Chapter 9
Product Take-Back Legislation and Its Impact on Recycling and Remanufacturing Industries

Gökçe Esenduran, Eda Kemahlioğlu-Ziya and Jayashankar M. Swaminathan

Abstract Take-back legislation holds producers financially responsible for handling and treating their products at end of life. A growing number of countries around the world have enacted such legislation, especially for electrical and electronic products. Clearly, such legislation impacts the strategic and operational decisions of companies operating in the affected industries and the operations management literature recently started to analyze these problems. In this chapter, we provide an overview of existing take-back legislation and the papers that have studied various research questions associated with them. Our focus is particularly on papers that have studied the impact of these regulations on the recycling and remanufacturing industries.

9.1 Overview of Product Take-Back Legislation

In this era of information technology, customers enjoy prosperity, convenience, and the low prices of various electric and electronic products. As the demand for these products increases, the amount of such products being discarded by customers has been increasing, too. Electronic waste (e-waste), such as televisions, computers and cell phones, is the fastest growing municipal waste stream in the US. In 2006, total volume of waste increased by only 1.2%, but the total volume of e-waste increased by 8.6% (http://www.electronicstakeback.com/). US Environmental Protection Agency (EPA) estimates that 400 million units of e-waste are discarded each year and the figure is going up steadily. It is unfortunate that only 11.4% of the disposed e-waste is being treated properly. The massive amount of untreated electronic waste leaves behind lead, cadmium, mercury and other hazardous substances, and poses a threat for...
human health and the environment. As a remedy to this issue, legislators have been imposing product take-back legislation in many countries. These take-back laws hold manufacturers responsible for the collection and proper disposal of their products discarded by customers. Examples include the Waste Electrical and Electronic Equipment (WEEE) Directive in Europe, Japanese Specified Home Appliances Recycling Law (SHARL), Japanese PC Recycling System, and state specific e-waste take-back programs in twenty four states in the US (http://www.electronicstakeback.com).

Although these regulations receive enthusiasm from environmentalists in general, there is debate on implementation details and it is not clear exactly what type of legislation will achieve the ultimate goals of reducing the amount of waste by increasing product take-back and recovery levels and creating incentives for environmentally-friendly product designs. It is clear that the legislation’s requirements affect companies’ responses, which in turn, determine the success of the legislation in terms of achieving these main objectives.

One of the main differences in implementation is whether the legislation imposes individual producer responsibility (IPR) or collective producer responsibility (CPR). Under IPR, each producer is responsible for the discarded products of her own brand, whereas under CPR manufacturers of similar products collectively fulfill the requirements of legislation and pay for the total volume of collected products regardless of brand. In a take-back program implementing CPR, the total cost of compliance is generally divided among the members of the program with respect to their market shares. From the view point of producers affected by legislation, there are pros and cons of each type of producer responsibility. For example, IPR gives companies greater control over end-of-life (EOL) product management. Under IPR, companies pay for the collection and treatment of their own brand-name products only. Thus they are in a better position to recoup the benefits of their environmentally-friendlier product design. For example, companies might choose to make costly design changes to facilitate EOL product treatment and to benefit from savings in recycling/treatment costs under IPR. In short, the rationale for pursuing IPR is that it provides incentives for producers to incorporate the environmental concerns into their product designs and to make design changes that would facilitate the EOL treatment. For the same reason, recently many researchers (e.g., Dempsey et al. 2010; Atasu et al. 2009) as well as some initiatives (e.g., “IPR works” set up by a group of companies and NGOs) passionately urge/support the implementation of IPR principle. On the other hand, CPR might be preferred over IPR by producers for a couple of different reasons:

i. In some countries (e.g., the WEEE Directive in EU) CPR is allowed but only for historical waste (i.e., products put on the market before August 2005). However when it comes to implementation, many countries found it easier to allow for/impose collective systems for both historical and non-historical products. It is argued that once the historical waste is cleaned up (approximately around 2020) it will be much easier to implement IPR (Clean Production Action 2007).

ii. It is known that recycling/treatment activities turn out to be economically infeasible if the total volume of products recycled/treated is low (Tojo 2003b) which might be the case under IPR. Hence, collective systems (where collection and
treatment activities are handled collectively) benefit from economies of scale in costs of compliance (Van Rossem et al. 2006). However, one should keep in mind that IPR can still be implemented in a collective system if the actual cost of compliance is calculated for each member firm (e.g., as in Japanese SHARL) (Van Rossem et al. 2006; Dempsey et al. 2010). In the following, we discuss this issue in more detail.

There has also been some confusion about which existing compliance schemes can be classified as IPR. We note that it is not required for producers to have individually-owned collection/treatment systems for their own products in order to implement IPR. Similarly, being a part of a collective collection system where the products are collected and treated in a common facility regardless of brand does not necessarily imply that CPR is being implemented. The literature clearly states that IPR can be achieved through brand segregation under a collective collection/treatment system because these systems can be set up so that they encompass individual responsibility (Van Rossem et al. 2006; Van Rossem 2008; Dempsey et al. 2010). Therefore it is not necessary to have a separate collection/treatment infrastructure for each producer. To summarize, as long as the producers are responsible for and have control over their own-brand end-of-life products IPR can be implemented regardless of how the collection and treatment are performed. Japanese SHARL, Japanese PC Recycling System, Maine’s Electronic Waste Recycling Law and ICT Milieu (Dutch take-back program for information and communication technology (ICT) equipments from 1999–2003) (Van Rossem 2008; Dempsey et al. 2010) are examples of legislation that incorporate the individual responsibility principle.

