structure fully compensates for the higher production costs of sustainable product designs, thereby eliminating any financial disadvantage associated with higher eco-design levels. The bonus scheme, followed by the penalty scheme, even performs slightly better than the granular scheme, although the differences do not reach statistical significance in our sample. One possible explanation for this is that the bonus and penalty schemes are simpler, and thus more intuitive, than the granular scheme, resembling incentive structures that participants are already familiar with from other contexts. It is important to note that, in all treatments, including T5, participants understood the instructions and treatment-specific game conditions, as indicated by low error rates in the comprehension questions and lack of significant differences across treatments. Another possible explanation is that the granular scheme may create a perception that individual choices hardly matter, as all profits appear similar and the fees are seen as compensating for environmental harm. This reflects the phenomenon of moral disengagement, as participants may feel morally released from further responsibility once compensation for environmental harm has been paid (Moore, 2015). In this sense, fees can serve as a form of moral justification, allowing individuals to perceive their actions as acceptable despite the absence of additional efforts toward more ethical or sustainable choices (Leviston and Walker, 2021; Bandura, 1999).

Moreover, the results do not suggest the presence of loss aversion in our setting, since the penalty scheme did not outperform the bonus scheme in stimulating more sustainable eco-design choices (see H3). Thus, positive incentives for meeting eco-design requirements appear to be no less effective than institutional punishment for failing to meet such requirements in the context of EPR. However, one possible reason for this could be the conservative design of our experiment, in which we deliberately kept the absolute profit range constant across the EPR/eco-modulation treatments.

Effectiveness of the weight-based incentive scheme

As expected, the weight-based fee scheme led not to improvements in eco-design, but rather to lighter products. It seems plausible that this outcome was driven by the weight-based fee structure, which monetarily rewards lighter products but not more sustainable eco-design choices. The robustness of this trend is supported by the fact that participants did not show a preference for climate protection project 1, which could otherwise have explained the observed weight reduction.

Implications of environmental consequences

The decision to design lighter products under the weight-based fee scheme resulted in a 17.33% lower mean CO_2 reduction in climate project 2 compared to the unregulated market treatment, suggesting an overall deterioration in product recyclability. The first-order environmental impacts improved by 13.02% in the weight-based fee treatment, leading to an overall environmental balance similar to that of the unregulated market treatment. While such an approach may yield some environmental benefits, such as reduced use of natural resources, lower landfill volumes, and energy savings, it contributes little to advancing a circular economy, where product recyclability plays a central role (Ellen MacArthur Foundation, 2013; Kirchherr *et al.*, 2023). Further, the core intention of EPR—to foster eco-design and reduce negative environmental impact—is not effectively addressed under a purely weight-based fee structure.

In contrast to the weight-based fee scheme, *all* tested eco-modulation schemes led to improvements in CO_2 reduction in both climate protection projects 1 and 2. This suggests not only substantially improved overall environmental performance but also a clearer advancement in product recyclability, which is more consistent with policymakers' circular economy goals.

In general, based on participants' decisions in the experiment, a total of 79.22 tons of CO_2 were reduced across climate projects 1 and 2.[10] This amount corresponds to approximately 11 years of CO_2 emissions produced by an average European (Friedlingstein *et al.*, 2025). Comparing average CO_2 reduction across the eco-modulation treatments (mean = 231.04 kg) with the mean CO_2 reduction observed in the unregulated market treatment and the weight-based treatment reveals substantial differences of 52.42 kg for T1 and 55.90 kg for T2. These differences correspond to the CO_2 emissions that an average European produces within 2.74 (T1) and 2.92 (T2) days, respectively, representing the average reduction per participant achieved through the eco-modulation schemes (Friedlingstein *et al.*, 2025).

Influence of individual differences on concern for nature

In terms of the influence of moderator variables, participants with a higher concern for nature selected more sustainable eco-designs. This suggests that the effectiveness of eco-modulation can be enhanced through measures that foster environmental awareness—such as federal environmental education programs, or training and awareness initiatives within companies (Stefanelli *et al.*, 2020; Ardoin *et al.*, 2020). The fact that the positive influence of nature concern,

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[10] Since we could only purchase whole tons from the climate protection organization, we rounded this amount up and purchased certificates equivalent to 80 tons (see Figure 2 in Appendix B).

especially among females, weakens and partly even reverses under the EPR schemes—particularly in the bonus and granular schemes—can be interpreted as a “crowding-out effect.” This finding is in line with previous studies showing that crowding out plays an important role in environmental decision-making and tends to be more pronounced among women than among men (Mellström and Johannesson, 2008; Marsiglio and Tolotti, 2020; Agrawal *et al.*, 2015). Crowding out describes the phenomenon whereby external interventions, such as monetary incentives, can undermine individuals’ intrinsic motivation (Frey and Jegen, 2001). Our data convey that participants with a comparably lower concern for nature react more strongly to the provided EPR incentives in T3–T5. This does not mean that participants with a high concern for nature (which are typically women) do not respond to the provided EPR incentives; rather, they simply respond *less strongly* compared to participants with a lower concern for nature, and this tendency is offset by the overall positive effect of eco-modulations.

