Take-Back Legislation and its Impact on Closed-Loop Supply Chains

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Abstract

In this article, we introduce and exemplify existing legislation that regulates the end-of-life processing of used products and discuss potential implications of such legislation on closed-loop supply chains (CLSCs). Using a generic CLSC model, we provide our perspective on how such legislation in general influences different stakeholders in closed-loop supply chains.
1. Introduction

In response to increased pressure from the public at large, as well as green organizations and the NGOs, governments around the globe have started to enact directives and pass legislation to tighten the control on waste generation and to reduce environmental damages. There are several types of environmental legislation that are currently in place or being planned, which differ in terms of the product life-cycle phase the legislation is mostly concerned with. For instance, the EU’s Framework Directive (2005/32/EC) on the eco-design of energy using products (EuP) regulates product design, the RoHS Directive (2002/95/EC) of the EU restricts the use of certain material and substances in production, The Basel Convention directs the export of recovered (hazardous) material and disposal, and the WEEE Directive of E.U. (Directive 2003/108/EC) regulates the take-back and recovery of end-of-life products.

Among these, take-back legislation arguably has the most comprehensive impact on closed-loop supply chains, and therefore constitutes the focus of this article. Our objective is to provide an overview of some of these regulations that deal with the end-of-life treatment of used products and discuss their impact on closed-loop supply chains (See article 4.5.9.1-Remanufacturing for further discussion). There are many different types of closed-loop supply chains in practice, and these structural differences impact the nature of both forward and reverse flow of products. In this article we utilize a generic closed-loop supply chain structure, where the closing of the loop occurs after the end-of-life phase. Specifically, we consider 5 phases, representing different stages of the life-cycle of the product. These are the production, distribution, use, collection and recovery stages. Thus, the main stakeholders in our analysis are the producers, distributor/retailers, end-user/consumers, collectors, remanufacturers and recycler/processors. We remark that we use these terms broadly. For example, the producer refers to original equipment manufacturers (OEMs) and their entire supply chains that eventually manufacture or import new products. Logistic firms are typically involved with the transportation of new products, as well as the collection of used products from end-users and their transportation for recovery operations. Likewise, municipalities, local and national governments play crucial roles in setting up the infrastructure for collection and recovery, as well as imposing regulations that impact the operations of the closed-loop supply chain.
2. Existing Take-Back Legislation Implementations

While all existing take-back legislations have a common goal, i.e., reducing the waste generated from end-of-life products, implementations significantly differ from one country to another (e.g., Atasu and Van Wassenhove 2009; Kahhat et al., 2008). Such differences naturally result in different effects on the involved stakeholders. Below we list some important factors that could have a bearing on the impact of take-back legislation on these stakeholders.

**Policy Tools:** An important difference between alternative take-back legislation implementations comes from the policy tools chosen. For instance, The European Commission has chosen collection, recycling and recovery\(^1\) targets as a policy tool for the end-of-life management of e-waste and end-of-life vehicles. The Waste Electrical and Electronics (WEEE) Directive (2003/108/EC) of the European Commission requires Member States to ensure collection of 4 kg of such waste per capita per year starting from December 31, 2006, free of charge to consumers. The new proposal, made in December 2008, calls for 65% collection rate target (by weight) to be reached by 2016. Producers are responsible for collecting and processing end-of-life products to meet regulatory targets (percentages by weight) on product recycling or recovery. These targets differ for each category of waste. For example, in the case of large household appliances the targets are 75% for recycling and 80% for recovery, whereas for small household equipment, tools and medical devices the rates are 50% and 70% respectively. Similarly, the End-of-Life Vehicle (ELV) Directive of the European Commission (2000/53/EC) mandates free take-back of ELVs from the last owner, with target rates of 80% for reuse & recycling and 85% for recovery (to increase to 85% and 95% by 2015 respectively).

On the other hand, The State of California (CIWMB, 2004) has chosen advance recycling fees for the management of e-waste. The Californian legislation requires all consumers to pay a non-

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\(^1\) In our discussion, *reuse* means any operation by which components of used products are used for the same purpose for which they were conceived. *Recycling* means the reprocessing in a production process of the waste materials for the original purpose or for other purposes but excluding energy recovery. *Recovery* includes both recycling and energy extraction.
refundable fee when buying a new or refurbished product that contains a Cathode Ray Tube (CRT) monitor or an LCD screen. The fee is used by local governments to pay authorized electronic waste collectors and recyclers.