In order to fulfill the requirements of a legislation, depending on whether it imposes IPR or not, firms need to either set-up an individual take-back program or join a collective one. However, in the context of product take-back this is not the end of the matter. One of the other key questions is how to treat (or recover the value in) the end-of-life products, i.e., which end-of-life treatment alternative to choose. Depending on product characteristics and legislation requirements, there might be various different treatment alternatives. Although requirements of take-back legislation can be different from one country to another, a common characteristic is that they set minimum target levels on the amount of products that should be collected and treated properly (e.g., e-waste laws of Minnesota, New York State, Illinois, etc.). Most legislation refer to “recovery” as the end-of-life “treatment” of discarded products. Recovery includes burning with energy recovery, composting, and recycling, which is defined as the reprocessing of waste materials into the production process. Another end-of-life treatment alternative for discarded products is reuse. Reuse refers to the situation where the whole appliances or components are used for the same purpose for which they were conceived. Since reuse reduces the consumption of virgin materials, it is typically perceived as being environmentally-friendlier than recovery (or recycling). A particular type of reuse is remanufacturing, which brings the appliance to “as new” condition.

Concerns about various implementations of take-back legislation are not limited to the type of producer responsibility or to treatment options per se. There are also concerns about the impact of these regulations on particular industries. Before
getting into these concerns, it would be helpful to understand the prevalent structures in the recycling and remanufacturing industries: Some companies manage/monitor the recycling of their products and feed recycled materials back into their manufacturing process. For example, HP has a strategic alliance with Noranda Inc., a third-party recycling company. Noranda occupies some space in HP plants and HP monitors the recycling in these plants. Similarly, Samsung has recycling programs for its EOL products (http://www.samsung.com/us/aboutsamsung/citizenship/). Samsung works with recyclers that have been confirmed by the e-Stewards program (http://e-stewards.org/) and re-introduces the recycled material into production process. However, when the OEMs are not engaged in recycling of their own products, often times independent recyclers might fill the niche. For example, Sanyo has no product take-back or recycling program unless required by legislation. In this case, independent recyclers collect and recycle Sanyo products. Gazelle, for instance, is an independent recycling service provider (www.gazelle.com) who collects (also pays for) EOL products and recycles or resells them. The situation in the remanufacturing industry is not much different. Some companies such as Xerox, HP, and Apple have well established product take-back programs and offer both new and remanufactured versions of their products even in the absence of legislation. While some of these companies might indeed remanufacture in-house, others outsource remanufacturing activities but still manage the sales of the their brand name remanufactured products. For example, IBM remanufactures servers in its plant (http://www-03.ibm.com/financing/pdf/ca/en/igf4-a143.pdf). On the other hand, Apple contracts with PowerOn, a third-party company for recycling and remanufacturing of its EOL products. Still, remanufactured Apple products are sold through Apple’s website under its brand-name. On the other hand, some companies like JVC and Philips do not have product take-back programs unless required by the legislation (www.electronicstakeback.com/). However, one can easily find refurbished products of these brands being sold by independent remanufacturers.

As mentioned earlier, product take-back legislation imposes specific collection and recycling targets. Therefore, no matter who recycles the EOL products, as long as the targets are set appropriately there is no reason for legislation to hurt the recycling industry. However, this is not the case for the remanufacturing industry. Some, indeed, argue that existing implementations of legislation may hurt the remanufacturing business (Gray and Charter 2007), which would be an undesirable outcome because remanufacturing is an environmentally-friendlier and more efficient way of capturing the value in discarded products than recycling/recovery. The reason behind the fear is that the legislation grants OEMs first access to discarded products through collection/recycling targets and thus limits the availability of those products to independent remanufacturers.

In this chapter, we first briefly go over the literature on papers that study product take-back in the absence of take-back legislation since these models form the building blocks of models used to study take-back legislation. In Sect. 9.3, we review papers that study IPR-type legislation and classify them with respect to how they model EOL management: in-house recycling, in-house remanufacturing, third-party recycling, or third-party remanufacturing. We also provide an overview of papers that model CPR-type and tax-based legislation. We conclude with a discussion of future research directions and main insights from the body of work on take-back legislation.
Other work that provides a review of the literature on environmental legislation includes Atasu and Van Wassenhove (2010, 2011). Different from these two papers, which provide a higher level review of the literature including some papers from environmental economics, we focus mostly on papers that explicitly model the product treatment step (recycling or remanufacturing) and provide details about modeling assumptions common to this literature.

### 9.2 Literature on Product Take-Back in the Absence of Legislation

The literature on closed-loop supply chains is rich and growing rapidly. Early work on closed-loop supply chains mainly focused on operational issues. The issues studied include inventory management (e.g., van der Laan et al. 2004; Toktay et al. 2000), production planning (e.g., Inderfurth et al. 2004), scheduling and shop floor control (e.g., Guide et al. 2005; Souza and Ketzenberg 2002), materials planning for remanufacturing (e.g., Guide and Srivastava 1997; Ferrer and Whybark 2001), and capacity expansion (e.g., Kekre et al. 2003). Dekker et al. (2004) and Atasu et al. (2008a) provide extensive reviews of this literature.

The papers that are of greater relevance to the literature on take-back legislation are those that model strategic aspects of product take-back. In the absence of legislation, firms take back EOL products only if there is economic value in the returned product. The economic value can be retrieved by recycling or remanufacturing the product. The early work in the closed-loop supply chain management literature mostly concentrated on models where the EOL treatment option for the product is remanufacturing. Studies on recycling exist mostly in the environmental studies and socio-economics literatures and Majumder and Groenevelt (2001) provides a review of this body of work.

