AUTOMOBILE LIFE CYCLE OUTCOMES AND POSSIBILITIES UNDER EXTENDED PRODUCER RESPONSIBILITY LEGISLATION IN JAPAN

by

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Abstract

The incorporation of life cycle perspectives in the manufacturing industry has been called on as a more effective way of reducing waste and resource use than conventional 'end-of-pipe' approaches. Reduce, reuse, recycle, and simple disposal is the list of life cycle options ranked in order from the most to the least desirable. While such rankings are robust from an environmental perspective, in practice it can be difficult to orient life cycle outcomes to match this hierarchy. Products can vary along many dimensions – technological complexity, physical durability, rate of technological change, and material characteristics. These attributes interact in complex ways with the market and regulations, obviating any straightforward relationship between product types and life cycle outcomes related to the theoretical hierarchy.

The first part of this study does a comparative case study of five categories of products in the Japanese market: copiers, household appliances, disposable cameras, personal computers and automobiles. It identifies four key factors of life cycle outcomes – product attributes, after-market demand, reverse logistics and recovery technologies, and examines the way in which these attributes interact to produce different life cycle outcomes.

An important trend affecting a product life cycle outcome is the recent regulatory approach that mandates manufacturers' responsibility of taking back products at the end-of-life. The second part of this study focuses on how *the End-of-Life Vehicle (ELV) Recycling Law* in Japan, which was designed to improve recovery rate of ELVs, has led to innovation and technological changes in design, development and ELV recovery processes. Japanese automobile manufacturers have focused on technological innovation that enhances the levels of material recycling and part reuse. Other life cycle outcomes, such as remanufacturing of vehicles, are less likely to emerge as a result of the enforcement of the law alone. There are constraining factors to remanufacturing vehicles, including longer life span versus the period of manufacturing and the difficulty of securing quality of parts from ELVs. An evaluation of early impacts of *the ELV Recycling Law* on technological innovation and product life cycle may also provide insights for policy design and product life cycle strategies for further progress in ELV recovery.

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Glossary

AEHA: Association for Electric Home Appliances (Japan)
ASR: Automobile Shredder Residue
CFCs: Chlorofluorocarbons
ELV: End-of-life vehicle
ELVD: End-of-life vehicle Directive (EU legislation)
EU: European Union
EPR: Extended Producer Responsibility
ESRI: Economic and Social Research Institute, Cabinet Office, Government of Japan
HFCs: Hydrofluorocarbons
JADA: Japan Automobile Dealers Association
JAMA: Japan Automobile Manufacturers Association
JEITA: The Japanese Electronic and Information Technology Association
LCA: Life cycle assessment/analysis
IMDS: International Material Data System
METEC: Matsushita Eco Technology Center
METI: Ministry of Economy, Trade and Industry, Japan
MOE: Ministry of the Environment, Japan
MSTC: Manufacturing Science and Technology Centre
PVC: Polyvinyl chloride
SOC: Substances of Concern
VOC: Volatile Organic Compounds

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Co-authorship statement

Yasuhiko Ogushi primarily wrote chapter 2 of this thesis with help from Milind Kandlikar and Hadi Dowlatabadi. Milind Kandlikar helped in framing the problem and sharpening the arguments in the final paper. Yasuhiko Ogushi also primarily wrote chapter 3 of this thesis. Milind Kandlikar was involved in helping select the topic of study as well as in guiding the data analysis. He also was involved in editing the final version.

Chapter 1: Introduction

1.1 Introduction: How to deal with millions of end-of-Life vehicles?

As automobiles have become an essential means of transportation in today's world, the automobile industry has grown to the extent that adds over 60 million automobiles a year to the existing over 800 million worldwide as of the end of 2003 (JAMA 2004). Consequently, tens of millions automobiles composed of variety of materials reach the end of life and are disposed each year. A huge burden is borne by the environment if these end-of-life vehicles (ELVs) are not appropriately managed. ELVs not only take up increasingly scarce disposal sites but also contain hazardous substances such as heavy metals and CFCs that dissipate in the environment and can cause serious environment and human health impacts. Given the scale of the problem, management of ELVs needs as much attention on the production end as it does on the disposal end if strategies are to be devised that minimise environmental impacts from the vast amount of ELV waste generated every year.

End-of-life management of automobiles does not only imply an exclusive focus on conventional waste management goals of processing ELVs in an effective and safe manner. Appropriate management of ELVs should focus instead on the entire cradle-to-grave processes including design, manufacturing, operation and disposal. Automobile manufacturers located at the upstream of the chain have the greatest capacity of controlling waste flows from automobiles although they have little direct participation in management of automobiles at the end of life (Hosoda 1999)[1]. This implies that the design and structure defined in upstream processes of automobile life cycle are likely to determine to a large degree the effectiveness of end-of-life management. Appropriate management of ELVs requires the shift away from a 'waste management' paradigm to one based on managing the entire life cycle. This study focuses on an ongoing shift in Japan and examines how technological choices, laws and market conditions interact in determining life cycle outcomes.

1.2 Entire life cycle perspective in waste management

Minimising environmental impacts from ELVs requires a focus on entire life cycle of the product. This includes forward (before the end of life, i.e. production) and inverse (after the end of life, i.e. recovery) processes. Such an integrated approach would minimise environmental impacts from a synergy of efforts made at different stages while meeting social and economic needs. Life cycle design is a methodology to achieve such goals; it refers to integrative design of the following key elements: business model that meets the needs with minimum resource consumption, a mix of appropriate life cycle options of the product (discussed in more details later), and product and process design that support the business model and life cycle options (MSTC 2004). In this paper, the term 'life cycle

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[1] The sensitivity of the upstream processes to the effectiveness of end-of-life management is likely to depend on product characteristics and the structure of entities in the life cycle chain. The evaluation of the degree of sensitivity needs further study. Also, the statement that manufacturers have the largest capacity of controlling waste flows may not necessarily be true for other types of products (Hosoda 1999).

strategies' is interchangeably used with 'life cycle design', implying intentional design or strategy of a mix of the above factors, while 'life cycle outcomes' refers to more empirical-based outcomes, scenarios or paths of a product life cycle with or without intentional strategies. Life cycle outcomes at the simplest level vary from linear chain of processes of production-consumption-disposal to partly cyclic and closed-loop systems where parts or all of products are taken back to upstream production stage after the end of life, but in practice may be a combination of different paths and are more complicated.

Life cycle options, options with regard to recovery method and product lifetime management, can be categorised by product stages as shown in Table 1.1 (MSTC 2004). Although a categorisation was made as this table, actual structure of life cycle options may be more nested. That is, the realisation of a life cycle outcome may not be achieved by choosing a specific option at one stage of the product, but may only be achieved by a combination of options at different stages. For example, reusing parts by reintegrating into products require both part recovery measures at post-consumption stage and specific design at pre-consumption stage.

Table 1.1 Life cycle options categorised by product stages

Cascading refers to using recovered material for other applications. For example, recycling plastics from drink bottles into plant pots is cascading recycling. On the other hand, using recovered material for the same products is referred to as closed-loop recycling (or reuse). Closed-loop recycling is also referred to as horizontal recycling.
Source: adapted from Manufacturing Science and Technology Centre (2004)

Product stages	Life cycle options			
Upstream of product chain Pre-consumption stage	Business strategy change	Model of service delivery (e.g. sale to lease)		
	Design and manufacturing	Reuse: Reusable design (e.g. design for easy disassembly) Recycle: Recyclable design (e.g. use of recyclable materials) Longer life design (e.g. improving durability of parts) Upgradeable design Repairable design		
Consumption stage	Continuation of usage	Maintenance Repair Upgrading		
	Transfer of ownership	Resale to second-hand market		
Post-consumption stage	Recovery	Reuse	Reusing parts/components (including remanufacturing parts)	Reintegrating into products Spare parts Cascading
			Reusing products	Product Remanufacturing
		Recycling	Material recycling	Closed loop Cascading (downcycling)
			Chemical recycling	Closed loop Cascading
		Energy recovery		
Downstream of Product chain	Disposal	Simple disposal	Incineration Landfill Other	

An associated concept, life cycle assessment or life cycle analysis (LCA) is methodology to quantify environmental impacts of a product or service throughout its lifetime. It measures energy and material usage, and emissions at different life stages of a product or service – material extraction, processing material, manufacturing, packaging, transport, operation, maintenance and end-of-life processing. LCA has been recognised as a useful assessment tool of products, services, processes, or technologies, and increasingly used in product development, communication and marketing since the mid-1990s. Although LCA itself is not a primary focus of this study, it is notable that LCA is a useful evaluation method of environmental impacts with the life cycle perspective.

1.3 Extended Producer Responsibility: new legislative paradigm for waste management

Extended Producer Responsibility (EPR) is an environmental policy approach in which a producers' responsibility for a product is extended to the post-consumer stage of a product cycle (OECD 2001). The key feature of EPR policy is to shift responsibility upstream toward the producer and away from municipalities, and to provide incentives for producers to incorporate environmental considerations at the design and manufacturing stage. EPR has been already applied for durable consumer goods such as electronic and electrical equipment, in addition to other types of waste such as packaging waste, bottles, paint cans and tyres in various OECD countries (OECD 2001). *End-of-Life Vehicle Directive* enforced in 2000 in European Union and *the End-of-Life Vehicle Recycling Law* enforced in 2005 in Japan are prominent but not the sole examples of EPR legislation. EPR was adopted in these laws in different forms: defined roles of producers, consumers and other stakeholders differ depending on laws. While EPR changes the balance of responsibility of products between producers and municipalities with regard to waste management, how EPR induces innovation to better manage ELVs and whether and how it transforms life cycle outcomes for automobiles is a focus of this study.

1.4 Focus of the study

Automobiles have complex life cycle outcomes, which do not easily fit into a single category of life cycle options shown in Table 1.1. An automobile can be transferred to another user through a second-hand market or be exported before it reaches physical lifetime. Once it reaches the end of life, it is typically taken apart, valuable parts and materials may be sent for reuse or remanufacturing, and the remainder is shredded and buried in a landfill site. Automobile parts may or may not be recovered depending on part conditions and demand from the market. The entire ELV recovery process may also vary in different regions and jurisdictions depending on infrastructure, regulatory requirements, and market conditions. In general, life cycle outcomes are not solely determined by technical design of a product, but are also heavily influenced by non-technical factors such as consumer behaviour, market conditions and regulatory requirements. The automobile is not an exception. In this sense, life cycle outcomes that minimize environmental impact need to be sensitive to considerations such as consumer behaviour, market conditions, regulation, and technical aspects of the product and logistics.