Institutional/PRO perspective

From the PRO perspective, we can confirm that concerns about a decline in revenues following the introduction of eco-modulation schemes are justified, since a significant number of participants improved the eco-design and consequently paid reduced fees. However, under the eco-modulation schemes, the relation between EoL costs and PRO revenue was balanced. This suggests that the eco-modulation schemes are in line with the polluter-pays principle, ensuring that producers, rather than taxpayers, bear the EoL costs of products. In addition, the finding indicates that eco-modulation schemes have the potential to comply with Article 8a(4) of the WFD, which stipulates that the fees paid within an EPR system—corresponding to the total PRO revenue—must not exceed, but should align with, the requisite costs for providing waste management services in a cost-efficient manner (European Parliament, 2018). Further, PROs appear to have sufficient flexibility in determining the size of eco-modulation fees, as the implemented schemes in the experiment demonstrated a clearly effective incentive effect on producers’ eco-design improvements. In contrast, under the weight-based fee scheme, the revenues were insufficient to cover the total EoL costs. This reveals a key weakness of the current EPR fee system, where weight reductions are incentivized, causing PRO revenues to decline when producers make their products lighter, even though this does not necessarily entail environmental improvements. Moreover, the eco-modulation schemes substantially improved the cost efficiency of environmental outcomes, as reflected in the higher CO_2 reduction achieved per €1 of PRO revenue compared to the weight-based system, thereby aligning with the call for lean institutional EPR implementation. Overall, based on the results of our experiment, it can be concluded that all eco-modulation fee schemes represent an improvement over the conventional weight-based system from the PROs' perspective.

Policy implications

First, our results bring good news to EPR policymakers: Eco-modulation incentives work and shift—when investigated in a strictly controlled environment—eco-design and associated environmental externalities into a socially desirable direction. But what type of eco-modulation scheme should be particularly recommended to policymakers? In light of our findings, the bonus scheme appears most recommendable, as it consistently achieved the highest average eco-design levels and the best environmental performance, although these results reflect tendencies rather than statistically significant differences. Nevertheless, the granularity scheme allows fees to be more precisely aligned by design with the EoL costs of specific product designs. From a behavioral perspective, however, the bonus scheme provides a clearer and more intuitive incentive that effectively motivates producers to improve product sustainability. In addition, while eco-modulation in general proved more effective among female participants, the bonus scheme showed similarly positive effects for both males and females. Although EPR scholars may assume that the bonus scheme will lead to the largest decline in PRO revenues—since producers are granted lower fees when meeting eco-design requirements—we argue, taking a strictly behaviorally informed perspective, that the bonus should rather be understood as a framing device, and that the basic fee, bonus threshold, and bonus size can each be set to ensure cost coverage for the PROs. Based on our experimental results, like the other eco-modulation schemes, the bonus scheme complies with the normative and legal requirements of the WFD, yet performs slightly better in terms of CO_2 reduction efficiency. In this sense, it is generally preferable to prevent externalities from arising in the first place rather than to compensate for environmental harm *ex post*.

The experimental method in EPR research

As noted above, laboratory experiments are rarely applied in the context of EPR research, and criticism may arise from the view that this method lacks sufficient realism and generates artificial data with limited relevance for understanding the real-world economy (Falk and Heckman, 2009). In general, we respond that our experiment reflects a plausible EPR decision-making environment, incorporating relevant institutional regulations while upholding rigorous experimental standards. Participants in our experiment perceived their decisions as relevant and experienced genuine emotions, as they followed rules and made substantial decisions that had real consequences for earning money and purchasing emission certificates. This enabled the elicitation of decisions that aligned with participants' true preferences (Falk and Heckman, 2009). As participants were industry professionals with decision-making experience in fields related to EPR, concerns about a lack of practical expertise seem unfounded.

In our experiment, we aimed to identify the causal effects of the different eco-modulation schemes—that is, to isolate their pure incentive effects on eco-design decisions. By doing this, as mentioned above, we respond to Pruess and Garrett (2025), who criticize the frequent misattribution of causality in EPR field studies and the limitations of corresponding *ex post* evaluations. In the real-world economy, producers are not only subject to EPR but are also confronted with multiple incentives arising from a broader policy mix that may influence the design of their products (Pruess, 2023; Lifset *et al.*, 2023). This means that even if a field study on EPR reveals significant changes—such as improved eco-design or reduced product weight—these effects could not be clearly attributed to a modification of the fee structure due to the absence of a control group or the potential influence of confounding variables. Consequently, it remains an open question as to whether, and to what extent, eco-modulations actually have an impact, or constitute an inefficient use of administrative resources.

