

Chapter 10

Operational Implications of Environmental Regulation

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10.1 Introduction and Motivation

Industrial production and consumption activities may have adverse environmental implications that lead to calls from the public, environmental groups, and non-governmental organizations (NGOs) for regulatory measures to promote sustainable practices in supply chains. As a result, many different forms of environmental regulations have been considered or enacted in the recent years, in many countries, and for various industries. Examples of those include the Restriction of Hazardous Substances (RoHS) (2002/95/EC) (Europa-Environment 2002), the End-of-Life Vehicle (ELV) (2000/53/EC) (Europa-Environment 2000), and the Waste Electrical and Electronic Equipment (WEEE) (2003/108/EC) (Europa-Environment 2003) Directives of the European Union, the Regional Greenhouse Gas Initiative in the US (RGGI 2013), and the new electronic waste (e-waste) regulation in China (State Council of China 2008).

Environmental regulation is inevitably an influential factor on different facets of firm operations. Nevertheless, implementation choices for environmental regulation are often made based on certain implicit assumptions that do not take into account firms' possible operational choices driven by such regulation or other dynamics on the implementation ground. Existing research in operations management has successfully demonstrated that this is indeed the case. In particular, recent operations management research has challenged numerous implicit assumptions made by high-impact regulations such as the WEEE Directive, identified the associated unintended consequences, and provided recommendations regarding the implications of different implementation choices for environmental regulation on the environment, supply chains, and the economy in general.

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In this chapter, we review a number of research papers to highlight challenges associated with environmental regulation implementations, particularly in the context of take-back regulation, given its popularity in the last decade. These papers cover a broad spectrum of possible issues that may arise in the transposition of regulative principles into working systems. Some of them challenge the assumptions implicitly embedded in the forms or specifications of regulation; some of them point out possible loopholes of regulation; and others identify how differences across the regulated industries or the nature of products will necessitate different supply chain responses to environmental regulation. These papers collectively show that the devil is in the details and highlight the importance of an operational perspective in designing, implementing, and coping with environmental regulation.

Consequently, we posit that an operational lens is crucial for defining appropriate environmental regulation implementation models so that regulators can set proper boundaries and scope for environmental regulation. We further suggest that supply chain managers should have a clear understanding of the operational implications of different regulation implementations in order to maintain the environmental and economic sustainability of their supply chains. In what follows, we first provide a basic background on environmental regulation, followed by our unit of analysis, take-back regulation. We then take a deep dive into operational challenges associated with such regulation and conclude with insights for supply chains and regulators.

10.2 Some Background on Environmental Regulation

The environmental policy literature contains many different classifications of regulatory instruments (see Richards 1999, for a detailed discussion), which can differentiate environmental regulations in multiple dimensions: Some regulations are product-related (such as the WEEE and the RoHS Directives of the European Union) and others are facility-related (such as the Clean Water Act (EPA 2015)). Some regulations impose restrictions (e.g., the RoHS Directive) and others require only disclosures (such as the US Consumer Protection Act, see Kalkanci et al. 2015). Some regulations are international (such as the Basel Convention (BAN 2005) and the US Responsible Recycling Act (Kyle 2011) for waste export), some are national (such as the WEEE Directive), and some are local (such as the 26 state level e-waste recycling regulations in the US (ETBC 2013)).

Among those, classifications that focus on policy implementation choice differences are relevant from a supply chain perspective. In this context, Fullerton (2001) is a very useful reference that classifies environmental policy in two basic dimensions: with respect to the form of control imposed by regulation, and the type of incentives utilized by regulation. In the first classification dimension, one distinguishes between emission restrictions (sometimes called performance standards) and technology restrictions (sometimes referred to as design standards). Examples of the former include the greenhouse gas emission restrictions with cap-and-trade

systems that can be found in different parts of the world including the US and the EU (Islegen et al. 2015). Examples of the latter include the RoHS Directive and the requirements to install flue-gas desulphurization in electric plants (Fullerton 2001). In the second classification dimension, one distinguishes between the types of incentives, i.e., taxes and subsidies. Examples of the former include the carbon taxes such as those used in Australia (Islegen et al. 2015) and examples of the latter include renewable energy credits (Ata et al. 2010). The unit of our analysis, e-waste take-back regulation, typically operates under a mix of these policy instruments. Some of these policies use performance standards such as collection and recycling targets imposed on producers (e.g., the WEEE Directive) and others charge unit disposal taxes to consumers or producers, as in California and Washington State, respectively (ETBC 2013). We provide a more detailed discussion on e-waste take-back regulation next.

The momentum for the recent rapid development of take-back regulation is driven by the urge to manage the growing volume of e-waste. The average lifespan of a computer has shrunk from 6 years in 1997 to just 2 years in 2005 (Greenpeace 2010). In 2010, 384 million units (2.4 million tons) of e-waste entered municipal waste streams in the US, with more than 142,000 computers and 416,000 mobile devices thrown away every day. Less than 20 % of those were recycled, and the rest were sent to landfills or incinerators (EPA 2011). Landfilling and incineration, however, can lead to release of hazardous substances such as dioxins, lead and mercury into the air, soil, or water, posing serious threats to the environment and public health. To deal with this problem, take-back regulation organizes proper treatment of e-waste, through environmentally friendly collection and recycling.