This study focuses on an ongoing shift in Japan and examines how technological choices, laws and market conditions interact in determining life cycle outcomes of ELVs in Japan. The goal of this study is to explore an appropriate and practical life cycle strategy for automobiles that minimises waste flow. In addressing this issue I focus on two key questions:

(1) What major factors affect life cycle outcomes of consumer products and how might they be used to explain observed outcomes?
(2) What is the current practice of ELV recovery and how is Japanese ELV take-back legislation influencing life cycle outcomes of automobiles?

1.5 Approach and research method

In answering the above questions, I begin by investigating the wide range of factors affecting life cycle of a product from empirical evidence and formulating a framework of how a product life cycle outcome is determined. This in turn allows to examine how strategies to intentionally manipulate life cycle outcomes might be formulated.

In Chapter 2, Case studies of five consumer products including copiers, home appliances, disposable cameras[2], computers and automobiles sold in the Japanese market with different life cycle outcomes are used to identify attributes that determine life cycle outcomes. This allows to develop a framework for life cycle outcomes based on market and consumer considerations, technology choice and legislative environment.

Chapter 3 takes a closer look at the automobile industry in Japan, with an emphasis on how recent EPR legislation is leading to technological innovation and the transformation of automobile life cycle outcomes. Automobile industry efforts toward better ELV management under the implementation of the EPR-based *ELV Recycling Law* that came into effect in January 2005 are reviewed. Literature review and surveys of automobile manufacturers were conducted to characterise technological changes under the ELV legislation. Based on the framework for life cycle outcomes developed in Chapter 2, considering current technologies and the landscape of market and regulation, I examine how the ELV legislation is influencing life cycle outcomes in Japan. More specifically, I argue that ELV laws are consolidating a move towards material recycling and away from remanufacturing of automobiles in the automobile sector in Japan.

Further, in Chapter 4, current practice of ELV management in North America is reviewed and implications are drawn from Japanese experience.

Table 1.2 summarises key steps of this research and methods used in each step. The rationale for focusing on products in the Japanese market are as follows: first, Japan has relatively large and mature automobile, white good and other manufacturing industry that

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[2] It refers to a single-use camera equipped with a film, made of plastic body parts and lens, and typically sold for US$8-20. In Japan, manufacturers market the product with the name of "film with lens", emphasizing that the product is not "disposable." However, it is likely that "disposable camera" is a more common generic name of the product in North America and I use "disposable camera" to refer to the product in this paper for easier recognition. It does not imply that the product is literally "disposable."

has for decades been at the cutting edge of global manufacturing. Manufacturing trends in Japan are likely to have a global influence. Second, Japan has been at the forefront of EPR laws. In recent years Japan has introduced several EPR-based waste management laws with the goal of building a "sound material-cycle society". Assessing Japan's experience will help more broadly in the debate over the usefulness of EPR laws in meeting environmental targets. Finally, the language competency of the author enabled the process of administering survey questionnaires sent to Japanese organisations, in addition to helping perform assessments of academic and grey literature in the Japanese language.

Table 1.2 Research frameworks and methods

Key steps	Methods
Identification of key elements which affect life cycle outcomes and characterisation of how these identified factors influence life cycle outcomes	Case studies: A review of different products in Japanese market which have different life cycle outcomes including: • Copiers: remanufacturing • Home appliances: material recycling • Computers: reuse (second-hand) and material recycling • Disposable cameras: remanufacturing • Automobiles: reuse (second-hand, used parts) and material recycling Information sources include: • Manufacturers' websites, environment/sustainability reports • Government reports • Academic and grey literature • News database, websites • Survey to manufacturers to reinforce reasoning why certain life cycle outcomes emerge Literature review A review of theoretical frameworks pertaining to life cycle design, life cycle engineering and related topics. Framework formulation Based on findings from case studies and literature review.
Characterisation of technological changes under ELV legislation in Japan	Literature review A review of technological changes taking place in ELV management throughout the life cycle chain. Sources include: • Manufacturers' website, environment/sustainability reports • Government reports • Academic and grey literature Survey to automobile manufacturers and related organisations Data analysis for reviewing feasibility of remanufacturing vehicles
Identification of current practice in automotive industry in North America and discussion on appropriate life cycle strategy for automobiles	Literature review • Reports from organisations • Academic and grey literature Comparative data analysis Based on the literature review result

1.6 Scope and limitation

The case studies focus on complex consumer products that are comprised of a large number of constitutive and interchangeable parts, considering that the main subject of this research, automobile, is highly complex product comprised of 20 to 30 thousand parts. Bottles, cans, paper, construction waste, and organic waste do not fit in this category and are not subject of this investigation. While the choice of five products in the Japanese market could provide useful insight, it may also provide a biased picture. This is unavoidable in any case-study approach especially if we wish to extrapolate to other markets and jurisdictions. The five different products chosen here have reasonable variation of life cycle outcomes along the mix of technical, market and regulatory factors that explain this variation.

Although EPR is a focus of this study, the objective of this study is not to analyse EPR policy per se; that is, this study does not discuss EPR in terms of policy evaluation criteria such as effectiveness, administrative simplicity, or any other. Rather, the study focuses on how EPR legislation drives change in product life cycle, technology and business practice with regard to waste management. This study recognises EPR as only one of many factors influencing product life cycle outcomes.

I am aware that there are studies of product life cycle based on in-depth investigation of factors, typically technical ones. The depth of discussion for any one factor in this study is unlikely to match those in studies that focus technical, economic or regulatory aspects alone. This study emphasises integrative aspects of various factors that influence product life cycle outcomes, i.e., this study focuses on interactions of the drivers of life cycle outcomes, rather than focusing on highlighting the role of a single driver.

The integrative framework formulated in this study only provides one way of explaining how different factors affect life cycle outcomes, and there may be other ways to explain the determination of product life cycle outcome using different key factors from ones identified in the case studies.

Data availability was a limitation throughout this study. Some statistical data that are required to construct an argument does not exist. In other cases, organisations and companies refused to provide data because of its proprietary nature or for other reasons. Therefore, the conclusions of this study are by no means a result of rigorous statistical tests. Rather they are a result of synthesis. The conclusions of this study have been synthesized using best available data derived in some cases from open-ended surveys to manufacturers and other stakeholders, and evidence from academic and grey literature.

1.7 Structure

The structure of this thesis adopts manuscript-based thesis model. Literature review, hypothesis, analysis, key findings, and syntheses are presented in each of Chapter 2 and Chapter 3 in the format of individual scientific papers. Chapter 2 identifies determinants of life cycle outcomes and formulates a framework of how different products end up with different life cycle outcomes. Chapter 3 focuses on technological changes taking place in ELV management processes, design and development, followed by a discussion on appropriate life cycle strategy of management of ELVs. Chapter 4 briefly discusses implications for North America derived from Japanese experience. The thesis will end with Chapter 5, which summarises findings and draws some concluding remarks.

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Chapter 2: Determinants of end-of-life outcomes[3]

2.1 Introduction

In recent years there has been an emerging focus on end-of-life recovery options for manufactured consumer goods. The reasons for this are myriad: reduction of lifetime environmental impacts of products; economic benefits for manufacturing firms and consumers; increased costs of disposal; and legislation on Extended Producer Responsibility (EPR) in Europe, East Asia, and regions in the United States that requires manufacturers to be responsible for collection and appropriate disposal. The current interest in end-of-life recovery of consumer products raises several questions related to life cycle outcomes: Why do some products flow into second-hand markets at the end of life, while others don't? Why are some more amenable to being remanufactured[4], while other products are more easily recycled? How might end-of-life regulations promote innovation geared towards reducing life cycle impacts? Answering these questions requires an understanding of the complex interaction of different technical and social factors affecting post-use disposal of consumer products. This study uses product case studies in Japan in an attempt to answer these questions.

In 2001 Japan adopted a new legal framework to promote social and technological changes towards establishing a "sound material-cycle" society. *The Basic Law for Establishing the Recycling-Based Society* sets the legal framework for such society, organizes priorities, and defines the responsibilities of governments, businesses and consumers (METI 2004). Under this legal framework new recycling initiatives including manufacturer 'take-back' legislations apply to several industries including: containers and packaging[5], home appliances, construction materials, food waste, computers and end-of-life vehicles. Consequently, Japan, a global hub for innovation in manufactured consumer products, is now at the forefront of innovation in recovery options.

While the changing regulatory landscape has forced companies in Japan to incorporate life

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[3] A version of this chapter has been published:

Ogushi, Y., Kandlikar, M., et al. (2005) What Makes a Product Lifecycle Strategy Work? Insights from Japanese Experience. *Proceeding of 2005 International CIRP Seminar on Life Cycle Engineering*, April 3-5, 2005, Grenoble, France.

and accepted for publication:

Ogushi, Y., Kandlikar, M., et al. Assessing Product Life Cycle Strategies in the Japanese Market in Brissaud, D., Tichkiewitch S. et al. (ed) *Innovation in Life Cycle Engineering and Sustainable Development*, Springer Science.

another version of this chapter has been submitted for publication:

Ogushi, Y., Kandlikar, M., et al. What Determines End-of-Life Outcomes for Consumer Products? Insights from the Japanese Experience, *Progress of Industrial Ecology, an International Journal.*

[4] Remanufacturing is the process of restoring a nonfunctioning, discarded, or traded-in product to a like-new condition, giving the product a second (or third, or fourth) life. (Hauser and Lund 2003) In this paper, it also refers to the integration of reused parts into newly manufactured products, and is distinguished from the incorporation of used parts into existing products.

[5] *Containers and Packaging Recycling Law* was partially in effect in 1997, before the above framework law was enforced.

cycle considerations into manufacturing for some products, some Japanese manufacturers were extensively recovering products before the 'take-back' legislation was instituted. These cases suggest that product recovery is not simply a matter of regulation or technical design, but is influenced by a host of market factors. Consequently, this study shows how differences in end-of-life outcomes for different products are a result of complex interactions between technically determined factors such as product durability, market factors related to end-of-life economics and business models, and EPR legislation aimed at meeting product stewardship goals. To make its case, this study examines life cycle outcomes for five consumer product types in the Japanese market, and provides a framework for understanding why post-use recovery of consumer products differs from product to product.

The remainder of this Chapter is laid out as follows. Section 2 describes the theoretical basis for understanding end-of-life outcomes. In section 3 we detail case studies of five consumer product types and analyse the technical, market and legislative drivers for their end-of-life outcomes. In section 4 we draw lessons from the case studies for a more generalised understanding of what determines end-of-life recovery.