Other policy tools, such as recycling fees (per sold or per collected unit), are also used in different parts of the world, e.g., in Japan or in Taiwan (see Dempsey et al., 2008 for further discussion.).

**Financial responsibility:** Some legislation hold the producers financially responsible for the costs of take-back (*producer pays* model), while others hold the end-user or the purchaser of products for the costs of product take-back (*consumer pays* model). For instance, the producers are financially and physically responsible for the treatment of e-waste according to the European WEEE Directive, while in California consumers pay an Advance Recycling Fee (ARF) at the moment of purchase to cover for take-back related costs of certain electronics products. With a slight variation, the Specified Home Appliances Recycling Law (SHARL) of Japan (Kahhat et al., 2008) charges end-users for the costs of take-back and recycling at the moment of disposal.

**Collective vs. Individual Responsibility:** When producers are physically responsible for the costs of product take-back, it is important to know whether the legislation enforces collective responsibility among producers or whether producers are allowed to act individually. For instance, while the WEEE Directive states that each producer should be responsible for his own waste, the majority of Member States have their producers join *collective take-back schemes* (e.g., Belgium - Walloon, Denmark, France, Spain, and the UK). This approach has been criticized by most producers (Lifset and Lindhqvist, 2008) because it creates fairness concerns and lacks incentives for design improvements. Accordingly, some countries (e.g., Austria, Germany, Ireland, Italy, Sweden, and the Netherlands) allow producers to form their own *individual take-back systems* (www.iprworks.org).

**Recycling Markets:** Some legislation require that all producers recycle the end-of-life products through a monopolistic recycler. Other types of legislation allow competition in the recycling market. While the WEEE Directive states that each producer should be responsible for his own waste, some Member States, e.g., Belgium, in E.U. have their producers join a *single take-back scheme*. Other countries, e.g., Austria, Germany, and the Netherlands, allow producers to join
one of multiple competing take-back systems (Dempsey et al., 2008). The most important difference between monopolistic and competitive recycling markets systems appears to be on the cost side. It is argued that monopolistic take-back systems create higher recycling fees and hence higher costs to the producers (Toyasaki et al., 2008; Guilcher, 2005).

Cost Sharing: If a collective producer responsibility system is employed, the cost allocation between producers is a very important concern. Sometimes the cost allocation can be based on market shares (e.g., the current system in WEEE) or it can be based on return shares (e.g., as allowed by the legislation in Maine (www.computertakeback.com) or Japan (http://www.env.go.jp/en/laws/).

3. Impact of Legislation on Closed-loop Supply Chain Stakeholders

In this section, we provide a detailed account of how take-back regulations influence different stakeholders in closed-loop supply chains. Our discussion here is based on our understanding of the differences between previously discussed take-back legislation.

3.1 Consumers

Consumers represent one of the most crucial stakeholders in closed-loop supply chains. Take-back legislation imposes direct or indirect financial costs on consumers. In the context of ELVs, even in countries where free-take back is implemented, consumers are still required to bring their ELVs for dismantling. In some cases the vehicles are not in a condition to be driven, imposing additional costs to the consumers, beyond the administrative and handling fees that may be charged. Likewise, in the context of WEEE legislation that adopt consumer pays models, the consumers are charged fixed recycling fees at the moment of purchase (e.g., California) or disposal (e.g., Japan). Even in implementations where take-back is free to consumers (e.g., in most of E.U.), the costs of collection and recovery are picked up by the producers, and it is not known as to what extent such costs are reflected on the consumers. Consequently, the most direct impact of take-back legislation on the consumers is economic in nature. Consumers are directly or indirectly paying for product-take back, meaning that the

2 This extra cost and hassle is one of the main reasons for garaging or roadside abandonment of ELVs.
consumer surplus is likely to be lower with such legislation. An immediate impact of reduced surplus is reduced future consumption (see Atasu et al., 2008; Toyasaki et al., 2008)

What is the benefit from such legislation to the consumers? The answer is probably the reduction in the environmental impact from production and disposal of hazardous goods and increased environmental sustainability due to greener designs. It is therefore no surprise that many consumer organizations and NGO’s have been actively involved in the establishment of take-back legislation. Consequently, the trade-off that the consumers face is between short term economic drawbacks and long term environmental benefits. We remark, however, that the long term environmental benefits are likely to result in economic benefits as well. This is because without take-back legislation, consumers will have to pay for increased taxes for toxic clean-ups, water stream contamination and increased landfill space. Take-back legislation is likely to please the consumers as long as consumers are aware of such potential future costs and they care sufficiently about the environment. Otherwise, the main impact of such legislation seems to be a reduction of the consumer surplus.