The strategic decisions the original equipment manufacturer (OEM) needs to make when remanufacturing is available as an EOL option include whether the OEM will also sell the remanufactured product and how the OEM should compete with independent remanufacturers. Majumder and Groenevelt (2001) is one of the first papers in this stream of research. They model an industry where the remanufactured product is offered by both the OEM and an independent remanufacturer. Through numerical experiments they show that while the OEM wants to increase remanufacturer’s remanufacturing cost, the remanufacturer has incentive to reduce OEM’s remanufacturing cost to induce the OEM to produce more in the first period, which in turn would increase the number of available units for remanufacturing in the next period. A seminal work by Ferrer and Swaminathan (2006) extend Majumder and Groenevelt (2001) and analytically prove some central results on which the literature builds later on. For example, they show that if remanufacturing is profitable enough then the firm increases first period production and gives up some of the first period profit to increase the number of available units for remanufacturing in the subsequent periods. They also study multi-period models and show that the optimal strategies under the two-period model are mostly valid under longer planning horizons.
The work by Majumder and Groenevelt (2001) and Ferrer and Swaminathan (2006) on competition between a remanufacturer and an OEM has been extended in several directions. In Ferguson and Toktay (2006), the OEM’s remanufacturing decision is endogenous to the model. In order to compete with the independent remanufacturer, the OEM either remanufactures or collects and disposes of cores in order to push the remanufacturer out of the market. Ferguson and Toktay provide the conditions under which each of the strategies is optimal for the OEM. Most of the literature studies the competition between a single OEM and a single independent remanufacturer. A notable exception is Debo et al. (2005), which studies the competition between an OEM and N independent remanufacturers. Ferrer and Swaminathan (2009), on the other hand, model the competition between new and remanufactured products but the same firm sells both. Since this body of work provides the building blocks of the papers that model take-back legislation, in Sect. 9.3.1.3, we describe the models from these papers in greater detail and explain how the models should be modified when the OEMs are faced with take-back legislation.

9.3 Literature on Product Take-Back under Legislation

9.3.1 Product Take-Back under IPR-Type Legislation

Electronic waste might contain valuable, recoverable materials such as gold, silver, aluminum, copper, ferrous metals, and plastics. For that reason dumping such EOL electronic products in landfills is akin to dumping money in the trash. That explains why some companies, such as Xerox and IBM, have product take-back programs even in the absence of take-back legislation. These companies continue to run their in-house recycling and/or remanufacturing efforts when faced with legislation. Next we discuss some models from the literature.

9.3.1.1 In-house Recycling

Some firms such as HP are engaged in recycling of their EOL products either through their in-house recycling efforts or through third-party service providers (which we group under in-house recycling since the original equipment manufacturer makes the recycling-related decisions and just contracts out the job), such that they reintroduce the recycled materials back into their production process. Although improving environmental image is one factor that affects company’s take-back decisions, recycling efforts are not always completely altruistic. For products with valuable material content, such as cell phones or computers, which contain precious metals (e.g., gold\(^1\) or platinum), the recoverable value remaining in discarded products would turn recycling of these products into a profitable business.

\(^1\) For example, 1 metric ton of electronic scrap from obsolete computers contains more gold than 17 metric tons of gold ore (http://pubs.usgs.gov/fs/fs060–01/fs060–01).
Atasu et al. (2009) is one of the first papers that studies the implications of take-back legislation using a stylized model motivated by the WEEE Directive. Although they clearly state that their model is motivated by the WEEE Directive, they do not explicitly mention whether they model IPR or CPR-type of legislation. However, neither a consortium structure nor the allocation of total compliance cost in a collective system is modeled explicitly. Therefore we discuss the findings of Atasu et al. (2009) in the context of IPR-type legislation. They model a social planner who picks the collection target \((\beta)\) as a percentage of sales and a producer who decides how many of the returned cores to manufacture \((q_M)\), and what percentage of these items to collect and recycle \((\tau)\) at the end of their lives. The manufacturer incurs per unit production cost \(c_M\) but reaps the benefit from recycling per unit as \(b_R\). The total cost of collecting \(\tau q_M\) units is \(c_C \tau^2 q_M\) and thus it is convex and increasing in collection rate \(\tau\). The underlying assumption is that per-unit collection cost increases as the collection rate increases, because it gets increasingly difficult to reach consumers. The manufacturer maximizes her profit

\[
\max_{q_M, \tau \geq 0} \Pi_M = q_M (p_M - c_M + b_R \tau - c_C \tau^2)
\]

\[
s.t. \quad \beta \leq \tau \leq 1
\]

(9.1)

where the price of the product is \(p_M = 1 - q_M\). Constraint (9.1) ensures that the collection rate is higher than the target imposed by legislation (i.e., \(\beta\)) and smaller than 1. Atasu et al. omit the case of linear collection cost because it leads to a binary solution that depends on the sign of \(b_R - c_C\) (i.e., if \(b_R - c_C > 0\) then \(\tau^* = 1\) and otherwise \(\tau^* = \beta\)) with this formulation. They provide the optimal decisions of the manufacturer under collection target \(\beta\) in Lemma 1 (pp. 255). For the sake of brevity, below we only present their results regarding the optimal collection rates:

**Lemma 1** (Atasu et al. 2009). When \(\beta \leq \frac{b_R}{2c_C} \leq 1\) then \(\tau^* = \frac{b_R}{2c_C}\). However, when, \(\frac{b_R}{2c_C} \leq \beta \leq 1\) then \(\tau^* = \beta\). Otherwise, \(\tau^* = 1\).