2.2 Determinants of end-of-life outcomes

Figure 2.1 provides a representation of a commonly used 'hierarchy' of post-use recovery options – reuse, remanufacture and recycle (Graedel and Allenby 2003). Simply put, the higher up the process in the hierarchy the more environmentally friendly it is. For example, the performance, reliability and appearance of a remanufactured item can be as good as 'new', but reprocessing it may take far less energy and inputs than an equivalent newly manufactured product. Recycling on the other hand, recovers the material value of the product but destroys its function, thereby requiring additional inputs. Theoretical work on the determinants of end-of-life outcomes has attempted to explain the occurrence and rationale of different life cycle outcomes such as remanufacture and reuse. We briefly outline the most findings of theoretical work that are most relevant to an understanding of our case study.

Thomas (2003) modifies a theoretical model of second-hand markets developed by Anderson and Ginsburgh (1994) to examine the environmental implications of product reuse. In this model, second-hand markets can be stimulated in a number of ways – by increasing product lifetime; by decreasing transaction costs in the sale of used goods, or when products do not significantly change over time. The analysis by Thomas shows that increased reuse does not necessarily result in lowered environmental impact. Environmental impacts depend on the extent to which reuse stimulates increased demand for new products by allowing buyers to access the market of new products, as is the case for products with non-zero second-hand value such as housing, books and automobiles.[6]

[6] Deviations from the hierarchy can also result products where the energy and material inputs for reuse and remanufacturing are similar to those for new products. While deviations from the hierarchy need to be recognized, the hierarchy is robust for many applications (Faruk, Lamming et al. 2002), particularly those involving products with large numbers of manufactured components. It is not surprising therefore that use of the hierarchy is recommended as a mechanism to set design goals for products (Graedel and Allendy 2003).

(Most environmentally preferable)
Reuse components / refurbish assemblies
Remanufacture
Recycle materials
Incinerate for energy recovery
Disposal as waste
(Least environmentally preferable)

Figure 2.1 Hierarchy of post consumption life cycle options

Source: Graedel and Allenby (2003)

Much of the literature on remanufacturing is focused on technical design for product disassembly (Guide and Srivastava 1998; Rose, Ishii et al. 1998; Tsuchiya, Kato et al. 2003) on operational aspects such as inventory control (Toktay, Wein et al. 2000; Inderfurth 2002) and on scheduling (Guide, Jayaraman et al. 1998). There is also an emerging literature on the market related issues (see Toffel 2004 for a review). From the manufacturer's perspective engaging in product recovery and remanufacturing can be undertaken to reduce production costs, meet customer demands, enhance brand image or protect after-market. Strategic choices faced by manufacturers are highlighted in the design of reverse logistics systems (Klausner and Hendrickson 2000; Fleischmann 2003), for example, in choosing between internal vs. third party recovery programs (Savaskan, Bhattacharya et al. 1999; Guide and Wassenhove 2001), in choosing between and among recycling and remanufacturing options and on the impact of supply fluctuations on firms engaging in end-of-life remanufacturing (Guide and Wassenhove 2001). Work by Debo, Toktay et al. (2003) highlights the rôle of consumer's willingness to pay for remanufactured products in determining the decisions made by manufacturers' on the extent of new manufacturing.

From the perspective of this study, the literature on remanufacturing economics offers the following insights:

- Since the flow of used parts is critical in remanufacturing, reverse logistics systems should be designed to minimize part-supply uncertainties and leakage.
- The viability of remanufacturing depends strongly on heterogeneity of consumer preferences – the more consumers choose remanufactured goods of a lower value, the less profitable it is, and vice versa.
- The combination of new and remanufactured products creates a product portfolio where future levels of one product type (remanufactured products) depend on present levels of the other (new products) that leads to some counter-intuitive dynamics. For example, technologies that reduce remanufacturing costs can lead to increase in volume of *new* sales in order to supply remanufactured products to meet increased demand.

Material recycling is the third outcome of interest. In general, materials that are *recyclable* are *recycled* when the costs of recycling are lower than the economic value of recyclable end-of-life materials. Materials that are not or cannot be recycled are simply consigned to waste. The economic value of end-of-life materials, however, depends on a number of local and global factors. These include shifting technical capability to use recyclate[7], changes in the design and material composition of products, and local transportation costs. In the absence of regulations, recycling systems have arisen spontaneously and can be quite complex. For example, in North America automotive dismantling and recycling can have a dozen to two dozen independent participants with different roles, different technologies and different mixes of automotive and non-automotive business. This complexity makes it difficult to design regulatory intervention (Graedel and Allenby 1998). In part as a response to these complexities, and facing increasing environmental pressures governments have begun to pass EPR laws that provide incentives for increased technological innovation among manufacturers as the means to reduce end-of-life impacts (Gerrard and Kandlikar 2005).

Theoretical approaches tend to rigorously study specific determinants of end-of-life outcomes, while individual case studies provide insights into end-of-life outcomes for a single product. Products can vary along many dimensions – technological complexity, physical durability, rate of technological change, and material characteristics. These attributes interact in complex ways with the market and with regulations, obviating any straightforward relationship between product types and end-of-life outcomes. Comparative case studies of product types (within a single regulatory and market system) help in understanding these synergistic effects.

2.3 Case studies

In order to capture a range of influences on life cycle outcomes, we examine five different product case studies for copiers, home appliances, computers, disposable cameras and automobiles in the Japanese market. Data on case studies was collected through literature review (primarily from company websites, academic papers and government documents) and the responses to an open-ended email-based survey of five copier and five home appliance manufacturers. (Appendix 1: list of manufacturers, Appendix 2: survey questions) For each case study we describe the outcomes in the Japanese market, followed by a brief examination of two factors that influence these outcomes – Consumer and Market Considerations, and Product Attributes and Supporting Recovery technologies. Where appropriate we also analyze how the Japanese recycling legislation has influenced these factors.

2.3.1 Copiers

Copiers are a good example of a successful use of remanufacturing in a product cycle. Remanufacturing has emerged as an important strategy in copiers from market forces alone, i.e., in the absence of regulation mandating recovery. There is much evidence in the

[7] For example, in the 1960s large amounts of scrap steel from automobile shredders lost its economic value when steel mills shifted to the basic oxygen furnace that could accept 10-30% of input as scrap steel, down from 50% for the earlier Open Hearth process. The situation changed in the 1980s when Electric Arc Furnace that can accept 80-100% scrap steel was introduced (Wernick and Themili 1998).

literature that remanufacturing can result in cost savings for copier manufacturers. Xerox (USA), reportedly saves "hundreds of millions of dollars" each year from remanufacturing (Maslennikova and Foley 2000). Japanese copier manufacturers now offer remanufactured product lines. For example, five types of Ricoh's remanufactured copiers use 87% (weight basis) of reused parts (Ricoh 2004). Other major manufacturers – Fuji Xerox, Canon, Sharp – also use reused parts in some products at more than 70% of weight (Okada 1999; Fuji Xerox 2003; Canon 2004b). Although remanufacturing is a primary focus, material recycling is also carried out for the parts that are hard to reuse. The materials for such parts are either closed-loop recycled into the same parts or down-cycled into different parts or products (Ricoh 2004). Manufacturers report that recycling rates of copiers—defined as the reused and recycled mass divided by the collected mass—exceeds 90% (Fuji Xerox 2000; Canon 2004a; Ricoh 2005).

Consumer and Market Consideration

A majority of copiers are leased rather than sold to business users, with a lease period of three to five years. The chance that equipment will be remanufactured is greater if it returns to the manufacturer at the end of life. Lease-based business models can dramatically improve the chances of manufacturer ownership, thereby facilitating recovery (Fishbein, McGarry et al. 2000). Once dedicated collection routes for leased products are established[8], the chances that used products will 'leak out' of the loop are dramatically reduced. 97% of used copiers are reportedly returned to manufacturers through reverse sales routes (METI 2003) although study shows there can be significant leakage in the ownership/responsibility loop (Fishbein, McGarry et al. 2000).

An additional aspect of leasing that has an impact on copier remanufacturing, as evidenced in the responses to our survey, is predictability of use. Most users of leased copiers are business users, and their usage patterns are predictable, i.e., most products are used in a manner that is within the range of manufacturers' assumptions about usage patterns. Consequently, copiers returned to manufacturers show lower variability in the levels of wear and tear in components. There are several reasons for this – businesses users may be more likely to follow instructions on appropriate use, leasing companies are responsible for maintenance and upkeep during the lease period thus providing ways to continuously monitor components, and reducing the chance that components might be in disrepair. Two appliance manufacturers pointed to predictable usage pattern as one of the reasons why copiers can be remanufactured and appliances cannot be. Finally, 'controlled ownership' in the form of the short life of leases (3-5 years) might imply that copier components are generally in good working order.

From a market perspective, the fundamental question is whether remanufacturing is profitable. The cost of a remanufactured product can be more or less than a new product

[8] There is some debate in the literature on whether it is best for manufacturers to engage in product recovery themselves, collect products through retailers or to employ a third party (Guide et al, 2001; Savakasan, 2000) Using retailers appears to be the theoretically superior option. Under the Japanese *Home Appliance Recycling Law*, retailers collect products and return them to the manufacturer.

depending on costs of collection, disassembly and cleaning of reused components. Further, if consumers' willingness to pay for remanufactured products is lower than that of new products, remanufacturing is unlikely to be profitable. Manufacturer response to this question in our survey differed somewhat. One manufacturer surveyed suggested that users were positively inclined towards accepting remanufactured copiers so long as the quality of product was assured. In particular, the manufacturer singled out government offices as particularly accepting of remanufactured copiers. Another manufacturer, however, noted that costs of remanufacturing were higher than those of new products and users were less willing to use remanufactured copiers. The cause of this inconsistency in manufacturers' responses to the survey needs further investigation, but a possible cause is the difference in remanufacturing costs. As predicted in the theoretical literature (Debo, Toktay et al. 2003) the existence of heterogeneity in consumer's willingness to pay appears to be an important factor that determines the profitability of remanufacturing, i.e. the balance should be maintained between the group of consumers who prefers to buy new products at higher cost and another group who prefers lower-cost remanufactured products, to maintain remanufacturing at a profit. The survey result indicates that there exist such heterogeneous consumer groups. On the whole, the increased trend towards remanufacturing, and the success of manufacturers in achieving high collection rates and high component reuse rates – 70% or more reused components in remanufactured product marketed by the four of the five largest manufacturers – suggest that technical barriers to remanufacturing have been overcome, and remanufacturing is becoming profitable.