3.2 Distributors/Retailers

Distributor or retailers of new products (henceforth referred to as retailers for brevity) are ideal collection points for products to be recycled within the scope of take-back legislation. This is particularly relevant for WEEE products that are relatively less bulky, enabling collection and sorting at point of sale locations. As the closest contact point to end-users, retailers can be instrumental in collecting fees under consumer pays models. Currently in Japan, end-of-use electronics products and the associated recycling fees are collected via retailers (Dempsey et al., 2008). In California, even though retailers are not involved in the collection process, they contribute to the recycling system by collecting the advance recycling fees (CIWMB, 2004). In the context of ELVs, retailers’ contribution is relatively insignificant, serving only as drop-off points in some cases (e.g., Belgium, Italy (Fergusson, 2007)).

From the retailer’s perspective, take-back legislation may have both positive and negative impact. The negative impact stems from a possible demand reduction through an effective increase in the cost to the consumers. This follows our discussion of possible reduction in consumer surplus. In addition, additional physical and administrative costs might be incurred
when retailers act as designated collection points. Some of these costs are offset by allowances made for the retailers to keep a portion of the collected recycling fees in *consumer pays* systems. Such allowances are present both in California and Japan WEEE legislation. On the less tangible but positive side, these activities can be seen as a value-adding service by the consumers. Another potential benefit to the retailers is bringing the consumers back to the retail stores. Especially with small equipment that is easy to hand in at the retailers, consumers may end up in the retail stores which may trigger potential sales of other equipment. While there is no clear indication as to how frequently this occurs, it definitely deserves more investigation.

When the retailers do not act as designated collection points, their involvement with take-back operations is relative limited. Hence it is less clear what positive impact such legislation has. This is particularly relevant for *producer pays* systems with collective schemes, where collection is usually taken care of by third parties.

### 3.3 Collectors and Logistics Service Providers

As most take-back legislation come with target collection rates and encourage easy access of the collection facilities to end-users, there is more business volume created for third-party collectors. These are the independent dismantling & treatment firms dealing with ELVs, municipalities or public points that collect WEEE (financed by local authorities and/or producers). In the case of ELV, some countries have stricter requirements for the accessibility of the collection network, which has led to the installation of many new facilities. For example, the UK ELV regulation dictates that 75% of end-users should be within 10 miles on average of the nearest facility, and no one should be more than 30 miles distance (DTI, 2005).

Another key player in the collection phase is third-party logistics providers who carry out most of the transportation activities. Product take-back legislation is likely to create more business for them as well. Here, a distinction has to be made with respect to the nature of product that is collected. When products are collected with the purpose of recycling, there are usually certain aggregation centers from which the logistics providers access the material and transfer them to the recycling facilities. This is different from collection with the purpose of reusing products or components, where additional sorting and inspection is needed to make sure that valueless junk material is not transported.
An important factor in logistics business is economies of scale. When there is a single clearing house, a collective scheme for take-back, or when the producers form consortia to handle product take-back, greater economies of scale are likely to be observed. This may result in greater benefits for the logistics providers.

Existence of second-hand markets and restrictions put on the export of waste are likely to have a significant impact on the logistics companies that take part in closed-loop supply chain operations. There is an active second-hand international market for used vehicles as well as components. Likewise, many electrical and electronic types of equipment, after being reconditioned, can be sent to developing countries where there is a market for them (see, for example, www.takebackmytv.com). With take-back legislation that restricts the use and cross-boundary transport of certain material, along with international regulations like the Basel Convention, it may not be allowed to export used products out of the country, which limits the logistics business.\(^3\) This is likely to turn the global closed-loop supply chain business into a local recycling business, in turn resulting in local logistics with lower margins instead of global logistics.