Social planner, on the other hand, chooses the optimal collection target \(\beta\) that maximizes the social welfare which is the sum of manufacturer’s profit, social surplus and environmental savings. Lemma 1 implies that when \(\beta \leq \frac{b_R}{2c_C}\) choosing a collection target becomes unnecessary because the optimal collection rate is already higher than the target. Therefore, Atasu et al. solve the social planner’s problem for the case where \(\frac{b_R}{2c_C} \leq \beta\).

\[
\max_{\beta} W = \Pi_C + \Pi_M + \Pi_E
\]

\[
s.t. \quad \frac{b_R}{2c_C} \leq \beta \leq 1
\]

where total consumer surplus is \(\Pi_C = \frac{(1-q_M^*) q_M^*}{2}\) and the environmental savings are \(\Pi_E = -\varepsilon (1-\beta) q_M^*\) where \(\varepsilon\) is the environmental cost of not recycling a product. They show that when \(\varepsilon = 0\), \(\beta^* = \frac{b_R}{2c_C}\). Therefore, when recycling is profitable, the
authors deduce that the socially optimal collection target/rate is positive even when the environmental hazard of not recycling is zero. When the recycling is profitable, unit manufacturing cost of the manufacturer decreases and thus the manufacturer’s profit increases. The decrease in manufacturing cost results in lower prices and thus higher consumer surplus. Finally, the total hazard to environment is always reduced by higher collection/recycling rates. Therefore, the total welfare increases when the recycling is profitable.

For some products, such as televisions (HECC 2005; Sodhi and Reimer 2001), the benefits generated from using recycled materials may outweigh the total cost associated with recycling, but for others the net benefit is negative. Atasu et al. also solves the cost model where recycling does not bring any benefits, but it is a costly endeavor. For the cost model, in addition to the monopolistic scenario they also solve the oligopoly scenario with \( n \) players. While some findings carry over to the cost model, others do not. For example, different than the benefit model, when the environmental hazard is zero the optimal collection target is zero under the cost model. On the other hand, similar to benefit model, they find that as environmental hazard increases or collection cost \((c_C)\) decreases, optimal recycling target increases.

9.3.1.2 In-House Remanufacturing

For the firms engaged in product take-back, remanufacturing might be a profitable EOL treatment alternative depending on the product characteristics and condition. However, there are some industry and market characteristics that might affect the attractiveness of remanufacturing. First, the amount of discarded products available for remanufacturing is bounded by the amount of new products sold by the firm in the earlier periods. Therefore, there is a natural limit on the maximum amount of remanufacturing a firm might achieve in each period. Second, the firms are typically concerned about the cannibalization of new product sales by the remanufactured versions. Therefore, it is important to understand how customers perceive remanufactured products as compared to newly manufactured products. Next we review the assumptions about the availability of remanufactured products and then we discuss how the assumption regarding customers’ perception of remanufactured products lead to the generally utilized demand model in the literature.

The first step in a product take-back program is the used product return/collection and it is the only input to the remanufacturing operations. In an industry regulated with take-back legislation, the manufacturer is responsible for collection and treatment of all products discarded by her customers. Therefore, the remanufactured product supply depends on the product sales in the previous period. Ideally all products discarded at the ends of their useful lives are available for collection and treatment. Depending on the industry, customer behavior and market characteristics, there might be uncertainties in quality, amount and timing of product returns. These elements of uncertainty in used product collection have been studied in the literature. For example, the variability and/or uncertainty in used product condition is considered in Ray et al. (2005), Galbreth and Blackburn (2010), Galbreth and Blackburn (2006),
Guide et al. (2003), the uncertainty in the amount of product returns is considered in Ferguson et al. (2009), and the uncertainty in the timing of returns is considered in Souza and Ketzenberg (2002), and van der Laan et al. (1999).

In regards to how the remanufactured products are perceived by customers compared to newly manufactured products, literature uses two different assumptions, each of which could be true for specific types of products. Some papers in the literature assume that the remanufactured products are perfect substitutes for newly manufactured products. However, the more recent and prevalent assumption is that remanufactured products are perceived as lower quality or older technology version of the newly manufactured product.

The deterministic demand model we present next is widely used in the literature. The underlying assumptions are: First, for a new product, the customer’s valuation, i.e., willingness-to-pay, is uniformly distributed between 0 and $Q_t$ where $Q_t$ is the potential market size in period $t$. Each consumer is defined by her valuation of the new product, $v_t \in [0, Q_t]$ in period $t$. When a customer with valuation $v_t$ purchases a new product priced at $p_{tM}$ her utility is $v_t - p_{tM}$. Second, a customer’s valuation for the remanufactured product is a fraction, denoted by $\alpha \in [0, 1]$, of her valuation for the new product. Therefore, when a customer with valuation $v_t$ purchases a remanufactured product priced at $p_{tR}$ her utility from the remanufactured product is $\alpha v_t - p_{tR}$. Finally, a customer purchases the product that provides her the highest utility. Since each customer maximizes her utility, using participation and incentive compatibility constraints it is easy to show that the inverse demand functions for the new and remanufactured products respectively are as follows:

\[
\begin{align*}
    p_{tM} &= Q_t - q_{tM} - \alpha q_{tR} \\
    p_{tR} &= \alpha(Q_t - q_{tM} - q_{tR})
\end{align*}
\]

where $q_{tR}$ is the amount of remanufactured product and $q_{tM}$ is the amount of manufactured products in period $t$. For a detailed derivation of the demand functions from the consumer utility functions see Ferguson and Toktay (2006) or Ferrer and Swaminathan (2006). In the rest of this chapter, in accordance with the literature, unless otherwise stated we assume that $Q_t = Q$. Note that, when $\alpha = 1$ the customers value the remanufactured and new products the same, i.e., do not differentiate between new and remanufactured products (perfect substitutes). Therefore this demand model can be used to model either of the assumptions regarding the substitutability of new and remanufactured products. Still, it is worth emphasizing that there are not many examples of perfect substitutes in the market. Retreaded tires for commercial fleet companies and single-use cameras are some of the examples (Souza 2008; Atasu et al. 2010a).