The profitability of remanufacturing is also evidenced in internal 'environmental accounting' systems manufacturers adopted, which calculate costs for improving the environment and the benefits derived from such improvements. Expenses include research and development cost, cost of recovery, energy saving and antipollution measures, and additional labour cost related to improving environmental impacts. Benefits include profit from recovered material sold to recyclers, saved energy and material of the company, supply chain and users. For at least two companies benefits from attempts to 'close the loop' exceed the costs of doing so (Ricoh 2003; Canon 2004a).

Remanufacturing of copiers is also a way that companies use to improve their environmental performance by increasing recovery rates for their products. Copier manufacturers regularly appear on the top survey of environmental performance in Japan. For example, in an annual survey on environmental performance conducted by Nihon Keizai Shimbun (a Japanese business newspaper) in 2003, Canon was ranked first, Fuji Xerox on the fourth and Ricoh on the sixth among 599 manufacturing companies (Nikkei Research 2003). Consequently, copier manufacturers are locked in a 'race to the top' that provides additional incentives to maintain and improve recovery efforts.

Product Attributes and Supporting Recovery Technologies

A copier is outdated and replaced at the end of the lease period (three to five years) or even earlier, while parts are still usable at the time of replacement. In other words, the physical lifetime of parts is longer than the lifetime over which the product has a useful life.

Manufacturers also report that they intentionally make parts' life longer (Canon 2004a). Theoretical models (Geyer and Van Wassenhove 2003) show that leased products with full recovery and highly durable designs (e.g. where motors can be physically reused up to three times) can help meet 75% of a steady-state demand[9]. For less durable parts such a single reuse components the fraction of steady-state demand met by remanufacturing drops to 50%.

Leasing also facilitates product design. Manufacturers can plan ahead because they know the timing, quantity and conditions of products being returned to them, thus avoiding the problem of uncertainty in part availability during remanufacturing. One manufacturer in our survey suggested that the company had "a 10-year plan of product design, identifying which units and parts of which product a future product will have." A 10-year plan would help manufacturers build in components that could be reused 2-4 times (depending on the length of the lease) and help meet between 50%~75% of component demand based on the theoretical model mentioned earlier. It is not surprising therefore that copier manufacturers are investing in research and development aimed at optimizing remanufacturing strategies. The focus of research and development is on damage-free packaging and transportation, diagnosis used part function, cleaning techniques, and improved design for easier disassembly (Ricoh 2005).

2.3.2 Home appliances

The Japanese *Home Appliance Recycling Law* (2001) regulates life cycle outcomes for four designated appliances – refrigerators, air conditioners, televisions and washing machines. Prior to implementation of the law, 75% of the 18 million units were annually collected for disposal by retail chains (57%) and municipalities (14%). The rest were exported (24%) or sold in the domestic second-hand market (5%), while a small fraction (<1%) was 'illegally dumped' (METI 2002b). Waste management companies were responsible for shredding the products, recovering valuable metals and sending the remainder with a high heavy metal content to the landfill (Matsuo, Jung et al. 2004). After the law has come into force, the responsibility for disposal shifted to manufacturers. The law defines collection routes, obligates retailers to collect used products and return them to manufacturers.

Under *the Home Appliance Recycling Law*, manufacturers are responsible for recovering used products through their retailers but consumers share the economic burden by paying disposal fee that varies based on the type of appliance[10]. Under the new law, end-of-life products are taken back by retailers and transferred to one of 380 regional storage facilities located all over the country. Users pay collection and recycling fees to retailers when the end-of-life products are collected. Products are distributed to recovery and recycling facilities from collectors in two ways depending on the manufacturer (Matsuo, Jung et al.

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[9] At least one manufacturer noted that it is desirable for parts to be used a minimum of three times.

[10] For example, consumers are charged 4,830 yen (US$44 at the exchange rate of 1US$=¥110) for a refrigerator, 2,520 yen (US$23) for a washing machine, 2,835 yen (US$26) for a TV set, and 3,675 yen (US$33) for an air-conditioner. These charges slightly vary depending on manufactures, but basically do not consider the size, weight or other physical characteristics.

2004). Products from one set of manufacturers (including Matsushita, Toshiba) are sent to one of 24 private shredding companies for recycling, where the manufacturers have made additional investments in the form of dismantling and recovery equipment. These shredding companies process other products (automobiles) in addition to home appliances. Products from a second set of manufacturers (including Sanyo, Sharp, Sony, Hitachi and Mitsubishi) are taken to one of 14 newly constructed facilities that exclusively process home electrical appliances. The manufacturers made investments in these newly constructed facilities with financial support from the Government. Orphan products, i.e., those products whose producers have ceased to operate in the market, are handled by a designated legal entity that recycles products for a fee.

Thus, like copiers, used home appliances are returned to manufacturers for recovery. Unlike copiers, however, the central recovery strategy appears to be aimed at material recycling, and not at reuse or remanufacturing. Manufacturers appear to be successfully meeting their obligations under the law, and as shown in Table 2.1 by 2002 recycling rates for many appliances had well exceeded the standard rates set in the legislation (AEHA 2005). This is not surprising since the 38 recycling facilities described earlier have become operational since the legislation was brought into force. For example, used televisions are disassembled at a manufacturers' facility and then recyclable resources are carefully recovered manually or using advanced separation techniques. Panel glasses and funnel glasses (containing lead) are separated, crushed into cullet and recycled into glass for use in new televisions (METEC 2005). Metal parts go to steel manufacturers and refinery to be recycled into new material. Electric circuit boards go to refinery to recover lead and precious metals[11].

Table 2.1 Recycling rates of four designated home appliances

The standard was set based on the metal composition, recovery efficiency and lifetime of products in the 1980s and 1990s. These rates may have been set too low in the legislation partly because recovery efficiencies and plastic recycling rates might have been underestimated in calculations used for determining recycling targets. Consequently, standards were well exceeded even in the first year.

Source: Association for Electric Home Appliances (2005)

	Recycling rate				**Standard set by the legislation**
	FY2001	FY2002	FY2003	FY2004	
Air conditioners	78%	78%	81%	82%	60%
TVs	73%	75%	78%	78%	55%
Fridges	59%	61%	63%	64%	50%
Laundry machine	56%	60%	65%	68%	50%

Consumer and Market Considerations

Most home appliances in Japan are sold to individual consumers, and the number of leased products is negligible. This increases the distance between a manufacturer and the products

[11] A detailed assessment of the environmental outcomes associated with recycling and product recovery done by Matsuo, Jung et al. (2004) showed that recycling of appliances has resulted in a significant reduction in heavy metal discharge to the environment.

they sell. Once the ownership is transferred to a consumer, it is impossible to monitor the usage and the physical and operating conditions of a product. Manufacturers have no way of knowing when a particular user disposes a product, and whether usage patterns of a particular product have deviated from the norm. The absence of such feedback makes it more difficult for manufacturers to anticipate the number and quality of used products they can expect to receive at any given time, thereby reducing the possibility of reusing or remanufacturing product components. Three appliance manufacturers surveyed pointed to the variability and unpredictability of usage patterns and conditions, and/or a sale-based business model as an obstacle of reuse and remanufacturing.

Modest changes in use and disposal patterns are evident following the requirement that consumers pay a fee for disposal of home appliances. In particular, the time over which products are used has being increased through the emergence of rental business, where some manufacturers and retail chains have begun renting home appliances to meet the needs of short-term users such as students and workers away from home for a limited period. *The Home Appliances Recycling Law* provides an incentive to rental businesses because it obligates consumers to pay recycling expenses at the time of disposal (2,520-4,830yen, AEHA 2005, US$23-44 at the exchange rate of 1US$=110 yen[12]). Rental customers do not pay recycling fees, while simultaneously benefiting from a rental companies' repair services. For example, Toshiba Techno Network, a subsidiary of Toshiba, provides free repair during rental period, through their existing service network. Returned rental products are inspected and repaired, and to flow into second-hand market after the rental period (NTTRI 2003). The rental market is small compared with the 'new' sales market – the number of rental appliances is estimated in the order of tens of thousands (EIC NET 2003), while the domestic shipment of these four appliances is four to eight million units per year (MOE 2004). Consumers' obligation to pay the recycling fee also provides a small incentive to the second-hand market, but the scale of the second-hand market is also tiny – e.g., 160,000 second-hand washing machine were sold in 2001, compared to new product sales of 4.06 million (IBPC 2003; MOE 2004). Illegal dumping also seems to be on the rise, though the number of products dumped illegally is still small (MOE 2005).

Product Attributes and Supporting Technologies

The average period of usage of regulated appliances in Japan is nine to eleven years (ESRI 2004). Failure is the most common reason for consumers disposing their appliances – the rate of consumers who replace appliances due to failure is 60% for fridges, 69% for air conditioners, 72% for televisions and 76% for washing machine (ESRI 2004)[13]. Assuming

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[12] This currency exchange rate applies throughout this thesis unless otherwise specified.

[13] These figures are based on survey conducted for 5,040 households by Economic and Social Research Institute, Cabinet Office, Government of Japan. For those who replaced appliances, a reason was asked from four multiple choices including failure, upgrading, moving and other. However, there is no evidence that all the failures were serious enough to require replacement. Thus the high percentage of people who pointed to failure as a reason of replacement may capture those who only had a minor failure but wanted to justify a replacement. Also note that it is a common practice in Japan to remove large appliances such as fridges, washing machine and wall-mounted air conditioners when moving. Moving can be a good reason for discarding an old appliance and getting a new one.

that these consumers replace appliances due to failure that is unrepairable and serious enough to require replacement, this suggests that home appliances tend to be used to the end of their physical lives. Surveyed manufacturers noted that parts in used appliances were at the end of their physical lives, making their use in remanufactured products unlikely. This appears to be a dominant reason for why home appliances are not remanufactured.

Survey responses also indicated that technological changes over a products' lifetime reduced the likelihood component remanufacturing. For example, CRT displays recovered from used televisions are no longer useful for rebuilding televisions using recent technologies such as liquid crystal and plasma display panels. Rapid technological change, along with the long lifetimes of products and unpredictable timing of disposal lead to heterogeneity of collected parts, which makes reusing parts difficult. Two manufacturers raised heterogeneity of end-of-life products as a major barrier to remanufacturing. Consequently, the response of major appliance manufacturers to *the Home Appliance Recycling Law* has been the construction of facilities dedicated to material recycling of products. All manufacturers we surveyed indicated little interest in reuse or remanufacture. Material recycling requires technologies of disassembly and separation. For example, Matsushita Eco Technology Center (METEC), which started its operation at the same time as the enforcement of *the Home Appliance Recycling Law*, has filed 68 patent applications including the high speed separation of CRTs, normal temperature crushing of compressors, high grade separation of copper and aluminium from heat exchangers, and the whirlpool sorting of blended plastics (METEC 2005). All these technologies exemplified above are separation and recovery technologies, and not those that facilitate reuse and remanufacturing.