### 3.4 Producers

It is evident that producer responsibility measures embedded in take-back legislation ensure that producers face the most direct and significant consequences. For ELVs, producers bear most or all of the costs associated with take-back and recovery. Similarly WEEE legislation with producer-pays implementation imposes the direct cost on the producers. In addition, mandatory (high) targets for recovery such as those in the EU have forced firms to go beyond the recycling of valuable material, which was for the most part economically viable, and recycle additional material, and combust certain waste for heat recovery. This has further increased the costs of recovery and disposal (Fergusson, 2007). Given the intensity of competition in global markets and low profit margins, take-back legislation imposes significant economic burden on producers, and may reduce overall profitability. Consequently, the efficiency of such legislation is extremely critical for the welfare of these sectors. For instance, in some EU countries (e.g.

\(^3\) We remark that despite these regulations, significant amount of WEEE and ELVs end up (illegally) in developing countries (e.g., Kahhat et al, 2008).
Belgium, see www.recupel.be) where a monopolistic, collective WEEE take-back scheme is employed, producers have been quite vocal about the high recovery fees they are charged and the fact that they cannot opt out of such systems. As a result, intensive lobbying has been observed for competitive take-back systems (see www.iprworks.org). A group of major electronics producers (Braun, Electrolux, HP and Sony) has joined forces and established the European Recycling Platform (www.erp-recycling.org) in 2002 for this purpose, and by initiating competition between schemes, they have been able to reduce recycling costs significantly in countries such as Austria, Germany, and Ireland.

As the economics of recovery is the quintessential component of producer interest in take-back legislation, producers would also like to be able to influence it by designing products for recovery. A critical impact on the closed-loop supply chains is observed in this aspect. Product take-back legislation usually does not give enough incentive for re-use options (Atasu et al., 2008; Zuidwijk and Krikke, 2008). Firstly, since remanufactured/reconditioned products are usually targeted for developing markets and such legislation comes with export limitations, the possibility to access those markets is restricted. Furthermore, take-back legislation do not set specific targets for re-use, but rather combined targets for reuse and recycling/recovery. These rates can go up to 80-85% by weight. When such targets exist in the legislation, producers have minimal incentives to design products for re-use, because re-use is a higher-level recovery option and is considered to be quite different from recycling. Thus, product take-back legislation is likely to drive design incentives mostly for recycling and even just for the purpose of reducing the recovery costs.

Lack of standardization in take-back legislation and their implementation across different countries impose additional challenges for producers, in particular for those operating in multiple international markets. Such global producers have to deal with differing policies, financial and operational structures, and come to grips with immensely complex and diverse administrative structures. On the brighter side, the legislation induces producers operating in regions with no existing legislation to comply with these rules in order to export their products. This is likely to have positive spill-over effects on their local markets as well.
3.5 Processors/Recyclers

The stakeholders that mostly benefit from the existence of take-back legislation are probably the recyclers and waste treatment and processing firms (henceforth referred to as recyclers). Clearly, take-back legislation with recycling and recovery targets brings additional business to these firms. This is evident also from the recent growth of the recycling industry. According to International Association of Electronics Recyclers, the number of WEEE recyclers in the US (500 recyclers and 19,000 employees in 2005) increased about 10% between 2003 and 2005 (www.iaer.org).

From the recycler’s perspective, there is a growing stream of products that are being retired by end-users which have to be recycled. Before take-back legislation came to effect, recyclers would have preferred to process products or material that had high recovery value to have high profit margins. Current legislation (for both ELV and WEEE) allows recyclers to process products or new material with less recoverable value at sufficiently high margins, because there is someone paying for the cost of recycling.

Nevertheless, take-back legislation comes with certain duties and standards. Recyclers are often responsible for tracking the amount of processing they conduct and regularly report to administrating bodies. They also have to meet strict environmental standards relating to the storage, treatment and recovery of end-of-life products to maintain authorized status. Furthermore, these standards are likely to tighten in the future. For example, while shredding is an acceptable form of recycling in the case of electronics, it may not be so in the future. Consequently, from the recyclers’ point of view, investing in R&D and looking for superior recycling technologies may be essential for future profitability.