The majority of take-back regulation implementations utilize the Extended Producer Responsibility (EPR) principle, which directs the financial or physical responsibility of proper end-of-life product treatment to producers (see Walls 2006, for an extensive overview) via performance standards or disposal taxes as explained above. The rationale behind EPR is to have producers internalize the negative environmental impacts created by their products, so that they find incentives to redesign their products to overcome such externalities. As such, take-back regulation based on EPR aims to not only divert end-of-life products from landfills, but also create incentives for producers to embed environmentally superior attributes in their products (OECD 2001). This potential of EPR appears to explain its popularity across the globe. The WEEE Directive of the European Union, which probably has the largest scope in the world, is EPR-based. Moreover, despite the lack of federal level regulation in the US, 25 out of the 26 states (except for CA) that have passed state level e-waste bills stipulate producer responsibility (ETBC 2013).

It is important to note that successful implementation of and response to environmental regulation are challenging (Drake and Just 2015). Be it with respect to take-back, emissions control, or any other environmental objective, setting up the ground rules for regulatory objectives is a critical step and should not rely on basic convenient assumptions. Recent research has observed that efficient implementations of cap-and-trade or tax-based emission regulations need to carefully consider the incentives they create for carbon leakage (Islegen et al. 2015, Sunar 2015).

Likewise, it has been shown that environmental taxes can drive producers to invest in environmentally inferior technologies (Krass et al. 2015), and disclosure mandates can drive producers towards not learning their actual environmental impacts (Kalkanici et al. 2015). Similarly, in the context of take-back regulation—our unit of analysis—the landfill diversion and product redesign potentials of EPR heavily rely on certain premises, which, from a basic economic point of view may make sense. These basic premises include (1) that recycling end-of-life products (particularly electronics) must be costly and if left unregulated, hazardous waste will leak into the environment (see Sect. 10.3), (2) take-back regulation will create incentives to recycle only end-of-life products that can be considered as waste (see Sect. 10.4), (3) design incentives coming out of take-back regulation will mainly focus on designing more recyclable products (see Sect. 10.5), (4) such regulation is appropriate for most product categories including durables or consumables (see Sect. 10.6), (5) regulatory distortion of competitive markets is not a concern (see Sect. 10.7), (6) implementation details that relate to the existing reverse supply chain infrastructures (networks) will not matter (see Sect. 10.8), and that (7) take-back and recycling take place in the country where the regulation is enacted (see Sect. 10.9). While these assumptions may appear reasonable at the stage of designing and planning to cope with potential take-back regulation, they (or the invalidity of any of those) can be quite harmful in terms of the efficacy of the implementations on the ground and have important supply chain management implications, as we demonstrate in the following sections.

10.3 Trash or Treasure?

A fundamental assumption underlying take-back regulation is that environmentally sound treatment of end-of-life products is always costly. This also constitutes the reason why regulation is needed in the first place: to ensure that producers take the responsibility for proper collection and recycling. The thinking that logically follows is that increasing the stringency of requirements for regulatory compliance should strengthen incentives for landfill diversion and environmentally friendly design of products, which appears to underlie the 2012 Recast of the WEEE Directive (2012/19/EU) increasing the collection target to 45 % by 2016, and then to 65 % by 2019. However, in recent years, doubt has been cast on the assumption of costly recycling, especially with the roaring prices and scarcity of certain raw materials. For example, the amount of gold that can be recovered from 1 mt of computers is 17 times greater than that from a gold ore of equal weight (USGS 2001). In other words, recycling some of the e-waste can be more profitable than metal ore mining. Consequently, it appears that producers may be motivated to recycle some electronics voluntarily even in the absence of take-back regulation. At the same time, it is important to note that this opportunity presents itself to others as well, i.e., third party recyclers may also be attracted into the product recovery business, introducing competition in the market for end-of-life products with recoverable value.

These observations slightly contradict the costly recycling premise, and may imply challenges on the effectiveness of take-back regulation, which is explored by Esenduran et al. (2014).

In their paper, Esenduran et al. (2014) consider a stylized model of a recycling market in which producers and third party recyclers may compete for recycling valuable waste. They focus on a single product category. After reaching the end-of-life, products remain in the hands of a set of waste-holders that may be geographically dispersed. The recoverable value in each waste-holder's product may vary depending on its proximity to the producers and recyclers. Hence, producers and recyclers can extract different values from end-of-life products, and they compete on acquiring the e-waste from waste-holders by respectively offering recovery prices. Given the recovery prices and their respective value heterogeneity, waste-holders decide on whether and to whom to return their end-of-life products to maximize their utilities from waste recovery. In this context, the authors assume take-back regulation in the form of a collection and recycling target imposed only on the producers. They further assume that producers can enhance the product end-of-life value by increasing the recyclability at a cost.

The authors show the following: Even when waste has value, the existence of regulation may be necessary if the producers exhibit a strong position in terms of their access to the recoverable waste. The reason is that although the value of waste turns into some incentives for the producers to recycle, it is only limited to inducing recycling of the "low-hanging fruits" (i.e., easier or cheaper to access items). As a result, the recycling level chosen by the producers remains below the social optimum. In this case, enacting regulation is beneficial in several ways: It increases landfill diversion, encourages more recyclable product design, and also guarantees improvement of social welfare. However, in the presence of competition in the recycling market, regulation can lead to unintended consequences. First, more stringent regulation can reduce landfill diversion. This is because an increased collection and recycling target imposed only on the producers drives the producers to act more aggressively in acquiring the products from waste-holders. This may lead to very high prices paid to waste-holders, driving third party recyclers to hold back from the product recovery market. Effectively, this suggests that the overall collection and recycling volume in the end-of-life product market may suffer because the portion of volume contributed by the third party recyclers may go down. Furthermore, this may happen to an extent that the decrease in third party recycled volume actually offsets the increase in producer recycling induced by take-back regulation. Second, a higher collection and recycling target imposed on producers may discourage improvement on product design. This is because the spill-over of design benefits can be accentuated by competition, which makes design improvement a less appealing option for the producers. In turn, the authors suggest that more stringent regulation may not always be ideal, particularly when waste is valuable. Rather, reducing the stringency of collection and recycling targets imposed on producers, while regulating the third party recycling market in terms of the quality of recycling standards may be an ideal solution from both the economic and environmental points of view under such circumstances. The take-away from Esenduran et al. (2014) is that even