Next we provide a common approach for modeling the monopolistic situation where the OEM is the only party remanufacturing discarded products of her own brand. Esenduran et al. (2011) studies this problem in detail and investigates the impact of take-back legislation on an OEM with in-house remanufacturing capabilities. Monopolist OEM offers both newly manufactured and remanufactured products. Note that the OEM might have in-house remanufacturing capability or she might
outsource the remanufacturing activity; however in either case the OEM has full control over the fate of remanufactured products and she sells these products under her brand-name. In a two-period setting the OEM decides how many units of new products to manufacture in each period ($q_{1M}$ for $t = 1, 2$), how many cores to collect in the second period ($q_{2C}$), of the collected cores, how many to remanufacture ($q_{2R}$). Let $c_M$ be the unit cost of manufacturing, $c_R$ the unit cost of remanufacturing, $c_D$ the unit cost of disposal and $c_C$ unit cost of collection. Then the OEM’s problem is formulated as follows:

\[(P1) \quad \max_{q_{1M}, q_{2M}, q_{2R}, q_{2C} \geq 0} \Pi_{1M} = q_{1M}(Q - q_{1M}) + \phi \left( q_{2R} \left( p_{2R} - c_R \right) + q_{2M} \left( p_{2M} - c_M \right) \right) - q_{2C} c_C - (q_{2C} - q_{2R}) c_D \]  

\[(9.4)\]

\[s.t. \quad q_{2C} \leq q_{1M} \]  
\[q_{2R} \leq q_{2C} \]  
\[(9.5)\]

where $p_{2M}$ and $p_{2R}$ as in (2) and (3), $\phi$ is the discount factor. Note that in the absence of legislation there is no incentive to acquire cores unless they are being remanufactured. Therefore total amount of remanufacturing would be equal to total amount of collection unless a product take-back legislation is in force.

Next we discuss how problem (P1) is modified under IPR-type legislation. When there is legislation that imposes a collection target on the OEM as a percentage of the output of the company, it is OEM’s responsibility to pay for the proper collection and treatment of at least $100\beta$ percent ($\beta$ is imposed by the legislation) of the items sold in the previous period. For example, Minnesota sets $\beta$ to 80%. Therefore under a regulated market OEM’s problem would change to account for the requirements of legislation. There are two modifications to formulation of problem (P1). First, we introduce a constraint that ensures that the amount of collected cores is at least as much as required by legislation, i.e., $q_{2C} \geq \beta q_{1M}$. Second, the OEM needs to pay for the treatment and collection of $100\beta$ percent of its second period production. Thus, we impose the additional cost of doing so, i.e., $q_{2M} \beta (c_C + c_D)$, in the objective function. Here we should point out that the above-formulation builds on the assumption that the items sold in the second period cannot be remanufactured. This is a reasonable assumption because take-back legislation in general covers electronic products that change significantly over the course of a short period of time, thus old cores cannot be manufactured after a certain period of time.

Solution to this problem yields some interesting insights (Esenduran et al. 2011). First, if the cost of manufacturing is very low, legislation on collection levels alone neither induces remanufacturing nor creates incentives to make design changes that would lead to reduced remanufacturing costs. Therefore, policymakers should be aware that for products that are cheap to manufacture, imposing collection targets alone will not be sufficient to induce remanufacturing. However, targets on collection levels alone may stimulate remanufacturing of a high percentage of the collected cores if they are correctly chosen given the product’s cost characteristics and the customers’
valuation of remanufactured products. In that case, legislation also creates incentives for the OEM to reduce the remanufacturing cost unless the cost of manufacturing is too low. Hence imposing a single collection target that covers a wide range of products would not be effective if the aim of the legislation is to provide incentives also for remanufacturing of these products.

9.3.1.3 Independent Remanufacturing

In the previous section, we discussed that when the OEM sells remanufactured versions of her own-products some of the new product sales might be cannibalized. On the other hand, even when the OEM chooses not to offer remanufactured versions of her products a third-party remanufacturer might (Ferguson 2009). When a third-party remanufacturer collects, remanufactures and sells the remanufactured products, this introduces competition with the newly manufactured products of the OEM. This issue has been widely studied in the literature. Ferrer and Swaminathan (2006) is one of the first papers to study this issue analytically. They characterize the Nash equilibrium between an OEM and a third-party independent remanufacturer in a two period setting. They find that if remanufacturing is profitable then the OEM increases the first period production in order to increase the amount of cores available for remanufacturing in the second period. This result holds regardless of the OEM being a monopolist or facing competition from an independent remanufacturer. Besides, they show that as the intensity of competition increases, the OEM utilizes all available cores and offers remanufactured products at lower prices. Their results also continue to hold under multi-period and infinite planning horizons. Similarly, Majumder and Groenevelt (2001) consider the pricing and remanufacturing decision of an OEM facing competition from a third-party independent remanufacturer. They numerically show that it might be to the benefit of the remanufacturer to cooperate with the OEM to reduce OEM’s remanufacturing cost. In another paper, Groenevelt and Majumder (2001) also model the competition on the procurement of cores. Ferguson and Toktay (2006), on the other hand, consider pricing, collection and remanufacturing decisions of an OEM facing competition from a third-party remanufacturer. They show that an OEM may deter the entry of an independent remanufacturer by either introducing a remanufactured product or collecting cores but not remanufacturing. They call this “preemptive collection”. In addition to the competition introduced by a single independent remanufacturer, the industry with multiple independent remanufacturers has also been studied in the literature. Debo et al. (2005) investigate the joint technology selection and pricing decisions for new and remanufactured products for an OEM competing with $N$ independent remanufacturers and compare their results with monopoly situation. They find that OEM increases the sales of new products to generate the supply of remanufactured products. Furthermore, for an OEM competing with $N$ independent remanufacturers the sufficient condition for the introduction of remanufacturable products is the same as the one for a monopolist OEM. The optimal level of remanufacturability, however, might be lower than the one offered by a monopolist OEM. Although the competition between an
OEM and a third-party remanufacturer is studied in depth in the literature, the same is not true for the competition between two OEMs with remanufacturing capability. Heese et al. (2005) is one of the few papers that explore the competition between two OEMs. They show that for the first-moving firm remanufacturing would be a profitable option. Atasu et al. (2008b), on the other hand, show that remanufacturing might become an effective marketing strategy under competition. Especially, they show that remanufacturing is the most attractive in the presence of a strong brand image competitor.