3.6 Remanufacturers

Take-back legislation has significant effect on third-party remanufacturers. Given that most legislation comes with collection and recycling targets, producers have a vested interest in getting access to the used products with their own brand name. Consequently, it seems quite probable that third-party access to end-of-life products will be harder in the future.
Furthermore, as we discussed earlier, exporting used products out of the country for secondary resale markets is getting more difficult due to raised awareness against exporting of waste. This may lead to reduced business opportunities for third party remanufacturers, especially in the electronics sector.

4. Research Progress and Needs

In our preceding discussion, we have highlighted the impact of take-back legislation on closed-loop supply chains, based on our understanding of the existing legislation. We believe that there is a need to investigate these issues in further detail. The current academic research in this area is at its infancy. The existing operations management literature is mainly concerned about how such regulation impacts producers’ operational choices and how the economics of recovery would have a bearing on their profitability.

There are two generic modeling approaches regarding product take-back and its impact on CLSCs. The first class of models is economic in nature, and includes different stakeholders and governments as decision makers. Atasu et al. (2008) use this approach to take the first cut on how production economics would be affected by target-based take-back legislation. They discuss how recovery targets should be jointly based on recovery economics and environmental impact of products. Further, they show that intense competition leads to higher recycling and collection target requirements. Jacobs and Subramanian (2008) take this one step further and discuss the possibility of sharing recovery costs within supply chains. They show that the sharing of take-back related costs between supply chain members (e.g., between producers and suppliers) can indeed increase supply chain profits and under certain circumstances, the social welfare.

The second class of models takes into account operational aspects as well. This part of the literature investigates how strategic and/or tactical decisions related to closed-loop operations, such as product design, CLSC structure and coordination, would be affected by take-back legislation. Toyasaki et al. (2008) model and compare collective (monopolistic) and individual (competitive) take-back schemes when collection, recycling and treatment costs display scale economies. Assuming that target collection and recovery targets are met, they derive and compare equilibrium recycling fees, product prices, recycler and producer profits. They show that a win-win outcome can be achieved under the individual competitive scheme for
the consumers (lower prices, higher surplus), producers (higher profits), and recyclers (higher profits). An exception to this occurs when the product substitutability is high, in which case the recyclers prefer the collective scheme since the non-profit organization shields them from the highly competitive producer market.

Several studies investigate the impact of legislation, and in particular the minimum collection and recovery target rates, on CLSC network structures and costs. Hammond and Beullens (2006) model a CLSC network of producers and consumers assuming diseconomies of scale in operational costs, and study the impact on prices and product flows. They find that minimum recovery targets can stimulate reverse supply chain activities, but are not sufficient to reduce virgin material and landfill use. Using a more detailed CLSC structure, Walther and Spengler (2005) estimate the impact of WEEE-Directive on reverse supply chain network and cost structures utilizing data from Germany. They show that transportation and disassembly costs increase (and hence marginal revenues decrease) significantly as the targets or recycling and recovery are elevated. In a similar vein, Quariguasi et al. (2008) study both the economic and environmental impact in a multiple-objective framework taking European pulp and paper sector as the background, and show that mandatory recycling targets may deteriorate the efficient frontier. Krikke et al. (2003), on the other hand, study the simultaneous CLSC network design and product design considering both economic and environmental effects. Applying their mathematical model on a data set for refrigerators, they find that the effects of minimum recovery rates are ambivalent; they reduce waste but increase energy use and costs. They emphasize the need to enhance product return rates and feasibility of recovery.

There are other papers that investigate the impact of take-back legislation on product design related issues. Zuidwijk and Krikke (2008) explore two possible responses to legislation, product eco-design versus new recovery processes, and show that investing in eco-design is preferable but has delayed effects. They conclude that legislation like the WEEE Directive in E.U. is appropriate in the sense that they stimulate recovery, but more incentives are needed to reward eco-design efforts. Atasu and Subramanian (2008) study the environmental design incentives provided under take-back legislation and show that individual producer responsibility models create superior design incentives compared to collective producer responsibility models. Subramanian et al. (2008) bring the supply chain considerations in the picture and investigate
how take-back legislation drive product design and supply chain coordination. Plambeck and Wang (2008), on the other hand, look at the impact of legislation on the rate of new product introductions in a competitive market. They find that the frequency of new product introduction depends on the specific form of producer responsibility in the legislation.