the simplest and possibly the most reasonable assumption that underlies the need for environmental regulation may be challenged by market dynamics. When this happens, the solution may appear to be trivial, e.g., in the case of valuable e-waste one may argue that the more value in waste, the more producers (or the supply chain divisions that are responsible) will recycle. Yet, how the competition on the ground functions may completely change this perspective. As demonstrated by Esenduran et al. (2014), competing for geographically dispersed heterogeneous waste in the presence of design improvement options may imply the need for supply chain managers to think differently about how they cope with such regulation. In particular, reverse supply chain managers will play a key role in such compliance efforts, as they are the parties to see waste competition related issues and inform compliance departments about such challenges in advance. In sum, the operational considerations (i.e., devil in the detail) that matter in this case are the geographical dispersion of waste (see Dhanorkar et al. 2015; Sunar 2015 for similar observations in the waste exchange and emissions regulation contexts) and whether and how producers and their reverse supply chains can effectively access the waste under competition with third parties.

10.4 End-of-Life or Used Product Recycling?

Another basic assumption of take-back regulation is that in order to fulfill the EPR obligation, producers solely obtain end-of-life products from waste-holders such as municipal collection locations. Intuitively sound as it is, this assumption may not directly extend to durable goods. In particular, durable good producers can also acquire used (midlife) items from the secondary market for product recovery, despite the remaining lifespans these items have.

Producers may have incentives to pull used products off the secondary markets and use them as inputs for recycling due to two reasons. First, a secondary market offers used products as cheaper (although maybe inferior) alternatives to the new ones and hence potentially attracts consumers away from buying new products, i.e., cannibalizes the new product sales. In this case, reducing the cannibalization constitutes a motivation for producers to interfere with, or even suppress the secondary market. Second, acquiring used products also helps lower the need and cost of collecting end-of-life items to meet the collection target. In addition to being viable, this option is also feasible for producers: They can obtain used products through offering trade-ins or buyback programs.

However, from the environmental and regulatory standpoint, retiring used products before they reach the end-of-life can be unfavorable because this practice shortens the average useful life of products and increases the total waste volume. This leads to two critical questions: How will the producers' optimal strategies to interfere with the secondary market change when faced with regulation? Consequently, how will such interference influence the effectiveness of take-back regulation? Alev et al. (2014a) shed light on these questions.

Alev et al. (2014a) develop a stylized economic model to study the decisions of a monopolist durable good producer under EPR-based take-back regulation with (1) collection targets, which can be met by collecting both end-of-life or used products, (2) requirements on collection infrastructure, which will be reflected in the unit collection cost of end-of-life products, and (3) recycling standards, which will be reflected in the unit cost of recycling every product. Their analysis shows that the decision of the producer on interfering with the secondary market is indeed influenced by the regulation. This is evident by the fact that retiring used products can be purely induced by the need to fulfill the regulative collection target and will not exist in the absence of regulation. When such interference occurs, it can lead to a lower reuse level and a higher new production volume, both commonly associated with unfavorable environmental consequences.

In this case, the effectiveness of take-back regulation is weakened by the fact that there are two types of collection channels that a durable good producer can strategically use for compliance: In addition to collecting end-of-life products, the producer can also acquire used products from consumers in the secondary market for recycling. Since the existence of this alternative collection channel is unique to durable products, regulators and producers of durable products should pay particular attention to the environmental and supply chain implications of take-back regulation.

From a regulator perspective, the results in Alev et al. (2014a) suggest the following: First, recycling standards remain effective. Higher recycling standards help ensure the producer collect and recycle end-of-life products. Consequently, premature retirement of used products decreases. Second, collection infrastructure requirements bring in similar benefits as the recycling standards, but only up to a certain stringency, beyond which their effect negates and leads to increased producer interference with the secondary market. Finally, the effect of the collection target is not always positive. To be specific, when the collection target increases within a low value range, it may incentivize the producer to interfere with the secondary market, and hence adversely results in increase in new production and decrease in reuse levels. These results suggest that the take-back regulation for durable goods, while achieving the objective of increasing the level of collection for recycling, may compromise other environmentally sound objectives such as reuse and consumption reduction. This outcome appears undesirable from the perspective of the well-established Waste Management Hierarchy, which prioritizes reduce over reuse, and reuse over recycling.

From the supply chain perspective, these observations once again highlight the importance of the reverse supply chain manager's role in compliance. In particular, the reverse supply chain manager who observes the costs of compliance and different product recovery options can help resolve such dilemmas for the firm. For instance, the reverse supply chain manager can bridge the connections between compliance and marketing departments to manage the acquisition of used products through trade-in programs and direct such flows towards take-back regulation, which appears to be the essence of Apple's recent Recycling and Reuse program (Apple 2015).

