# Design Implications of Extended Producer Responsibility for Durable Products

Take-back legislation based on Extended Producer Responsibility (EPR) holds producers responsible for proper end-of-life treatment of their products. By internalizing the waste product management into the cost considerations of producers, EPR incentivizes producers to incorporate eco-design into products. In particular, because EPR emphasizes recycling for landfill diversion, the design incentives under such legislation are assumed to be geared towards recyclability. However, this assumption may be one-sided for durable products: Durable product producers can also choose durability as an additional design lever to deal with the economic burden associated with EPR obligations. In contrast to design for recyclability (e.g., incorporating easy-disassembly features) that helps reduce the unit recycling cost, design for durability (e.g., using more durable materials) helps reduce the recycling volume. The rationale is that when products are more durable, they offer higher overall consumer value. Therefore the producers can price the products higher while selling a smaller volume, resulting in fewer items for recycling and hence a lower total compliance cost.

When both recyclability and durability are available as design options in response to EPR for the producers, how these two product attributes interact critically influences the design outcomes of legislation. Intuitively, recyclability and durability are synergistic attributes, which means they can be enhanced simultaneously by similar design changes. For example, a desktop computer becomes more recyclable and durable when the plastic in the case is replaced by aluminum. Surprisingly however, they can also be conflicting, which means design improvements in recyclability (durability) may compromise product durability (recyclability). This observation is inspired by the photovoltaic panels (PVPs). PVPs have been recently added to the scope of the Waste Electrical and Electronic Equipment (WEEE) Directive of the European Commission. PVP producers face trade-offs between recyclability and durability in multiple dimensions of product design. For example, a framed design makes the panels more durable but less recyclable. Similar trade-offs also exist in the design of other products. In turn, to realize desired outcomes of EPR as it expands its scope and raises its stringency, we need to examine the following important question: *In the presence of durability-recyclability interaction in product design, how does EPR legislation influence a producer's design choices*? In this paper, we answer this question that has not been explored to-date.

This research contributes to the existing literature in multiple aspects. First, we study the product durability choice that has been largely overlooked as a design option in response to EPR. Second, we model the possible design trade-off between recyclability and durability. As such, we uncover interesting insights on how it influences the design outcomes of EPR. Third, our conclusions point out that common legislative levers of EPR such recycling and collection targets can create very different design incentives.

To analyze the design implications of EPR, we focus on EPR that imposes recycling and collection targets, following from common EPR implementations such as the WEEE Directive. Under EPR, the producer first chooses the recyclability and durability in the design stage, and then determines the new product price and the product recycling level. After observing these producer decisions, the consumers make their purchasing decisions. The interactions between the producer and the consumers are modeled as a discrete time, dynamic and sequential game over an infinite horizon. In addition to deriving insights from the analytical model, we also demonstrate how the design implications can be realized in a real-world scenario by conducting a calibrated numerical study. Based on data and expert input from the PVP industry, the study predicts a design path for PVP producers under the WEEE Directive.

Our analysis first derives an important technical result: a joint characterization of the optimal recyclability and durability in closed-form in the steady-state equilibrium. To the best of our knowledge, this is the first closed-form solution to the durability-recyclability interaction by endogenously considering the effects of design for durability in a durable good market subject to EPR. Building on this result, we derive several interesting managerial insights: We first show that when recyclability and durability are synergistic (as in the example of desktop computer casing), higher recycling and collection targets create incentives for producers to enhance both recyclability and durability in design as intended. However, when the two design attributes conflict (as in the example of PVPs), the outcomes of EPR can be counter-intuitive. In particular, relatively low recycling targets incentivize producers to design for recyclability, while lowering product durability. On the contrary, further increases in the recycling targets incentivize producers to switch to design for durability, while lowering product recyclability. On the other hand, the collection targets have very different influences: Relatively low collection targets lead to increase in product durability at the expense of product recyclability. However, further increases in the collection targets result in increase in recyclability at the expense of durability.