While a detailed assessment of the R&D implications of recycling laws on appliances manufacturers is beyond the scope of this paper, there are clear indications that manufacturers are attempting to bring down the costs of recycling and incorporating them into product design. Each manufacturer uses at least one recycling plant to "compile and communicate information from the downstream to the upstream, to accumulate knowledge, and to grasp the actual costs of recovery and environmentally sound treatment" (Tojo 2001). Exchange of information between recycling plants and product design departments is done in the form of meetings, seminars, and visits by designers to recycling plants. In addition, one of the manufacturer surveyed conducted training for design engineers toward easy-recycling products, another pointed that the law triggered the development of separation techniques.

2.3.3 Computers

The value of computers declines rapidly with the speed of technological change in the industry. Typically, consumers dispose or replace a product earlier than the point at which physical breakdown occurs. This is particularly true of early adopters of computer technology, who are willing to forgo useful life of a computer in exchange for new technologies. This creates a steady supply of second-hand computers. A computer eventually loses its value as current software is no longer compatible with its hardware capabilities, or it reaches the end of its physical lifetime, and needs to be disposed. *The Law for Promotion of Effective Utilisation of Resources* enforced in 2001 regulates the disposal of used computers. Manufacturers are responsible for collecting and recycling used computers, and users, both business users and personal ones, pay the expense for recycling. The legislation requires that used computers be collected and recycled by manufacturers.

Collection of PCs for recycling is facilitated by a joint collection system administered by JEITA, the Japanese Electronic and Information Technology Association. 36 major manufacturers representing 98% of all PCs sold in Japan are collectively involved in this process. Consumers can either drop their used computers at a post office, or arrange to have postal officials come and pick up used computers. Collected used computers are first disassembled by hand into their constituent parts (PC3RPC 2005). Reusable parts (e.g. hard disks, power unit etc.) are recovered at this stage, and those that pass inspection are reused. Remaining parts are crushed and separated into materials such as glasses, plastics and metals before being handed over to recyclers for material recycling.

Consumer and Market Considerations

The typical recycling fee for a personal user is 3,150yen (US$29) for a desktop and laptop computer and 4,200yen (US$38) for a CRT monitor (PC3RPC 2005) These fees are included in the price of products sold after the legislation enforcement in October 2003, but not included in the price of products sold before. Users pay the fee at the time of disposal if the fee is not prepaid.

Japan has a very large used computer market. In 2001, prior to the enactment of the computer recycling law, the size of the Japanese market for used computers was 830 thousands units or about 7% of all new products (MIC 2004). The recycling law appears to have given a boost to this already thriving market, and the sale of used computers has increased by over 10% per annum to over 900 thousands in 2003, and over a million by 2004 (MIC 2004). The growth of the second-hand market has led to sale of refurbished PCs by large manufactures. Since 2003, IBM Japan sell used computers under its "refreshed" brand (IBM 2005). Majority of used computers are lease returns from companies and they are sold at retail store chains (Impress Corporation 2003). NEC, on the other hand, collects used computers from individual users, refurbish them, and sell them with the brand of "NEC refreshed PC" (NEC 2004a). The obligation to pay the recycling fee at disposal works as an incentive for users to sell a product to the second-hand market further facilitating used computer transactions.

As with appliances 'illegal dumping' or sale to companies that export computers to developing countries is a potential problem for computers sold before 2003, though there is little data on whether this is happening in significant numbers. A substantial number of Japanese computers are exported to other parts of Asia, particularly People's Republic of China, for material recycling by low-wage labour. The health and environmental impacts resulting from toxics pollutant release on poor workers in recipient countries involved recycling of 'e-waste' have been well documented (Puckett, Byster et al. 2002), and the practice appears to continue apace (Goodman 2003). While data are hard to come by, one source estimates that roughly 20% of all used computers from Japan are exported for material recycling abroad before the enforcement of the law (METI 2002a).

Product attributes and Supporting Technologies

Computer designs have little flexibility for building in the reuse of components and parts. Reusing of computer parts is limited to certain modules and units such as hard disks and power units, while second-hand use of the entire product is more widespread. In the past, computer hardware was rapidly outdated as new software requiring higher hardware speed was developed. Since the late 1990s onward hardware advancements have allowed the average user to take greater advantage of newly developed software without the need for an upgrade. A two-year old computer can meet the needs of such users. The dynamics of hardware and software advancement has led to an increase in demand for second-hand products (PC View 2003).

Under the mandate of the law, discarded computers are disassembled, separated and recycled once they reach the manufacture. The separation is conducted by hand, and a computer can be disassembled and separated by a worker in 10 minutes (NEC 2004b). Recycling rates (reused and recycled mass divided by collected mass, not including energy recovery) are the following: desktop computers 78.0%, notebook computers 50.3%, CRT displays 72.8% and LCD displays 64.8% in the period of October 2003 and March 2004 (PC3RPC 2005). These rates far exceed the legal standards for recycling which are set at 50%, 20%, 55%, and 55% respectively. Recycling of plastic is likely to provide the greatest further improvements to recycling rates. (NEC 2004c; Toshiba 2004)

2.3.4 Disposable Cameras

Disposable cameras were first introduced in the mid 1980s and have been widely available for close to two decades. When they were first released in 1986, they were not recycled and tended to be disposed after a single usage. Four years later, owing to consumer pressure, manufacturers started to build recycling systems and renamed their products as "film with lens", emphasising that the product was no longer disposable (Hokkaido University 2004). At present, more than 90% of disposable camera parts are reusable and the recycling rate (reused and recycled mass divided by collected mass) exceeds 95% (Fuji Film 2004; Konica Minolta 2004). Although manufacturers of disposable cameras do not retain ownership of products over its lifetime, remanufacturing is the primary end-of-life outcome. Products are recovered from customers through camera stores and disassembled into modules and parts. These modules and parts (e.g. flash module, shutter unit, battery etc.) are inspected and reused in new products. Camera cover material is either recycled into the same product or downcycled into other products.

Consumer and Market Considerations

The nature of the product makes it easy for manufacturers to collect used products since a buyer is expected to bring the product to a shop for developing the film. However, ease of collection does not automatically imply that reuse systems were always in place. In the

1980s when disposable cameras first came to market, they were sent to the landfill or incinerated upon use. In the early 1990s, disposable cameras became the symbol of the disposable age, and manufacturers faced criticism over the wasteful nature of their product. Critical public opinion helped to redirect manufacturers toward recycling and reuse (Hokkaido University 2004). Three major manufacturers collectively started to build recycling systems in 1991. Reused cameras faced little opposition from the public.

Although most of parts of a disposable camera are designed for remanufacture and recycle, the number of cameras that escape the closed loop is not negligible. Roughly 60% of shipped products return to a manufacturer. Most of the rest goes to third parties who attempt to restore a film for resale (Fuji Film 2004). Refurbishment by third parties might be deemed as part of 'reuse,' but once a product is modified, it cannot be remanufactured. On the other hand, components of products that are returned to a manufacturer can be repeatedly used in remanufacturing as long as they pass the quality test. Manufacturers would rather have complete access to their products but have no ability to control third party resale. Third parties have collection points, techniques to restore a film, and sales channel. They are also engaged in a legal business as ownership is transferred to them from users of disposable cameras who choose to provide used products to them. It is difficult to keep third parties from reselling used products only by moral persuasion, and this remains a big obstacle for the recycling system.

Product attributes and Supporting Technologies

The time of usage for disposable cameras is short, and it is unlikely for camera parts to reach the end of their physical lifetimes before the product is recovered. For instance, the battery, a component with a short useable life, has the capacity to power a flash more than 200 times, while the number of exposures in disposable cameras is typically less than 40 (Hokkaido University 2004). Other mechanical and electronic parts, such as lens, a shutter unit and a switch unit are reusable if used in an appropriate manner. Disposable cameras and copiers are common in that remaining lifetime of parts is long enough to be reused when a product returns to a manufacture, although business models of recovery logistics are different.

The other factor contributing to remanufacturing of disposable cameras is the rate of technological changes. Although manufactures have a variation of products targeting different users, disposable camera technology is mature and shows little change in technological platforms from year to year. The relatively slow evolution of the technology contributes to 90% of parts being reused. Over the years, manufacturers have developed their own recovery facilities where used products are classified, disassembled, tested, repaired as necessary, and remanufactured. Manufacturers also strive to improve recyclability at design stage; for example, only recyclable materials are chosen, and modular design of component parts are common (Konica Minolta 2005).

2.3.5 Automobiles

The end-of-life outcomes for automobiles are more diversified than they are for any of the products discussed above. In 2003, over a million used cars, accounting for about one fifth of total end-of-life vehicles (ELVs), were exported from Japan to different parts of the world (MOE 2002). Export of Japanese cars is facilitated by the "Shaken" inspection system, a costly combination of taxes and mandatory roadworthy tests. "Shaken" renewal is mandatory after three, five, seven and nine years from the time of purchase, and can range from $680 from a compact car to $910 for a full-size sedan (JMF Shaken Centre 2005)[14]. This reduces the effective lifetime of cars used by consumers in Japan, as they choose to buy new automobiles rather than continuing to invest in the ones they currently own[15]. The presence of a large pool of used automobiles in good working order has created a strong market for used Japanese cars abroad. At the same time strict maintenance requirements and the need for parts created a thriving market for used components. As in other parts of the world, the bulk of an automobile by weight is steel, and is recycled. The recovery systems for automobiles is complex, and historically been entirely determined by market forces. *The End-of-Life Vehicle Recycling Law* that provides manufacturers with recycling targets and timetables came into force in January 2005.

The End-of-Life Vehicle Recycling Law is primarily aimed at the reduction of Automobile Shredder Residue (ASR) that goes to scarce landfill sites. Under this law, manufacturers and importers are responsible for collecting and recycling ASR and airbags, and collecting and destroying CFCs. Expenses for recycling ASR and airbags are paid for by car owners at the time of purchasing new cars or at the time of inspection of cars purchased before the implementation of the law. The target recycling rate (including energy recovery) is 95% by 2015, while the recycling rate before the law enforcement is around 80% (JAMA 2005).