10.5 Durability or Recyclability?

The durability embedded in products raises complexities in regulation in regards to not only how it influences the collection decisions for producers by providing an additional collection channel as discussed above, but also how it influences the design decisions. Recall that incentivizing environmentally sound product designs is one of the basic goals of take-back regulation. When regulation on recycling is enforced, one expects that it should induce producers to make recycling cheaper by improving product recyclability (e.g., incorporating easier disassembly features) in the design. This assumption is also popular among regulators as reflected in regulative statements. One example is the E-waste Recycling Law in Washington State, which spells out that “The legislature further finds that the system must encourage the design of electronic products that are less toxic and more recyclable” (New Section, Sec 1, SB4628). However, for durable products, enhancing recyclability to reduce the unit cost of recycling is not the only option for producers to alleviate the total economic burden associated with the recycling obligation. Producers can also improve the product durability to lower the recycling volume. The underlying rationale is that making products more durable enables the producers to set a higher price for new products and sell less, leading to a smaller amount of end-of-life products and hence a lower total cost of recycling. As such, when recyclability and durability are both available design options for producers, it may be of interest to review the design implications of regulation. In particular, one would like to understand how the producer’s design choices and the regulatory efficiency change in the presence of these alternative design options, especially when they are interdependent. This problem is examined by Huang et al. (2014).

Huang et al. (2014) consider a monopolist producer selling a single durable product and facing take-back regulation that imposes a collection target and a recycling target for end-of-life products. The producer, in response to take-back regulation, can choose both the product recyclability and durability in the design stage to deal with the cost associated with the regulation. The authors find that when the product recyclability and durability are independent or complementary attributes, increasing the recycling target helps induce the desired outcome with improvements on both the product attributes. However, when recyclability and durability are substitutes, the design trade-off between them can result in non-monotonic effects of the recycling target, which is in sharp contrast to common expectations: As the recycling target goes up, it first leads to recyclability improvements (while the durability may decrease) and then leads to durability improvements (while the recyclability may decrease). Note that increasing recyclability in product design encourages recycling by bringing down the unit recycling cost, while increasing durability promotes waste reduction by leading to a lower production volume. Therefore, when recyclability compromises durability, the design trade-off suggests that recycling comes at the expense of waste reduction. Finally, contrary to the non-monotonic effects of the recycling target, the collection target always favors recyclability when recycling can generate value since a tighter collection target results

in an increase in recyclability while durability may be compromised due to the recyclability-durability trade-off.

These conclusions send an important message to regulators: Design alternatives for the producer to deal with the costs associated with the EPR obligation are critical operational factors that influence the outcomes of take-back regulation. As demonstrated by Huang et al. (2014), the existence of durability as an alternative design option to recyclability may not necessarily expand the effective scope of regulation (i.e., enhance both product attributes). On the contrary, the possible trade-off between design choices may diminish or even negate the effectiveness of regulation (see Plambeck and Wang 2009, Krass et al. 2015 for similar observations in the context of new product introduction frequency and technology choices, respectively).

From the supply chain perspective, these results once again suggest that effective compliance with take-back regulation will require coordination between the reverse supply chain manager, the compliance department and the design/engineering department. Consider photovoltaic panel (PVP) producers for instance, who face a clear trade-off between designing products for durability and recyclability (see Huang et al. 2014 for details). The 2012 Recast of the WEEE Directive has recently added PVPs into the regulated product categories. Even though compliance with such regulation may not be a concern for the producers today because the lifespans of PVPs are estimated to be 25 years, it will be critical for the producers to prepare for future liabilities take-back regulation will impose on them. In this case, it is important for PVP producers to plan for a reverse supply chain infrastructure that will be able to accommodate different design profiles and help reduce future liabilities associated with PVP recycling.

10.6 Durable or Consumable Products?

While our discussion so far has been centered around durable products, EPR-based take-back regulation has also extended to consumable products in recent years, with examples being the announcements of the Pharmaceutical Stewardship Act of 2011 (H.R. 2939 (112th) 2011) and the Alameda County Safe Drug Disposal Ordinance (Alameda County, CA 2012) in the US.

In the context of take-back regulation for consumables, leveraging experiences from durable product markets may appear ideal. However, producers and regulators must be aware of the implementation differences stemming from the consumable and perishable nature of consumable products and adjust accordingly. In particular, contrary to durable products, the volume of end-of-life waste does not equal to the volume of production for consumables. Moreover, recovery options for consumables are limited because reuse and recycle are usually not applicable. Therefore, regulation for consumables needs to focus more on reducing the volume of unused items that are not disposed in an environmentally friendly way. In doing so, there exist two prevalent implementation approaches. The first is Source Reduction (SR),

which aims to lower production by charging a fee based on production volume. The second is End-of-pipe Control (EC), which mandates the producer to organize or finance proper waste treatment. Given the product nature of consumables, further exploration is needed in order to determine how one can choose between the SR and the EC approaches to effectively improve the environmental and economic impacts of regulation. Alev et al. (2014b) pioneer in this area and their findings depart considerably from the existing results for durable products.

The products considered in Alev et al. (2014b) are consumable pharmaceuticals. The decision makers in the pharmaceutical chain include a social planner, a producer, a doctor and a patient, whose interactions are captured by a sequential game model. The doctor acts as an intermediary between the producer and the consumer (the patient). Therefore, the sales volume of pharmaceuticals is not directly determined by the consumer behavior, but by the doctor's prescription instead. The prescription amount that exceeds the actual consumption by the patient (overprescription) constitutes the main source of pharmaceutical waste. The doctor makes the prescription decision based on not only the cost of treatment and the impacts of the prescription on patient's health, but also the doctor's own utility from the prescription. The producer influences the sales volume by deciding the market price, as well as setting the promotion efforts on both the doctor and the patient. The social planner chooses between the two implementation approaches of regulation from below and sets the respective policy parameter.