In this section, we provide an approach commonly used for modeling the competition between an OEM and an independent remanufacturer. In the literature the competition is typically modeled as a Cournot game (e.g., Atasu et al. 2009; Ferguson and Toktay 2006; Majumder and Groenevelt 2001). Although Bertrand competition has also been used occasionally (e.g., Ferrer and Swaminathan 2006), we only provide the formulation for Cournot competition, because it is more relevant for modeling the industries regulated by product take-back legislations. Recall that Cournot competition is useful in modeling capital-intensive industries where production capacity is relatively fixed, such as electronics and automotive that are affected by legislation, whereas Bertrand competition is appropriate when the firms can easily adjust their capacity and production quantity, such as information goods.

Esenduran et al. (2011) studies the effect of legislation on an OEM who faces competition from a third-party remanufacturer. They consider a scenario where the OEM has a product take-back program but is not involved in remanufacturing. For the products she takes back, she incurs collection and proper treatment cost, where treatment involves recycling or environmentally sound disposal. The independent remanufacturer, on the other hand, might collect cores from the market or buy them from the OEM. Here we assume that the OEM has first access to the cores in the market and thus she is the leader in the Cournot competition. This is a reasonable and prevalent assumption because the OEMs has usually well established distribution channels and stronger relationships with their customer. Therefore, it would be easier and cheaper for the OEMs to reach their customers and collect the used products back. Because of the same reason, like Ferguson and Toktay (2006), we also assume that $c_C^R > c_C$, where $c_C$ is the collection cost of the OEM and $c_C^R$ the cost of collection for the remanufacturer.

The independent remanufacturer maximizes his profit by choosing the amount of cores purchased from the OEM, $q_2S$ and the amount of cores collected from the market $q_2C^R$. Since there is no incentive to acquire cores unless remanufacturing is profitable, the remanufacturer remanufactures all the cores on hand, namely the total amount remanufactured is given by $q_2R = q_2S + q_2C^R$. Since the legislation is imposed on the OEM, regardless of the form of take-back legislation under which the problem is analyzed the remanufacturer maximizes his profit

$$(P2) \quad \max_{q_2C^R,q_2S \geq 0} \Pi_{2R} = q_2R(p_2R - c_R) - q_2SP_2S - q_2C^Rp_2C^R$$

s.t. $q_2R = q_2S + q_2C^R$

$0 \leq q_2C^R \leq q_{1M} - q_2C$
where \( p_{2S} \) is the price at which the OEM sells the cores to the remanufacturer. The remanufacturer’s constraint ensures that the quantity collected by the remanufacturer cannot exceed the amount left in the market after the OEM collects. The OEM, on the other hand, maximizes her profit by choosing how much to manufacture, how much to collect and how much to charge for the cores:

\[
\begin{align*}
\text{(P3)} \quad \text{Max} \quad & \Pi_{2OEM} = q_{2M}(p_{2M} - c_M) - q_{2C}c_C + q_{2S}^*p_{2S} - (q_{2C} - q_{2S}^*)c_D \\
\text{s.t.} \quad & q_{2S}^* \leq q_{2C} \leq q_{1M}
\end{align*}
\]

where we use the superscript (*) to denote the optimal value of the corresponding decision variable. Note that OEM is the only player offering a product in the first period, therefore she maximizes her profit

\[
\Pi_{1OEM} = q_{1M}(Q - q_{1M} - c_M) + \phi \Pi_{2OEM}.
\]

When the legislation does not impose any collection target, the above formulation remains valid. However, under the form of legislation that sets an explicit collection target \( \beta \) as a percentage of the earlier period sales we need to modify the formulation slightly. As the OEM needs to ensure the collection and proper treatment of 100\( \beta \) percent of the first period sales, we introduce the constraint \( \beta q_{1M} \geq q_{R2C} + q_{2C} \).

As there is no nonnegativity constraint on \( p_{2S} \), the model allows the case where the OEM pays the remanufacturer to take the cores.

Solution of this problem reveals some interesting results (Esenduran et al. 2011). First one can show that legislation still creates incentives for the OEM—even though she is not remanufacturing in house—to reduce the remanufacturing cost unless the cost of manufacturing is too low. As for the concern regarding the effect of take-back legislation on remanufacturing levels, imposing very high collection targets may indeed cause a decrease in remanufacturing levels and hence the concerns raised by environmentalist groups are not unfounded. The same problem can be solved under the multiple period scenario. Then results show that when the product’s life cycle is longer than two periods and the potential market size changes over the product’s life, remanufacturing is not a very profitable business. Also, legislation with collection targets fails to induce higher levels of remanufacturing or incentive for designing environmentally-friendlier products. Furthermore, results show that legislation might incentivize the OEM to push the remanufacturer out of the market through preemptive collection in an effort to sell as many new products as possible while the demand for the product lasts. Therefore in order to avoid unintended consequences, policymakers should be vigilant before imposing high collection targets in industries where third-party remanufacturers remanufacture.