It is apparent from this brief review that there are large gaps in the current operations management literature. While some research streams consider the impact of take-back legislation on social welfare and producer profits, others deal with operational issues as well. A unifying research framework is needed and this framework should provide details on how the legislation impacts all of the major stakeholders. Research on the welfare implications of take-back legislation should take a broader perspective and identify the impact on these stakeholders. Similarly, the stream of research looking at the strategic and tactical decisions related to closed-loop operations should consider the specifics of the existing legislation, i.e., what is relevant in practice, to identify the important research questions. Bridging the gap between the existing research streams is likely to create a better understanding of the impact of legislation and can result in improvements in the existing legislation from the perspectives of all stakeholders. We believe there are significant opportunities for applying operations research (OR) and management science (MS) methods and tools to resolve these challenges.

5. Illustrative Models

In this section, we illustrate how OR&MS models can be used to study the impact of legislation on closed-loop stakeholders. The first example investigates the economic and welfare implications of legislation, whereas the second example includes operational aspects as well.

The first model is based on Atasu et al. (2008). Economic models investigating welfare implications of take-back legislation usually include a typical utility structure for consumers, e.g., consumer valuations (θ) for the product of interest are uniformly distributed between θ and 1. Given the associated recycling fee (say ρc) and sales price of the product p, a consumer with valuation θ for the product gets utility $U = \theta - p - \rho_c$. In this case, the demand for the product can be developed as $d = 1 - p - \rho_c$, as a function of the sales price and take-back fees charged to consumers. As an illustrative example, consider an integrated producer (who represents distributors, manufacturers, collectors and recyclers) who anticipates the consumers’ response and tries to
maximize his/her profit \( \Pi = (1-p-\rho_m) (p-\mu-\rho) \) with respect to the sales price \( p \), where \( \mu \) is the marginal production cost and \( \rho_m \) is the take-back fee charged to producers. The producer optimally chooses the profit maximizing price \( p^* = (1+\mu+\rho_m-\rho_c)/2 \). At this optimal price, the sales quantity would be \( q^* = (1-\mu-\rho_m-\rho_c)/2 \). In this case, the producer profit will be realized as \( \Pi(p^*) = (1-\mu-\rho_m-\rho_c)/2 \) and the consumer surplus (CS) can be calculated as \( CS = q^*^2/2 \). Given the producer’s optimization problem, the social planner (government) tries to maximize the social welfare which consists of producer profit (\( \Pi \)), consumer surplus in the economy (CS) and possible environmental externalities (\( E \)). Modeling the environmental externalities is a challenging task, because multiple factors, such as level of consumption, virgin or recycled material use, disposal amounts, recycling amounts or recycling technologies, may be affecting the environmental impact of production and take-back. The typical trade-off the social planner faces is between the economic surplus (e.g., \( \Pi + CS \)) and the externalities, where the economic surplus decreases and the environmental externalities (e.g., environmental benefits) increase with higher fees (\( \rho_c \) and \( \rho_m \)). Finally, the task of the social planner is to choose the optimal levels of \( \rho_m \) and \( \rho_c \), such that the social welfare is maximized. For details of such a procedure under alternative cost structures, legislative implementations or competitive settings, we refer the reader to Atasu et al. (2008). Note also that such models can be further developed to take into account the existence of disintegration in CLSCs, e.g., how does the welfare change if producers, distributors, collectors and recyclers are not integrated?

The second model is based on Toyasaki et al. (2008) and compares the two prevalent implementation forms of take-back legislation -collective and individual responsibility- in a competitive setting. Suppose that the market consists of two (groups of) producers indexed by \( j=1,2 \) and two (groups of) recyclers, indexed by \( i=A, B \). The demand in the product market is given by \( d_j = \alpha - \beta \rho z_j, j=1,2 \) where \( \alpha \) is the market size of each producer and \( \beta < 1 \) is the cross elasticity of demand. A given fraction \( \tau \) of the sales are collected and sent for recycling and treatment. The unit recycling fee charged by each recycler is \( t_i, i=A,B \). In the collective scheme, there is a nationwide non-profit organization which is responsible for allocating the waste for recycling and treatment and charging the resulting costs to the producers. Suppose that the non-profit organization employs a fixed allocation rule, where Recycler A gets a fraction \( \lambda \) of and Recycler B gets the remainder \( 1-\lambda \) fraction. The non-profit organization then calculates the
average recycling fee \( t = \lambda t_A + (1-\lambda) t_B \) per unit collected to each producer. This ensures that the cost of recycling and treatment is borne by the producers according to market share and the non-profit organization makes no profit. In the individual scheme, each producer makes an exclusive contract with a single recycler. Without loss of generality, Producer 1 bears the unit fee \( t_A \) set by Recycler A and Producer 2 bears the fee \( t_B \) set by Recycler B.