- (1) EC: Requires the producer to collect a certain fraction of unused pharmaceuticals. The producer also bears the associated collection cost. This implementation resembles a typical producer-operated collection and recycling system observed in prevalent EPR implementations.
- (2) SR: Imposes a fee on every unit of sales. After obtaining the fee payments, the regulator manages the collection (e.g., chooses the collection level) and the costs incurred. SR resembles a typical state-operated system observed in prevalent EPR implementations.

The analysis finds that for pharmaceuticals that are consumable in nature and have a different demand structure with the doctor acting as an intermediary between production and actual consumption, the comparison between the two implementation approaches is very different from that for the durable products. The paper shows that a producer-operated system (under EC) can be preferred by a social planner when the following conditions are met: (i) the cost of collection is high, (ii) the use-phase impact (i.e., the health condition improvement for the patient) is less significant, and (iii) the impacts on the society (e.g., medicine abuses) and the environment (e.g., chemical contamination in the ecology) are high. Notably, (iii) is in direct contrast to the conclusion for durables, which suggests that under similar condition the state-operated system should work more efficiently (Atasu et al. 2013).

This study, although solely focuses on pharmaceuticals, delivers an insightful lesson that may be generalized for other consumables. The product nature is the operational detail that matters. While take-back regulation is devoted to dealing

with products that are at the end of their useful life, the definition of useful life can vary substantially depending on the product nature. For a durable product, the end-of-life item has lost its functionality and will not be demanded by consumers. For a consumable, on the other hand, reaching the end of its useful life means it no longer provides the original designated usage, but it may still be in a functional state and may be consumed by others. This difference can significantly affect the efficiency and implications of different regulation implementation choices as demonstrated by Alev et al. (2014b).

Therefore, the product nature must be carefully accounted for by regulators and producers in order to avoid implementation choices that would compromise operational or regulatory efficiency. It is especially important that the reverse supply chain manager understands these implementation issues. In particular, Alev et al. (2014b) show that which implementation model will be preferred by a regulator depends on the unused pharmaceutical collection infrastructure the producer has access to. For instance, while leveraging existing pharmacies or municipal collection systems may appear a low-cost option for the producer, in those circumstances the regulator may favor a SR approach with higher taxes, eventually leading to a lower profit for the producer. In turn, the reverse supply chain design that serves take-back compliance needs not be the most cost efficient one in the context of consumables.

Our discussion so far has demonstrated that the proper evaluation and development of policy instruments must be based on correct and thorough understanding of the detailed operational characteristics of the target industries, including the commodity market dynamics, the alternative strategic responses available to producers, and the nature of products. Beyond that, the devil in the details also matters in the implementation stage, in which regulators and producers translate the regulation into a working system. We illustrate this phenomenon in what follows.

10.7 Collective or Individual Producer Responsibility?

Although EPR-based take-back regulation sets a unified principle of assigning producer responsibility, it leaves discretion for regulators to choose the operationalization of product collection and recycling. Typically, two models of implementation can be observed: Individual, and Collective Producer Responsibility (abbreviated as IPR and CPR respectively, see Plambeck and Wang 2009 for a similar discussion). Under IPR, each producer deals with only its own products. A somewhat similar model is adopted by the Personal Computer Recycling Law in Japan, where products are separated by brands after collection and then become the responsibility of the corresponding producers. Under CPR, all participating producers jointly conduct end-of-life product treatment and share the total costs. Examples of this model can be seen in the WEEE Directive implementations in several EU member states.

Both IPR and CPR models have certain pros and cons, and neither of them is dominantly better than the other. On one hand, CPR is commonly considered

superior in cost-efficiency because it realizes economies of scale by aggregating the collection and recycling of a large volume of products and also saves on the costs associated with brand identification and separation. However, CPR is criticized for significantly undermining the eco-design incentives. Under CPR where costs are shared, the benefits (such as recycling cost reduction) from the individual design efforts spill over to other producers or even competitors, and hence producers may be less motivated to improve the product design for recyclability. The IPR model, on the other hand, overcomes this weakness of CPR and creates stronger design incentives because the independence of processing costs among producers under IPR enables each producer to retain the returns from the investment on product design improvements. Therefore, the choice between IPR and CPR is largely driven by the trade-off between design incentives and cost-efficiency. At the same time, the impacts of these two factors also depend on the dynamics in the market. As such, it is a useful exercise to compare the two models following Atasu and Subramanian (2012) and Esenduran and Kemahlioglu-Ziya (2015).

Atasu and Subramanian (2012) build a single-period model with a duopoly sales market in which high-end and low-end products are sold respectively by two producers. Consumers make purchasing decisions based on their heterogeneous product valuations for the differentiated products. The regulation mandates producer responsibility by imposing a binding recovery target for end-of-life products on both producers. The regulation can adopt either the IPR or the CPR model. Under IPR, each producer only pays the cost associated with its own products. Under CPR, the two producers share the total processing cost. The cost-sharing can be set endogenously (i.e., according to the return shares, which also reflect the market shares in this context) or exogenously (which will be predetermined and fixed). In response to the regulatory obligation, each producer can invest in improving the product recovery attributes to reduce the cost of end-of-life recovery treatment of its products.

By comparing the outcomes under IPR and CPR, the paper shows that incentives to design more recoverable products exist under both models, but the incentives are always weaker under CPR than under IPR. The reason is that CPR allows for one of the producers to free-ride on the other's design efforts. Under CPR, although the existence of free-riding is less surprising, the detail as to who free-rides can be counterintuitive. When the cost-sharing is endogenous, the bigger contributor (whose processing cost has a higher weight in determining the final shared unit cost) may suffer from being free-ridden just as expected. However, when the cost-sharing is determined exogenously, the bigger contributor can become the free-rider. This reversal of the outcome is caused by the competitive structure in the primary market. Under IPR, however, the market competition does not have direct influences on the design incentives. In return, the free-riding under CPR also has feedback effects on the primary market because the producer who benefits from free-riding can lower the price more aggressively and hence provides a higher surplus to its consumers, while its competitor only offers a lower consumer surplus. Note that these observations are nicely aligned with perspectives from different fields such as industrial ecology (Lifset and Lindhqvist 2008) and practitioners (Atasu et al. 2015).