Webster and Mitra (2007) also studies the competition between an independent remanufacturer and an OEM. They characterize the Nash equilibrium for price competition in the absence of take-back legislation and generate insights regarding legislation numerically by changing the values of cost parameters to mimic different types of legislation. They show that, surprisingly, if the government is responsible for collecting the discarded products then both the OEM and the remanufacturer may benefit from legislation in terms of higher profits when compared to the no take-back scenario.
9.3.1.4 Independent Recycling

Manufacturers may outsource their recycling activities to independent third-party recyclers. Especially under take-back regulations, where the OEM is responsible for proper treatment of collected items, it is common to contract with independent recyclers to have the cores recycled properly. In such cases, the OEM sends the cores to the recycler and pays a recycling fee. Her role (or involvement) in the product’s life ends at this point and she does not interfere with the recycler’s decisions/processes again.

Even though it is quite common for third-parties to carry out the recycling activities, few papers model the recyclers explicitly and the research questions addressed are a variation of the following: given a total demand for recycling, how should these jobs be routed across recyclers in order to minimize costs or maximize revenues. Sodhi and Reimer (2001) models the revenue maximization problem of a recycler as a nonlinear, mixed integer program. In their model, the recycler decides what products to recycle and which smelters to use. Nagurney and Toyasaki (2005) generalizes Sodhi and Reimer (2001) and models a e-cycling network framework, which consists of e-waste sources, recyclers, processors, and consumers. Walther et al. (2008) is motivated by the existing recycling networks in Germany. These networks consist of independent recyclers and a focal company who negotiates with OEMs and allocates the recycling jobs to the member recyclers. The negotiation process is modeled as a mixed integer program and a Lagrangian relaxation based heuristic is proposed.

Toyasaki et al. (2010) approach the problem at a more strategic level and analyze a supply chain where the OEMs outsource the recycling activities entirely and model a two-stage game with two manufacturers and two recyclers. They compare two different settings: one where the recyclers are independent which they call the competitive scheme versus one where a non-profit body allocates the waste products to the recyclers which they call the monopolistic scheme. Their aim is to understand the impact of consolidation and competition in the recycling industry on recycler and manufacturer profits. They conclude that the competitive scheme often performs better because it achieves lower product prices as well as higher recycler and manufacturer profits.

9.3.2 Product Take-Back under CPR-Type Legislation

Although there is a strong push for IPR (Tojo 2003a; IPR Works Press Release 2007; Sander et al. 2007; Dempsey et al. 2010) from legislators, non-profits and some companies like HP and Electrolux, CPR-type implementations are also prevalent due to reasons we stated in Sect. 9.1. Therefore, it is essential to understand how effective CPR-type legislation is and how well the objectives of take-back legislation (in terms of achieving higher collection rates and incentivizing environmentally-friendlier product design) will be met under CPR. For example, it is argued that collective schemes do not give incentives for designing environmentally-friendlier
products as producers do not bear the true costs of their own products. The most passionate discussion in this context has been regarding the transposition of the WEEE Directive into law. For products put on market after August 2005, the WEEE Directive (Article 8.2) not only allows producers to have access to their own products but also holds them financially responsible only for their own brand-name products. Article 8.2 in the WEEE Directive states that:

For products placed on the market later than 13 August 2005, each producer shall be responsible for financing the operations referred to in paragraph 1 relating to the waste from his own products. The producer can choose to fulfill this obligation either individually or by joining a collective scheme.

Therefore, the WEEE Directive allows and encourages IPR. However due to imprecise transposition of the Directive into law in some EU countries, CPR is allowed and the preferred implementation (e.g., in Bulgaria, Denmark, Finland, France, Greece, Portugal, Spain, etc. (Sander et al. 2007)).

Under the take-back law in Maine, producers are given two options: (i) If the total return share is more than 5%, they can start an individual or a collective scheme; (ii) otherwise they must join the collective scheme to manage the collection and treatment of their discarded electronic products. In response to the alternative compliance schemes allowed by legislation, companies may choose different ones at different locations. For example, Dell opted to be a member of the collective program in Maine while reserving the right to update its decision. However, elsewhere (e.g., in Maryland) Dell established its own individual take-back program.

Due to the complexity of the problem, the comparison of IPR and CPR-type legislation has not been explored much in the literature. One exception is Esenduran and Kemahlıoğlu-Ziya (2011) where the authors compare the individual and collective compliance schemes and identify the market and operating parameters that make one scheme more cost effective than the others from the view point of manufacturers. Under the individual compliance scheme, each producer sets up her take-back and recycling systems. Under the collective compliance scheme, producers form a consortium to carry out their responsibilities under law collectively. An important issue under collective compliance is how the total cost will be allocated to the consortium members. The most prevalent approach is to allocate costs in proportion to the partner firms’ market shares (MS). Another approach, which we call individual financial responsibility (IFR), allocates each producer her true share of compliance cost. Compliance schemes are compared by using a stylized model of each compliance structure. Among other results, authors show that collective compliance with IFR is, in general, the most cost effective alternative for producers because it allows producers to exploit the economies of scale inherent in a collective system as well as recoup the benefits of their environmentally-friendlier products. However, collective scheme with IFR is not easy to implement in practice because it requires sorting the end-of-life products by brand and tracking them through the treatment process in order to record the true cost of treatment. For that reason, the individual scheme and collective scheme with cost allocation by MS are the two more common implementations of compliance in practice. The authors also show that which of these two
gives lower compliance cost depends on the base collection rate maintained by the municipalities and non-profits as well as the market shares of partner firms. If the partner firms have large market shares then collective compliance, in general, yields lower cost for a producer. The producer not only benefits from economies of scale but also invests in increasing the treatability level, and thus decreases the treatment cost, with no fear that the others will free-ride on her investment. As for environmental benefits, they find that the collective scheme with IFR provides superior environmental outcomes than the others, but as evidence from the implementation of the WEEE Directive suggests, this scheme is difficult to implement and enforce. On the other hand, the treatability level is higher under the individual scheme and the collection rate is higher in the collective scheme with cost allocation by MS. Finally they find that high collection targets cause producers to switch to the collective scheme with cost allocation by MS and may result in lower treatability levels. Therefore, policy makers need to understand the trade-off between the collection rates achieved and the incentives producers have to increase the treatability levels of their products.