Consumer and Market Considerations

ELVs are typically handed to dismantlers through dealers, insurance companies and garages. Although dismantlers play an important role in recycling ELVs, the details of dismantler activities are not well known (Takeuchi 2004). There are about 5,000 dismantlers in Japan handling about four million ELVs every year. Dismantlers vary in origin, size, facility and scope of work, and it is hard to characterise the standard business model of a dismantler. In general, dismantlers have the following main functions: (Takeuchi 2004)

- Collecting residual oil, gas and CFCs from ELVs.
- Removing reusable (marketable) parts from ELVs. Parts that have no market value are left as scrap, to be shredded at a later stage.
- Cleaning, repairing and rebuilding used parts before sale
- Separating valuable metals and selling them to steel refiners and smelters.
- Handing over scraps to shredding factories.

The dismantling business is vulnerable to market conditions. Through the 1970s, the main source of profit was scrap metals sold to steel refineries and smelters. In the 1980s

[14] The cost of inspection varies depending on conditions of cars and contractors. The amounts shown are only examples.

[15] It can be seen that the Shaken inspection system is counter-productive for full utilization of automobile life time as it discourages longer usage of automobiles. I am not aware that the inspection system which is designed to maintain safety and health has any coordination with the goals of recycling ELVs.

plummeting price of scrap metal resulted in a shift in business focus to used car parts sold to users and garages (Takeuchi 2004). Over the years, dismantlers have independently developed marketing strategies for used parts including the establishment of brand names, networking with other dismantlers to extend marketable parts, and specialisation in part types. In this regard, the Japanese used parts industry follows what is observed in North America. The flow of revenues from dismantlers to shredding factories also started in the 1980s when final disposal costs increased as landfill space became scarce. In this way, the market largely defines the business of dismantlers. This indicates that the life cycle scenario of vehicles largely depends on market conditions. For example, the demand for used parts determines the level of disassembly for a given make and model of the ELV, regardless of reusability of parts.

The End-of-Life Vehicle Recycling Law requires consumers to pay the recycling expenses. The expense is less than 1% of the new car price: 9,100-9,700 yen ($83-88) for a compact car and 13,520-14,120 yen (123-128US$) for a full-size sedan, for example. The fees are intended to defray manufactures' expense to recycle ASR and airbags, and destroy CFCs. The enforcement of the law changes flows of money and designated waste (ASR, airbags and CFCs), but the end-of-life outcome of ELVs is likely to remain the same.

Product attributes and Supporting Technologies

The recycling fees charged by manufacturer at purchase differ for the different models and makes available in the Japanese market. In principle, this provides automobile manufacturers with an incentive to reduce recycling costs and improve dismantling and recycling technologies. However, there is some debate on the efficacy of this goal since the fees charged by most carmakers are almost identical (Kim 2004). To date, manufacturers have focused on easier handling of airbags, disassembly, and use of recyclable and recycled materials[16]. They also attempt to improve the quality and availability of used parts (Toyota 2005; Nissan 2005). A majority of these initiatives are aimed at supporting the maximum use of reusable parts and improvement of material recycling, however, remanufacturing is unlikely to be a viable option.

Although *the End-of-Life Vehicle Recycling Law* adopts the EPR principle, its design assumes taking advantage of the existing infrastructure. Manufacturers are only responsible for recycling ASR and airbags, and destroying CFCs. The remaining of the recycling system will be left to the existing mechanism and the market. Manufacturers of automobiles have had little participation in the historic recycling process of ELVs. Without the participation of manufacturers, closed-loop life cycle such as those of copiers are unlikely to take place because considerations need to be given at design and production stages.

2.4 Summary and conclusion

The five Japanese case studies we chose in this chapter capture a range of features that

[16] Nissan's March car is reportedly 95% recyclable.

influence end-of-life outcomes. They range from technically simple (disposable cameras) to very complex (computers and automobiles). The products involve the use of different business models (leasing vs. purchase), have lifetimes ranging from a few days up to a decade, have different consumer responses to use and ownership, and have different reasons to return to manufactures (business model and EPR legislation). The life cycle outcomes also differ in the extent to which products have second-hand markets, are primarily remanufactured or have most of their materials recycled. Copiers and disposable cameras are primarily remanufactured, while materials of household appliances are almost entirely recycled at the end of their useful lives. Computers and automobiles are recovered through a 'cascaded' approach (Graedel and Allenby 2003) whereby a fraction of components that are valuable in used parts market are recovered, while the remainder is materially recycled. Our research suggests four main factors for differences in life cycle outcomes – Product Attributes, Reverse Logistics, After-Market Demand and Recovery Technology. Figure 2.2 shows how the four drivers influence end-of-life outcomes. For example, the bottom half of the figure under the column labelled "remanufacturing" shows the potential key drivers for remanufacturing strategies. From the figure it is quite clear that remanufacturing needs to meets the largest number of criteria for efficient recovery, while simple disposal and energy recovery are outcomes that emerge when the recovery process meets none or only a limited set of criteria.

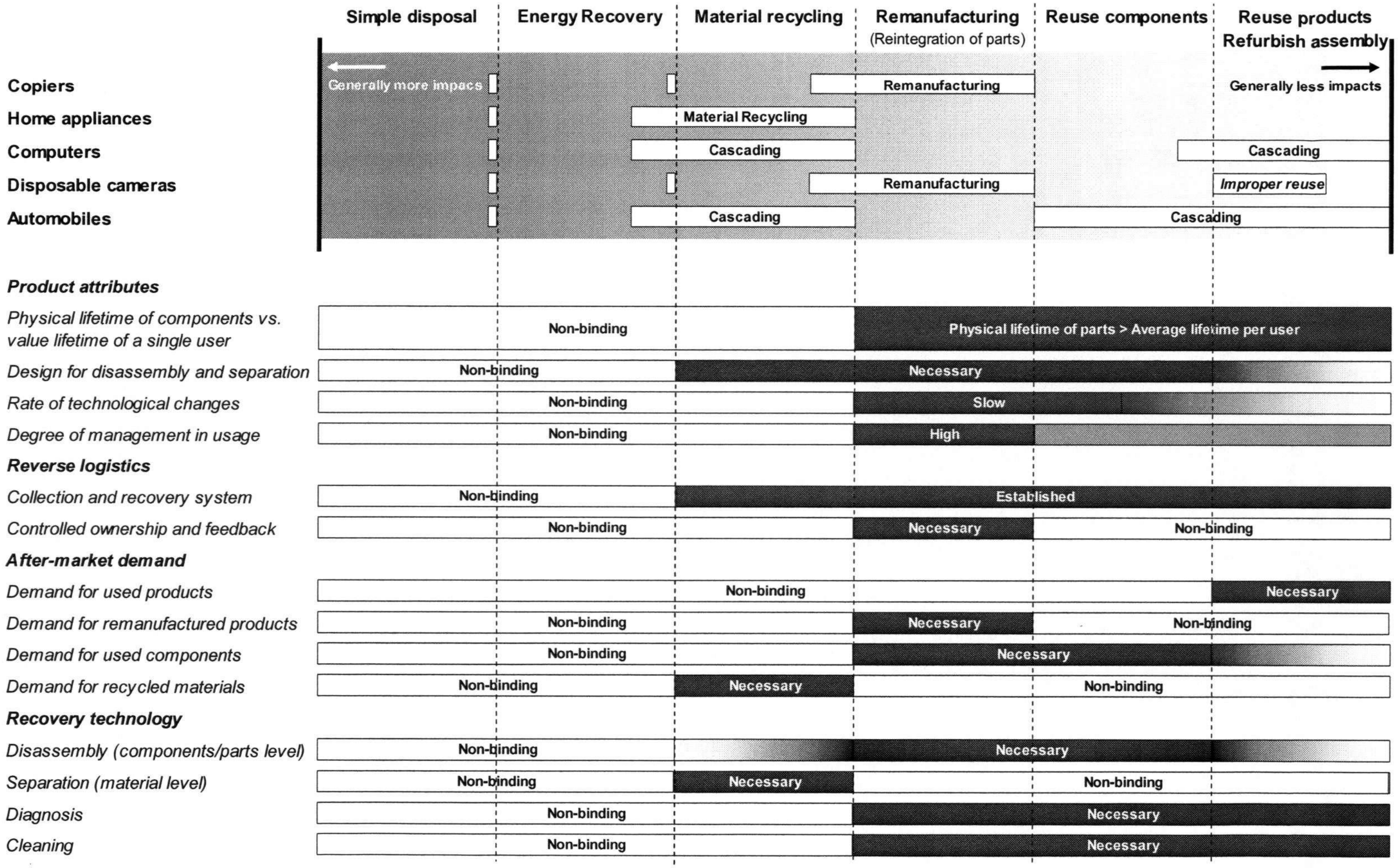

Figure 2.2 A map of dominant end-of-life outcomes for five products in the Japanese market on the 'spectrum' of recovery options and potential conditions for the outcomes

The top figure shows a 'spectrum' of end-of-life outcomes in accordance with the hierarchy discussed in 2.2. A product's end-of-life outcome is representated by bands shown in the top half of the figure. For example, 'Reuse components' involves resale or transfer of ownership of individual used components and is distinguished from remanufacturing where reused components are reintegrated into products before resale or transfer of ownership occurs. The bands are labeled by their dominant outcomes such as 'remanufacturing' and 'cascading', but do not represent exact propotions. The bottom half charts the drivers of end-of-life outcomes, categorised into four factors color-coded as black, white and grey. Black represents conditions that are binding, white represents no effect of a driver on an end-of-life outcome, and grey suggests intermediate effects or depends on cases.

At the simplest level attributes of the product – the physical lifetime which is determined by the physical integrity of a product, and rates of technological change that affect the design of products and their components potentially create the necessary conditions for end-of-life outcomes. Products that are no longer in use despite being physically intact are more likely to be resold or remanufactured. Clearly, disposable cameras that have a short period of use and whose technologies evolve only slowly are ideally suited for extensive remanufacturing. Conversely, products that are typically put to use till the end of their useful physical lives, such as appliances, are typically recycled for their materials. Further, products that are designed to be easily disassembled are more likely to have their components reused, while those that are harder to dismantle more easily slot into a 'rip, tear, shred' approach to product recycling. However, these seemingly 'technical' aspects of products can be shaped by local market conditions and consumer preferences. For example, at roughly one million units resold per year, the Japanese used computer market is large and facilitated by the presence of large manufacturers and chain stores selling used computers (The Japan Times 2004). For instance, Sofmap, a medium-sized retail chain derives 10% of its revenues from used computers. It is also claimed that a 'throwaway' culture that values new products over working but older ones creates a large supply of used computers and cars with a significant useful life that stimulates after-market demand (Dodd 2005).