This analysis draws our attention to another operational aspect that matters in implementing take-back regulation: The scope of responsibility, shared under CPR versus independent under IPR, may have different influences on product design. Furthermore, the strategic dynamics including competition and integration of the compliance-related considerations into the design and pricing decisions for producers are key drivers of take-back regulation efficiency.

Interestingly, while also looking at the comparison between IPR and CPR, Esenduran and Kemahlioglu-Ziya (2015) take a very different perspective: They analyze how the coalition structure under the collective model matters. The composition of a coalition is a non-trivial factor because it can vary dramatically in reality. For example, the European Recycling Platform (ERP) that is set up in response to the WEEE Directive mainly consists of large (in terms of market/return share) firms including Braun, Electrolux, HP and Sony. On the contrary, the collective systems set up by the local government authorities such as the one in Washington State covers a much wider range of both big and small firms. The authors argue that the coalition structure in a collective system may have important implications as to the efficiency of the take-back regulation implementation. Esenduran and Kemahlioglu-Ziya (2015) look at n firms with distinct market shares in a collective system. All firms are subject to the same regulation that mandates a collection target. In response, each firm can choose the recyclability of its products. A higher recyclability helps reduce the unit cost of recycling, but it also incurs the cost of increased recyclability because it makes production more expensive. To stay focused on the take-back context, the paper focuses on compliance-related costs that include collection and recycling costs, as well as the cost of increased recyclability. Compliance schemes can be of two types. Under IPR, each firm sets the actual collection rate to minimize its own overall cost. Under CPR, the central entity of the collective system determines the actual collection rate to minimize the total cost of collection and recycling incurred to the entire system, which will then be split among all producers by market shares. Note that the option of overcompliance for producers, i.e., the actual collection being higher than the regulation target, is also considered. Economies of scale are reflected in the marginal recycling cost that is decreasing in the total recycling volume.

Esenduran and Kemahlioglu-Ziya (2015) show that under CPR, the equilibrium recyclability level is lower for smaller firms, which is somewhat consistent with the free-riding result in Atasu and Subramanian (2012). In addition, the paper also reveals some unexpected conclusions. One result shows that the equilibrium recyclability level can be higher under CPR than under IPR, which is in direct contrast to Atasu and Subramanian (2012). The recyclability being higher under CPR tends to happen when the collective system is formed by big firms. The underlying rationale is that under CPR, free-riding issues are less severe for the partnership with big firms. Moreover, producers benefit from higher economies of scale. Therefore, the equilibrium collection rate is higher, which then drives up the total return of the recyclability investment (reduced processing cost for more units) and hence encourages better design. Another conclusion points out that although CPR appears to facilitate economies of scale and hence should always lead to a higher collection

rate (i.e., higher degree of overcompliance), it is in fact possible to have a higher collection rate under IPR than under CPR, especially when the collective system consists of small firms. The reason is that in addition to economies of scale, better designs can also induce more collection because when products are more recyclable they become cheaper to process. However, when a firm is in a collective system with other small firms, it bears the risk of being free-ridden and cannot retain the full benefit of design enhancements. As a result, it has lower design incentives than when it acts alone. The negative effects of diminished design incentives can even dominate the positive effects of processing at bulk and therefore results in a lower overall collection rate under CPR.

Another insightful finding is that a firm may incur a higher cost when it joins a collective system with other relatively smaller firms compared to when it collects and recycles individually. In that case, if the firm pulls out of the collective system and if the firm is big enough, then the compliance cost of the collective system goes up. Note that these observations have important implications for supply chain managers. In particular, these results suggest that the reverse supply chain manager needs to consider take-back compliance collaboration with other firms very strategically. Depending on the type of compliance partners, a reverse supply chain manager may increase or decrease the reach of its collection programs and inform the design/engineering department regarding the extent of take-back compliance cost savings that can be achieved by improved designs.

The take-away from this study is that the coalition structure in a collective system is another operational detail that makes a difference in implementation. Specifically, compliance behaviors of a producer in collection or product design can vary significantly depending on the relative size of the producer and those of the other participants in the coalition.

In sum, Atasu and Subramanian (2012) and Esenduran and Kemahlioglu-Ziya (2015) collectively provide a comprehensive understanding of collective and individual models of producer responsibility in implementation. Their results reveal certain weaknesses associated with each model, and motivate the need for research towards more powerful regulative tools for efficient implementation. One natural direction for such pursuit is to explore the possibility of integrating the most prominent advantages of the two models, namely, generating superior design incentives and achieving cost-efficiency.

As such, we start with the collective model as a base to seek potential improvements. First and foremost, note that the consolidation of end-of-life products, while facilitating economies of scale, does not exclude the potential of a collective model to properly internalize the associated processing costs for incentivizing eco-design. Rather, the root of the problem actually resides in the cost allocation mechanism, which is usually based on return share or market share. Such proportional cost allocations gain popularity among both scholars and regulators mainly due to their simplicity and transparency. However, they are not ideal solutions because they give rise to the first weakness of the collective model, which involves fairness and stability concerns. Producers who feel overcharged by a collective system may be driven to break away and operate in an individual system instead. This jeopardizes the

stability of the collective system, which is a prerequisite to sustain the scale advantage. This outcome is indeed observed in practice. One recent example is that in Washington State, where a centrally run standard plan is in place with a statewide collective system, some producers file requests for switching to self-operated independent plans with the belief that their stand alone cost will be lower. This is because the proportional cost allocation model employed by the collective system in Washington State falls short of accounting for recycling cost heterogeneity across producers. Note also that responsibility allocation problems are not unique to the take-back regulation context. See Caro et al. (2013) and Sunar (2015) for similar discussions in the emissions regulation context.