Another paper that compares individual and collective compliance schemes is Atasu and Subramanian (2009). They model two profit-maximizing manufacturers in a vertically differentiated market where one manufacturer is the high-end producer and the other the low-end. The brand positions are exogenous to the model. The paper studies how individual and collective compliance systems affect manufacturers’ recyclability choices and profits. This paper is different from Esenduran and Kemahlioglu-Ziya (2011) in two aspects. In Atasu and Subramanian, the manufacturers do not set their collection rates, but pay a per-unit treatment fee for each product sold. In addition, in allocating the collectively-incurred treatment cost to the manufacturers, Atasu and Subramanian use an average treatment cost where the weights with which each manufacturer contributes to treatment cost is exogenously set. Both Esenduran and Kemahlioglu-Ziya and Atasu and Subramanian conclude that IPR-type legislation provides better incentives for highly recyclable products. However, by making product take-back levels endogenous to the model, Esenduran and Kemahlioglu-Ziya is also able to identify a tradeoff between collection and recyclability levels.

Gui et al. (2010) also study collective compliance schemes and model cost allocation by return share. First, they show that cost allocation by return share may be perceived as unfair by some members of the consortium and result in disintegration of the collective system. Then using concepts from cooperative game theory, they propose modifications to the return share cost allocation rule and show that the resulting cost allocation schemes are in the core of the game under some mild conditions. Hence, the stability of the collective system is guaranteed.

9.4 Environmental Legislation that Taxes Consumers

The main focus of this chapter has been environmental legislation that requires producers to take their EOL products back and cover the related costs according to the extended producer responsibility principle. Another type of legislation taxes
consumers either when the product is purchased or at end of life. The collected tax is then used to finance take-back and recycling programs run by governments. Here, we provide a brief overview of such legislation and the related work in the operations management literature.

The best known example of tax-based legislation is the electronic waste recycling fee charged in California. The tax is imposed on products with video display devices and, depending on the size of the video display, ranges from $6 to $10 (as of 1/1/2011) (http://www.boe.ca.gov/sptaxprog/ewfaqsgen.htm).

Even though the literature on take-back legislation is growing, we are aware of only two operations management papers that have studied tax-based systems. Atasu et al. (2010b) models both tax-based legislation and legislation that enforces manufacturers to achieve mandated take-back rates. The paper compares the preferences of different stake holders, namely the manufacturers, the consumers, the social planner and the environment, and identifies the conditions under which one type of legislation is preferable to the other. The authors show that tax-based systems are more effective for products with high environmental cost while take-back legislation is preferred by manufacturers of products with lower environmental cost relative to take-back costs.

Plambeck and Wang (2009) also model both tax-based systems and legislation that imposes individual producer responsibility. They compare these two types of legislation in terms of their impact on new product introduction. They find that tax-based systems reduce the frequency of new product introduction and, hence, increase manufacturer profits. However tax-based systems do not provide incentives for design for remanufacturability. On the other hand, legislation that enforces individual producer responsibility does provide remanufacturing incentives but fails to reduce the frequency of new product introductions. Therefore, the regulators must make a trade-off between two environmental goals in choosing between these two types of legislation.

### 9.5 Conclusions and Future Research Directions

Fueled by the increasing number of countries enacting legislation on product take-back, the operations management literature on such legislation has been growing. A common feature of work to date has been the use of stylized analytical models and the research questions studied have been of the strategic type such as what type of legislation should regulators prefer and when, what type of legislation is most cost effective for producers, what type of legislation provides better incentives for remanufacturing and/or remanufacturability, etc. While this line of work generated invaluable insights regarding how environmental legislation affects various decisions in electronics supply chains, we believe that future research should concentrate more on the operational details of take-back legislation implementations.

An aspect of product take-back that has not been modeled in detail to date is the process of product collection. Models usually include a per-unit collection cost, but the party or parties who are allowed to take EOL products back have not been
explicitly modeled. In practice, one or more of the following parties may handle the collection: retailers, municipalities, producer-owned collection points, etc. The question of optimal reverse channel design has been studied in the absence of take-back legislation (e.g., Savaskan et al. 2004; Savaskan and Wassenhove 2006) and we believe that this question should be revisited for products facing take-back legislation. It is likely that the return volumes for products facing take-back laws will be higher, products returned may be in worse condition than products returned purely for economic reasons, etc. and because of these differences in the reverse channel, a channel structure that was optimal prior to legislation may not even be feasible under legislation.

To further the operations management research on product take-back legislation, we believe that it is necessary to better understand the recycling and remanufacturing processes and the related costs. Existing body of work on take-back laws have provided some insights regarding what type of legislation and compliance scheme is best for the environment and the producers, and the results, to a large extent, depend on how the compliance costs are calculated. Unfortunately, the functional forms that are used to estimate the costs of different steps in the collection and treatment processes are not validated by data but rather based on reasonable assumptions. For example, it is commonly assumed that collection cost is linear or convex in the number of units collected. Therefore, this line of research would benefit from testing the appropriateness of these assumptions by using the data that are available at the parties involved in different steps of compliance.

Finally, there is definitely room and need for empirical research in this field. Analytical models have provided some insights on what type of environmental benefits to expect from different types of legislation, and testing these findings empirically would make a nice research contribution.

References