The strategic interactions between the CLSC stakeholders can be modeled using a two-stage non-cooperative game. At the second stage, producers simultaneously set the product prices to maximize their profits based on the recycling fees. Letting \( c \) denote the unit production cost (same for both producers), Producer j’s optimization problem in the collective scheme is:

\[
\max_{p_j} \pi_j = (p_j - c)(\alpha - p_j + \beta p_{3-i}) - t \tau (\alpha - p_j + \beta p_{3-i}),
\]

For the individual scheme, Producer j’s problem is same as above except that the fee \( t \) is replaced with \( t_A \) for \( j=1 \) and \( t_B \) for \( j=2 \). For a given pair of recycling fees, \( \pi_j \) is concave in \( p_j \), so there is a unique Nash equilibrium product prices \( p_j(t_A,t_B) \). Based on these prices, the demand for each producer, and hence the amount of WEEE \( w_i(t_A,t_B) \) destined to each recycler can be derived for both schemes. In the first stage of the game, the recyclers simultaneously select their unit fees taking into account the resulting producer prices and WEEE amounts. Let \( r \) denote the unit revenue earned from recycling a unit. The total logistic, processing and treatment cost is taken as \((\eta w_i(t_A,t_B) - \theta w_i(t_A,t_B)^2)\), where \( \eta \) is the unit cost without economies of scale, and \( \theta \) is the economies of scale factor. Then Recycler i’s optimization problem can be formulated as

\[
\max_{t_i} \pi_i = (t_i + r_i(w_i(t_A,t_B))) - [\eta w_i(t_A,t_B) - \theta w_i(t_A,t_B)^2].
\]

Under mild conditions, \( \pi_i \) is concave in \( t_i \), hence unique Nash equilibrium recycling fees \((t_A^*,t_B^*)\) can be found for each scheme. The resulting equilibrium producer prices can be derived from the first stage game as \( p_1^* = p_1(t_A^*,t_B^*) \) and \( p_2^* = p_2(t_A^*,t_B^*) \). Comparing the equilibria, it is possible to derive conditions under which each scheme is preferable for each stakeholder. The model can be extended to the case where there is asymmetry in market sizes, operational costs and economies of scale factors, as well as to the case where the recyclers directly compete for WEEE allocation in the recycling market. We refer the reader to Toyasaki et al. (2008) for the details.
6. Conclusion

It is evident that the take-back of end-of-life products is a vital instrument for environmental sustainability. The importance of this is borne out by the number of existing and planned take-back legislation. Interestingly, the organization and financing of these activities show disparity across different implementations, and there are diverse views regarding the preferred system. Likewise there are conflicts of interest among various stakeholders. These signify the importance of taking a holistic approach and addressing the impact of take-back legislation from a comprehensive, multiple-stakeholder and multiple-objective perspective. To the best of our knowledge, existing literature has not yet accomplished this. The interactions between these stakeholders need to be identified and research on coordination between stakeholders is essential to determine the best case scenarios both from the industry and social points of view, considering the triple-bottom line impact - people, planet, and profits. In addition, a detailed investigation of product design implications of take-back legislation is also needed. While the existing legislation is usually local, we believe that its global impact should also be a concern for academics.

This article is aimed at providing an overview of existing take-back legislation, its impact on closed-loop supply chains, determining the pressing research issues, and illustrating how OR&MS tools can be applied to examine these research issues. We provided our perspective on the eminent effects of such legislation to the best of our knowledge, but we acknowledge that there surely exist other possible impacts that are not yet readily observable. We also realize that further research is needed to verify some of our arguments. This calls for a strong interaction with the industry and data-driven (empirical) research.

References