As such, a first step towards building a more robust collective system starts with a search for a cost allocation mechanism that accounts for product-specific metrics to help achieve fairness in cost allocation and guarantee stability. Meanwhile, the concrete operations of collection and recycling in a collective system are likely to be conducted in a network where the end-of-life items from numerous producers are processed by the aggregation of different recycling capacities. Consequently, the cost allocation model to guarantee fairness and stability should also properly incorporate network effects in a collective system. Gui et al. (2014a) present a fruitful attempt in this direction.

10.8 The Individual or the Network?

Gui et al. (2014a) study a set of producers that are faced with recycling standards imposed by regulation. A collection and recycling network (CRN), which effectively is a collaborative reverse supply chain, collectively handles all the end-of-life products from producers. The network comprises of three sets of nodes that represent the collection points, the consolidators, and the processors respectively. All items go through one of each set of these nodes in sequence. The edges in the network stand for costly processes of collection, consolidation, processing, and the transportation in-between. Product heterogeneity in the model is reflected by different costs of processing the products of different producers. The collective system is stable when a grand-coalition is formed and all producers choose to voluntarily stay in the system. The system stability requires a fair cost allocation, which is defined as one that ensures each producer to be better off by remaining in the grand-coalition. If a producer can achieve lower cost outside the collective system, it will leave the grand-coalition to operate individually or to form a sub-coalition with some of the other producers.

The processing capacities in the network consist of capacities that are privately owned (or contracted) by producers and capacities that are contracted by the central authority who runs the grand-coalition. While the former type of capacities can be used by any (grand- or sub-) coalition the owner producer belongs to, the latter can only be used by the grand-coalition at no additional cost. The total cost incurred by the collective system is calculated based on the socially optimal routing (i.e., the

cost minimizing solution to the network flow problem) and will be shared by the members in the system.

The paper develops a fair cost allocation model based on the prevalent return share heuristic: The cost-corrected return share with capacity adjustment (hereafter referred to as the dual-based cost allocation) makes two adjustments to the return share-based cost allocation. The first is that in deriving the return share, each producer's return volume at every collection point is weighted by the marginal cost of processing its products. This adjustment reflects the product heterogeneity in the network. The second adjustment is to grant a reward to each producer for the valuable capacities it contributes to the network, at a properly set unit reward price.

The study further shows that this cost allocation can be widely applicable and retain fairness even when economies of scale enter the model, or when the central authority-contracted capacities are open at a fee to producers outside the grand-coalition. These findings are validated using the actual EPR implementation data from Washington State.

This research once more highlights the importance of operational angle, this time in the form of network effects under the collective model. Since the key characteristic of operations in a network is the pooling of available capacities for better utilization, the critical operational angle here is how resource sharing can be reflected in the cost allocation. Notably, the dual-based cost allocation, in addition to maintaining system stability, also shows potential to make up for another deficiency of the prevalent return share-based allocation. To be specific, the dual-based allocation can help enhance the undermined design incentives in collective take-back regulation implementations because it rewards the ease of recycling of products by accounting for the product heterogeneity. Gui et al. (2014b) dive into exploring this possibility, and the result shows that not only the product design choices, but also the process technology matters in a network setting.

In Gui et al. (2014b), end-of-life product treatment is conducted collectively in a network with a similar setting to the one in Gui et al. (2014a). One crucial aspect of the network configuration highlighted in this paper is the differentiation in both cost-efficiency (i.e., process technology) and capacity of processors. When there are sufficient low-cost capabilities, cost synergy in the collective network is high because the resource sharing in collection and recycling has a higher potential for cost savings. In the network, product design improvements are also related to the characteristics of the processors, because the benefits of design are mostly realized through influencing the processing cost. Specifically, product design is a substitute (complement) for process technology when the enhancement of recyclability leads to higher (lower) cost reduction at the less efficient processors. The paper focuses on a collective system under a stable cost allocation, such as the dual-based cost allocation that ensures the grand-coalition stability, and concludes the following: Under certain conditions, a collective implementation, while having a cost advantage, can stimulate design incentives that are comparable or even superior to those under an individual implementation. The conditions to achieve this environmentally and economically desirable outcome are to have low (high) cost synergy when the product design and the process technology are substitutes (complements).

When these conditions are not met, the tension between achieving cost-efficiency and creating design incentives is irreconcilable under a collective system. That is, a collective system may not be both coalitionally stable (which facilitates economies of scale) and strong in motivating product recyclable design at the same time.

This paper points out the importance of another operational detail: Understanding the level of cost efficient technology in a collective system network and its relation to the product design is key to constructing effective regulation and successfully coping with it. It also suggests that the reverse supply chain manager needs to weigh the value of collection and recycling capacity investments or product design improvements it may make for take-back compliance in the light of the existing collection and recycling infrastructures. Such systems operated by other producers or statewide compliance schemes and the availability of the technologies they leverage can significantly influence the value-added from capacity investments or product design improvements.