After-market demand for used products, used components, and recycled materials is a primary determinant of the extent to which reuse, remanufacture and recycling takes place. The presence of, and reasons for, large used computer and car markets for Japanese products has already been discussed. Reuse of components for photocopiers and disposable cameras by manufacturers is also an outcome of chain of economic factors. The presence of such large volumes of remanufacturing by major Japanese copier manufacturers is an indication that remanufacturing is economically viable. While exact numbers for the Japanese market are not available to us, photocopier remanufacturing has also been documented to be profitable in other contexts. Xerox, for example, is reported to have saved $200 million in materials and parts by the mid-1990s (Davis 1996). Further, copier manufacturers also appear to be engaged in materially recycling components that are not being reused partly because they compete with each other in promoting the 'green' nature of their products. A similar case can be made for disposable cameras that are remanufactured to a large degree, with the remainder being materially recycled. EPR Legislation appears to be the primary reason for increased recycling of appliances and computers. Prior to the EPR legislation, after-market demand for materials accounted for only 50% of appliances, with an even lower figure for computers. There has been a significant jump in these figures since the legislation was passed, and the costs are being borne by consumers, manufacturers and the government. Over time, however, manufacturers appear to be confident that improved technologies will reduce dramatically reduce recycling costs (Perry 2002).

Reverse logistics, or the logistics of capturing after-market products can also be an important determinant of eventual life cycle outcomes. The Japanese legislation that was applied to appliances, computers and automobiles has two important principles: EPR and Shared Responsibility. The EPR principle obliges manufacturers to recover their end-of-life products. The Shared Responsibility Principle defines responsibilities of the manufacturers, retailers, consumers and other stakeholders in facilitating end-of-life capture[17]. Consumers are required to bear a part of the expense for recycling appliances, computers and automobiles. In cases where the existing responsibility for collection and disposal of used products was primarily municipal, i.e., for computers and household appliances, there has been a dramatic shift in responsibility. EPR and collective responsibility have shifted the burden of collection and disposal costs away from municipalities to those directly benefiting from the sale and use of products. In addition, appliance retailers are responsible for collecting used products and handing over them to manufacturers. Automobile collectors, dismantlers, and shredders are also responsible for handing over collected ASR, CFCs and airbags to manufacturers or importers through shredders. Evidence to date suggests that the reverse logistics infrastructure is working efficiently, and illegal dumping to avoid disposal fees remains a minor problem for most products.

Reverse Logistics for products in this study not legislated by EPR laws have emerged over time from market forces. By their very nature disposable cameras need to be brought in to a retail store for film development and printing. Efficient reverse logistics is therefore built in to the process by which a consumer derives utility from the product. However, the ownership of disposable cameras is transferred to the consumers creating the space for third party companies that might process and resell cameras outside the proper loop built by the manufactures. Photocopiers are more technically complex products with a lease-based business model that allows for efficient collection of leased item upon the end of lease. In addition to dramatically increasing collection efficiency, a lease-based model also allows for a recouping of products by manufacturers well before the end of their physical lives. Since copiers tend to occasionally break down, they require the services of a repairperson several times a year. Consequently, the operational attributes of the photocopy machine are in part responsible for the emergence of a lease model and consequent monitoring of photocopiers while in use. Lease models also necessitate constant monitoring of products, and improved maintenance of components. Taken together these factors facilitate design and implementation of remanufacturing as an end-of-life strategy for copier manufacturers.

With the advent of EPR laws, some manufactures have established recycling infrastructure required to recover used products. Research and development of relevant technologies in Japan is also being driven by the implementation of the laws. Appliance and computer manufacturers have made extensive investments in recycling facilities. While an extensive assessment of the research and development investments into disassembly and recycling is beyond the scope of this research, there is plenty of reports on research and development investments made by companies in response to the EPR laws. For example, the Matsushita Eco-Technology Centre, which recycles up to 500,000 home appliances per year, is also using the facility as a research laboratory for improving disassembly and material recycling operations (Perry 2002; Pierce 2003). Similarly, automobile companies are working on

[17] Some have argued that the shared responsibility principle resonates with Japanese societal etiquette and collective business norms. It is interesting to note that equivalent European 'take-back' laws do not explicitly legislate such a sharing of the disposal burden.

improving dismantling and recycling technologies both individually and collectively (Kim 2004).

An interesting question, and one that we do not fully address in this paper, is why copiers appear to be unique among technologically complex products that are extensively remanufactured. To answer this question one would need a detailed assessment of how copier manufactures have reduced the cost of remanufacturing and made it a competitive business strategy. We suspect that the lease model is in large part responsible for this. Techniques for testing part functioning, 'controlled' ownership which leads to less variable usage pattern and part conditions, relatively slow rate of technological change, and long physical lifetime of parts relative to lease periods appear to be preconditions for developing a remanufacturing strategy. Unless these conditions are met, manufacturers will find it difficult to put a remanufacturing strategy in place. Put differently, a striking characteristic of remanufactured products is manufacturers' (or service providers') 'proximity' to users, which provides continuous feedback on product performance, and enables improved product planning. Manufacturers surveyed indicated the critical role played by their ability to record usage histories of products in facilitating remanufacturing. The lease model has also allowed copier manufacturers to build sophisticated information management systems that help in coordinating the forward and backward component supply chains which significantly reduces coordination costs of remanufacturing (Nakagawa 2001). EPR legislation on the other hand is dramatically increasing the levels of recycling, but is doing little to enhance the levels of reuse and remanufacturing. In order to meet targets and timetables Japanese manufacturers are making significant investments in technologies for dismantling and recycling. Yet, there appears to be very little in the way of investments that facilitate remanufacturing. Unless the 'proximity' to users is reduced and new business models that shift the burden of ownership to manufacturers are devised, material recycling is likely to become the dominant approach to end-of-life disposal for manufactured products.

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Chapter 3: Automotive life cycle strategy[18]

3.1 Introduction

Japan has recently legislated waste management and recycling laws aiming at forming a "sound material-cycle society." A sound material-cycle society was proposed as an alternative to the current society where mass production, mass consumption and mass disposal are the dominant economic and social practices (MOE 2003). In a sound material-cycle society, resource inputs from the ecosystem and waste outputs to the ecosystem are minimised by effective and 'circulatory' use of resources. The idea has been made operational through five industry-specific laws aimed at improved recovery of specific products, in addition to laws which set the basic legal framework.

The End-of-Life Vehicle (ELV) Recycling Law is the latest among a series of industry-specific recycling laws; it was enacted in 2002 and was fully implemented in January 2005. As of March 2005 Japan had a total of 78 million vehicles (AIRA 2005a) of these over five million vehicles leave service every year – a million are exported and four million are scraped within the country (METI 2003d). Given the large quantity of ELVs generated every year, the management of ELVs can impact the environment on a large scale. At present, 20-30% of an ELV is recovered in the form of parts for reuse and 50-55% in the form of material recycling (METI 2003d), totalling about 80% of an ELV salvaged on a weight basis. The remaining 20%, called ASR or Automobile Shredder Residue, mainly consists of plastic, foam, fibre and glass. ASR is typically landfilled. ASR is considered to be the most problematic aspects of ELVs because landfill sites are increasingly scarce in Japan and cost to landfill waste is rapidly increasing. *The ELV Recycling Law* was designed primarily to reduce ASR.

This study focuses on life cycle strategy of automobiles under *the ELV Recycling Law* in Japan. A life cycle strategy of a product implies an integrative design and strategy of life cycle options (such as reuse, recycling etc.), business model, product and processes (MSTC 2004). The rationale of adopting such a perspective is that designing an appropriate product life cycle requires a holistic approach with the potential to reduce environmental impacts while meeting economic and social needs. Remanufacturing of copiers, a closed-loop manufacturing system under a lease-based business model is a successful example of transforming life cycle of a product to reduce material and energy intensity while meeting customer needs (Maslennikova and Foley 2000).

Previous work has shown that reusing and remanufacturing automobile parts reduces environmental impacts substantially over newly-manufactured parts from virgin material or recycled material. Figure 3.1 shows integrated and normalised environmental impacts of reused automobile parts compared with ones produced from new material and recycled

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[18] A version of this chapter has been submitted for publication:

Ogushi, Y. and Kandlikar, M (2005) The Impact of End-of-Life Vehicle Recycling Law on Automobile Recovery in Japan, *EcoDesign2005 proceedings*, December 12-14, Tokyo, Japan, IEEE Computer Science Press

A poster based on the contents of this chapter and Chapter 4 was also presented:

Ogushi, Y. and Gerrard, J. (2005) *Innovation in Automotive Lifecycle in a New Legislative Paradigm*, Auto21, a Network of Centres of Excellence, 2005 HQP conference, May 10-12, 2005, Oshawa, Ontario material (Nagata and Noutomi 2004). Hauser and Lund (2003) estimates that one kilowatt hour of energy spent in remanufacturing automobile alternators substitutes for five to six kilowatt hours of energy spent in manufacturing the original product. More generally, life cycle strategies aimed at transforming post-use recovery options of automobiles toward greater reuse and remanufacturing can substantially reduce energy and material inputs in addition to waste output to landfill. Nevertheless, whether a product can go up the theoretical hierarchy of post-consumption options, i.e. Recycle, Remanufacturing, Reuse (Graedel and Allenby 2003), is potentially contingent on a number of technical, legislative and market factors as shown in Chapter 2. This raises a number of important questions in relation to the automobile life cycle: What is the direction of technological change induced by *the ELV Recycling Law*? What recovery options – recycling, remanufacturing, and reuse – does it promote? Does *the ELV Recycling Law* direct automobile life cycle outcomes towards environmentally superior outcomes such as reuse and remanufacturing? The paper attempts to provide answers to these questions through the following steps.

(1) Examining the extent to which the law is influencing technological change geared to material recycling through design, development and manufacturing of automobiles; through ELV recovery and end-of-life processes.

(2) Analysing the extent to which the law may trigger changes the automobile sector that could lead to greater remanufacturing and reuse.