A key advantage of the experimental method lies in its ability to disentangle factors that are confounded in natural settings, and thus provide indications of how and why phenomena arise (Libby *et al.*, 2002). This is possible due to the tight control of the decision environment in lab experiments (Falk and Heckman, 2009). We were aware of and controlled, for example, the information participants received, what they could decide on, and the material consequences of their decisions. In each treatment, only a single exogenous variable (the EPR fee structure) was manipulated relative to the baseline condition. Consequently, observed behavioral differences in endogenous variables (e.g., weight, CO_2 reduction, or eco-design level) between the treatment conditions and the baseline could be causally attributed to this modification in the fee structure.

Moreover, this lab experiment was conducted at relatively low cost and within a shorter timeframe than would have been the case in a large-scale field study. Compared to more theoretical approaches—such as the game theoretical models by Alev *et al.* (2022) and Gui *et al.* (2018)—lab experiments offer the advantage of challenging the assumption of a universally selfish and rational *homo economicus* (Falk and Heckman, 2009). Systematic lab evidence—as well as findings from our experiment—shows that personal values (e.g., concern for nature) influence decision-making, yet individuals are rationally and ethically bounded (Chugh *et al.*, 2005; Harstad and Selten, 2013). To provide policymakers with targeted insights into how EPR managers actually behave, it is essential to systematically identify and investigate these phenomena.

Causal methods also improve external validity, as causal forces are more likely to generalize across policy environments (Libby *et al.*, 2002). While the exact magnitude of effects may vary depending on the policy mix, institutional setting, or market conditions, the direction of the effect is more robust to contextual differences. For this reason, our research questions ask for directional effects, rather than precise point predictions. This focus allows our lab experiment to yield insights that are both causally valid and broadly applicable, providing policymakers with reliable guidance on the mechanisms through which eco-modulation schemes influence producer design. Hence, our findings can be used to enhance the harmonization of EPR systems, as they hold independently of specific local cultural, economic, and legal contexts (Lifset *et al.*, 2023). Furthermore, our methodological approach can serve to inspire further research using behavioral economic paradigms. However, this can only be understood as a complementary contribution to research into the effectiveness of EPR incentive systems, as we are convinced that this problem area can only be better understood through the application of different methods and the generation of a wide range of evidence.

Limitations

A limitation of our experiment is that we did not account for the administrative costs associated with implementing the different EPR policy interventions, as their inclusion would have considerably increased the experimental complexity. Moreover, the existing literature provides little reliable guidance for estimating and experimentally implementing the magnitude of administrative costs across different policy schemes (Lifset *et al.*, 2023). While it is generally assumed that the introduction of eco-modulation increases administrative costs, the literature remains inconclusive on how substantial these costs are, and to what extent they actually affect the overall efficiency of EPR systems (Micheaux and Aggeri, 2021; Mallick *et al.*, 2024; Hogg *et al.*, 2020). A second limitation is that the EoL costs in our experiment, and their operationalization through the purchase of CO_2 certificates for each of the nine product designs, were based on reasoned estimations for an abstract, rather than specific, product. We deliberately chose an abstract product to maintain strict experimental control. Any concretization in the sense of choosing a specific product category would inevitably lead to specific and difficult-to-control preferences on the part of participants, which would potentially have distorted our results and made them interpretable only in relation to these specific products (Brutger *et al.*, 2023). For practical applications, we recommend that the alignment of fee sizes with the actual EoL costs of specific product designs be grounded in comprehensive LCAs to ensure that fees accurately reflect true environmental costs (Lifset *et al.*, 2023).

6. Conclusion

The first research question of this paper asked whether the different types of EPR/eco-modulation schemes are effective at incentivizing producers to enhance the eco-design of their products and reduce EoL costs. Based on our laboratory experiment, we conclude that eco-modulation schemes—particularly the bonus approach— indeed hold promising potential to improve both eco-design and overall environmental performance. The second research question asked whether EPR/eco-modulation schemes can provide an efficient system for PROs to internalize EoL costs. From an institutional/PRO perspective, we conclude that eco-modulation schemes hold the potential to internalize environmental externalities more cost-efficiently than the currently prevailing EPR systems, thereby fulfilling EPRs' normative and legal objectives. In this sense, eco-modulation schemes could bring EPR systems closer to achieving their fundamental objective: ensuring that producers genuinely bear responsibility for the post-consumer stage of their products. Future studies should use the field and the laboratory in a complementary manner, rather than as substitutes, in order to better understand the effects and underlying causal mechanisms of eco-modulation schemes in real-world EPR environments.

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