10.9 Local Regulation or Global Goals?

Another major concern in dealing with end-of-life products is their leakage from the regulated work management systems due to exports: As end-of-life product waste is costly to process, exporting the waste to developing areas such as Africa and Asia may become an attractive option to producers. The processing costs in these areas are typically much lower due to the lack of stringent processing requirements and the availability of cheap labor. Obviously, this is bad news for the exporting area because when the waste leakage is not properly handled, the effectiveness of regulation in meeting the environmental objectives is seriously undermined. On the other hand, mishandled waste poses an acute hazard to the health and environment in the destination areas of waste export. Note also that such global leakages of environmental externalities are not unique to the take-back context. Similar observations have been made for emissions leakage as well (see Sunar 2015; Drake and Just 2015; Islegen et al. 2015).

In view of this real threat that has already been observed in the practice of electronics recycling (e.g., documented in BAN 2005), the European Union has ratified the Basel Convention, which is an export restriction that prohibits export of end-of-life products. Nevertheless, although dumping waste is unacceptable, the export of used but still functioning products to developing countries may be allowed. The rationale is that exporting functional used products can be a win-win solution. It helps manage the unwanted items in the developed country and provides people in a developing country with affordable access to used products. This forms the foundation for what we call partial export restrictions, under which used products in working condition are permitted for export while end-of-life products are not. A similar example is the introduction of the Responsible Electronics Recycling Act in US Congress in 2011 (Kyle 2011).

Some NGOs, such as the Basel Action Network, however, argue that it may be beneficial to ban exports of even used products, i.e., a full export restriction. As we

compare the partial export restriction to the full export restriction, we have to keep in mind that producers may utilize the used products pulled off the secondary market along with the end-of-life products to fulfill the recovery obligation as aforementioned. Then allowing used products with remaining lifespans to be exported may accentuate this type of secondary interference that has been shown to be environmentally unfavorable. Therefore, the problem becomes of concern that how do different stringencies in export regulation (none, partial or full restriction) differ in terms of environmental performance. This problem is addressed in Alev et al. (2014a).

In Alev et al. (2014a), the setup and assumptions for this problem are the same as in the main model exhibited earlier. When products are exported from the developed country to a developing country, the associated unit recycling cost is reduced to reflect the lower cost in the developing country due to cheaper labor or lower processing stringency requirements. The authors then compare the partial and the full export restrictions, while the former forbids the export of end-of-life products, the latter forbids the export of both end-of-life and used products.

The first finding in Alev et al. (2014a) is that when compared to the case with no export restriction, under a full export restriction, the reuse level is higher and the new production volume is smaller in the developed country. This result substantiates the need for closing the door for the export of products from the developed country's perspective, because preventing the export of both used or end-of-life items reduces a producer's incentive for secondary market interference. The result of a partial export restriction, on the other hand, is surprising. Intuitively, we expect that the partial export restriction should partially attain the benefits of a full restriction. However, a partial restriction may lead to even worse outcomes. To be specific, with a partial export restriction, the reuse level may be lower and the total production may increase in the developed country. Moreover, the developing country that receives exports may suffer from the environmental consequences of a higher export volume.

These results once more show that the lack of understanding the operational mechanisms that underlie producer incentives can compromise the regulation effectiveness; not only in the developed economies where take-back regulation is enacted, but also in developing economies importing used products. The detail that critically matters in this case is that reverse supply chains for compliance can in fact have two destinations for recycling, namely, domestic and international. Overlooking the international export as a way to deal with end-of-life obligation can create loopholes in export restriction mechanisms.

10.10 Conclusion: The Devil in the Details

In this chapter, we reviewed a series of operations management papers dealing with take-back regulation implementations to discuss a broad spectrum of possible issues that may arise in crafting of and complying with environmental regulation. This review suggests that the supply chain challenges associated with environmental regulation may particularly be driven by policy implementation decisions, often because of certain assumptions based on abstraction of environmental problems and

industrial dynamics: Even basic assumptions that are intuitive, sound and applicable in general circumstances may in fact not hold due to various reasons. These may include technology or commodity market dynamics, differences across the regulated industries, nature of the products of interest, or less obvious but valid alternative responses for producers under regulation.

In turn, these observations suggest that successful design of and compliance with environmental regulation can only be possible with careful implementation choices that account for the devil in the details. This insight emphasizes the merits and importance of taking a supply chain perspective in the context of environmental regulation. We posit that for environmental regulation to achieve its goals, it must account for its influence on the operational decisions of all stakeholders involved, especially those who are directly targeted by the regulation, e.g., producers and their supply chains. In other words, an operational lens appears to be a key instrument in defining appropriate implementation structures for environmental regulations and responding to the ground rules they impose. It is critical that supply chain managers understand the details of take-back policies as they are often not what they appear to be on the surface.

As environmental regulation gains momentum, it will inevitably have to deal with more problems emerging from a wider scope of fields. To triumph in these new challenges calls for more supply chain research in different directions. Looking again at the take-back regulation, although extensive work already exists as discussed, its continuous development may still give rise to new questions to be answered. One instance is that, as recycling activities flourish, encouraged by the more stringent recovery targets, an increasing number of entities are entering the recycling industries to share the pie and make profit. To ensure regulatory effectiveness in promoting environmentally superior treatment of end-of-life products, current regulation on recycling standards may need to be modified and extended to also cover these recyclers. As demonstrated by research studies considered in this chapter, crafting more efficient regulation will require a thorough understanding of the operational details involved. The same is also true for other forms of environmental regulation, such as the RoHS and the REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) Directives of the European Union that regulate the use of certain substances and chemicals, and the variety of emission regulations around the globe. In particular, the emission issues have a wide range of influence because pollutants can transport to other areas easily. As a result, dealing with emission problems may involve extensive collaboration and coordination between various supply chain stakeholders and lead to different operational problems.

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