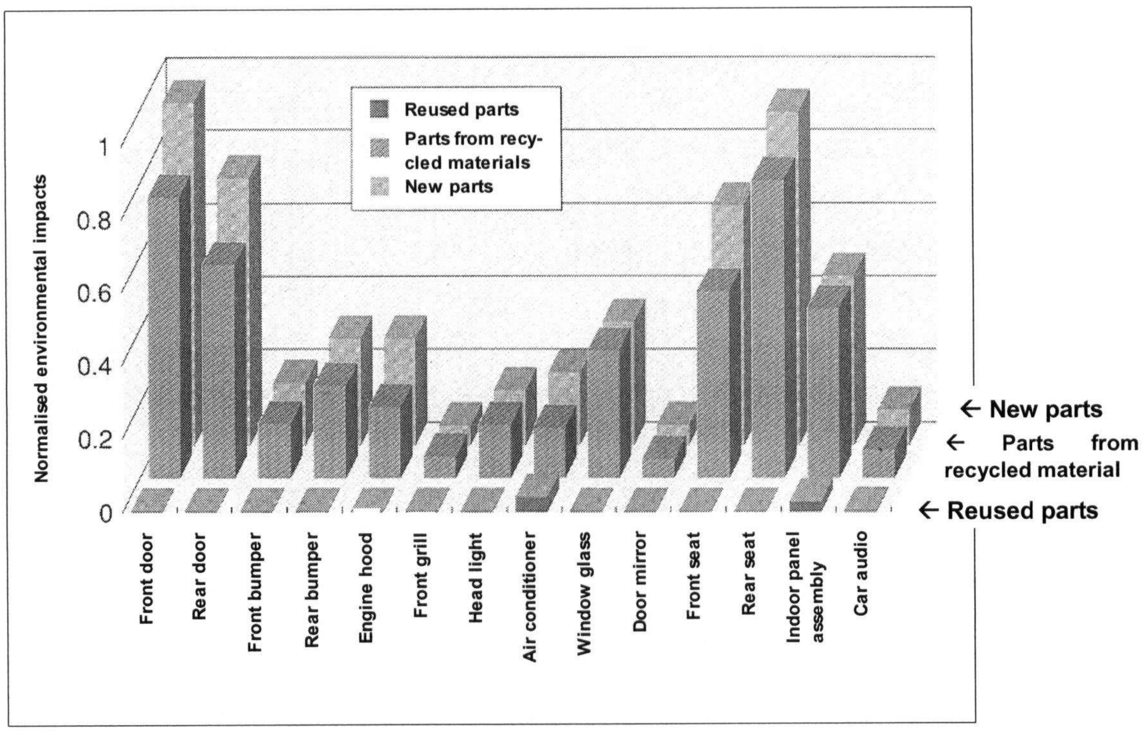

Figure 3.1 Comparison of environmental impacts of automobile interior and exterior parts

Normalised energy and material inputs for manufacturing processes of each reused parts, new parts from recycled material and new parts from virgin material.
Source: Nagata and Noutomi (2004)

3.2 Outline of method

In addressing the questions raised at the end of the previous section, we use two sources of information. The first set of sources are the environment and sustainability reports published by the six major Japanese auto manufacturers listed in Appendix 3 that account for over 80% of the market share of passenger vehicles in 2004. Truck and bus manufacturers, foreign manufacturers and smaller Japanese automakers were not included. The second data set was based on an open-ended email survey sent to the same six manufacturers in order to investigate manufacturers' view on the feasibility of remanufacturing of vehicles. Survey questions are shown in Appendix 4. All of six manufacturers responded; however, the number of survey questions answered varies depending on manufacturers. In addition, specific questions related to reuse of auto parts were asked of automobile part dealers and industry organisations listed on Appendix 5. The survey questions for these organisations are shown in Appendix 6.

It is not unlikely that manufacturers made decisions that directed technological advance primarily as a result of *the ELV Recycling Law*. Manufacturers began efforts related to recycling in the early 1990s, well before *the ELV Recycling Law* was enacted. In the absence of the ELV legislation, manufacturers probably would have continued making efforts for recycling. *The ELV Recycling Law* was designed not solely by the government, but through extensive consultations with stakeholders such as manufacturers and related industry organisations. Consequently, establishing strong causality exclusively between the law and innovation focused on recycling is rather difficult and not a goal of this study. However, if we assume, not implausibly that the law was a direct result of a stakeholder-based process aimed at improving ELV management, then the same processes that led to law also led to a focus on innovation aimed at recovery.

3.3 End-of-Life Vehicle Recycling Law

The business of dismantling ELVs in Japan dates back to 1920s, when the number of commercially imported vehicles rapidly increased (Takeuchi 2004). At that time the main source of profit for dismantlers was used replacement parts. The widespread diffusion of electric arc furnace technology after the Second World War made scrap metals become a valuable resource, and ELV dismantlers made profit primarily from scrap metals sold to recyclers. This model of business was relatively stable until the late 1980s. The appreciation of Japanese yen in the mid-1980s resulted in the inflow of cheap metals from overseas and the plummet of the value of domestic scrap metals. The price of shredded scrap dropped from over 26 thousand yen per tonne in 1984 to 15 thousand yen in 1986 and finally ten thousand yen in 2000 after some fluctuations (METI 2003d)[19]. ELV dismantlers shifted business focus from sales of scrap metals to used car parts to make up for diminished profits.

On the other hand, landfill space for ASR from ELVs is in short supply. As of 2001, the Japanese Ministry of the Environment estimated that final disposal sites for industrial waste would only last for 4.3 years (MOE 2005). Furthermore, in 1995, the government required

[19] These numbers are real number, not nominal.

ASR to be buried in more strictly controlled landfill sites, resulting in rapid increase in ASR processing cost. The cost of landfill disposal doubled in metropolitans area from an average of 15 thousands yen per tonne in 1996 to 30 thousands yen in 2001 (METI 2003c). Increased costs of disposal along with the devaluation of scrapped material, resulted in a negative price of ELV hulk (METI 2003d).

Under these circumstances, conventional ELV management system became dysfunctional as economic incentives to collect and scrap ELVs were diminished. Inappropriate processing and illegal disposal of ELVs emerged as a concern. For example, on Teshima, a small island in the southern part of Japan, a waste management company had dumped hazardous industrial waste including ASR for 13 years from 1978 to 1990. The illegal dumping left behind 500 thousand tonnes of hazardous waste and that caused high level of toxic substances leaching into the ocean. (Teshima citizens' council 2005) After a long dispute and arbitration between residents and the prefecture government, an agreement was reached to reclaim the land. The land reclamation project costs 26 billion yen (US$236 Million), 60% of which will be borne by the national government and will take until 2012. The Teshima case is not an isolated instance. The reported number of illegally dumped vehicles including illegal storage[20] was over 169 thousand in 2003 annual number – that is 3.4% of all ELV (MOE 2004).

The ELV Recycling Law was aimed at coping with these problems by building a new recycling scheme. The basic principles of the law are, like other industry-specific recycling laws in Japan, Extended Producer Responsibility (EPR) and shared responsibility among stakeholders. Under the law, automobile manufacturers and importers are responsible for recycling ASR and airbags, and collecting and destroying CFCs. Car dealers and repair shops are responsible for collecting ELVs from users and for passing them on for CFC recovery, disassembly and shredding. Expenses for recycling ASR and airbags, and processing CFCs are set by manufacturers and borne by car owners at the time of purchase of a new car or at the time of inspection of cars purchased before the implementation of the law. The users' expense was set at the discretion of each manufacturer, and currently set to approximately 10,000 yen (US$91) for a compact vehicle to 14,000 yen (US$127) to a full-size sedan. An electronic manifest system is used throughout the ELV recovery chain to track the flow of ELVs, ensuring proper processing. The law was also designed to take advantage of the existing mechanisms of the reverse supply chain for ELVs – the law leaves recycling of non-ASR portions, mainly ferrous and non-ferrous metals to the existing system, with the recognition that the market mechanism still can deal with non-ASR. The law set the standards of recycling rate of ASR, defined as a ratio of total mass of recycled ASR (including part reuse, material recycling and energy recovery) divided by the mass of ASR collected, to 30% in fiscal year 2005~2009, 50% in 2010~2014, 70% after 2015 (METI 2003a). These standards translate into overall recycling rates for ELVs of 88%, 92% and 95% respectively, up from a rate of 80% prior to the law.[21]

[20] In Japan, a proof of storage place is requisite when owning a car.

[21] These overall recycling rates assume that non-ASR portions continue to be recycled as at present.

3.4 Technological change and *the ELV Recycling Law*

3.4.1 Framework

The law requires auto manufacturers to be responsible for taking back three types of automobile waste – ASR, CFCs and airbags. ASR must be recycled in accordance with numerical standards described earlier, and CFCs must be safely recycled or destroyed. Manufacturers appear to be complying with the new legislation and sometimes exceed its requirements.

Japan Automobile Manufacturers Association (JAMA), the industry association of 14 auto manufacturers, set a voluntary action plan in place to coordinate the entire automobile industry actions toward appropriate management of ELVs (JAMA 2005). Table 3.1 shows the outline of the ELV Recycling Initiative Voluntary Action Plan, and Table 3.2 shows the numerical targets set by the Voluntary Action Plan.

Table 3.1 ELV Recycling Initiative Voluntary Action Plan

Measures for auto manufacturers

I. Newly manufactured vehicles	1. Improving recycling rate of new vehicles Use of recyclable material Design for easy disassembly Identification of material Safety in processing (reducing hazardous material) Safety consideration Reusing parts, separation of used parts Pre-assessment Information provision (car structure etc.) 2. Reduction of lead 3. Easier processing of airbags on board
II. Existing vehicles and vehicles that were designed before and still being manufactured	1. Technological development and information provision to improve recycling rate 2. Expansion of application of recycled material

Measures for all concerns in the auto industry

I. Cooperation for establishing the base for improving ELV recycling rate	1. Cooperation for establishing the base for improving ELV recycling rate 2. Plans and implementation for realising possible recycling rate 3. Suggestions and cooperation for parts manufacturers and suppliers engaged in recycling
II. Cooperation for appropriate processing of ELV and prevention of illegal dumping	1. Appropriate processing of airbag inflator 2. Appropriate processing of CFCs 3. Manifest system for ELV processing 4. Japan Automotive Recycling Promotion Centre

Table 3.2 Numerical targets in the ELV Recycling Initiative Voluntary Action Plan

Numerical target for auto manufacturers	1. Numerical target of recycling rate	Recyclability of new vehicles: 90% or higher in 2002 and after
	2. Numerical target of the use of hazardous materials in new vehicles	**Lead** (except batteries): Less than 1/2 of the 1996 level by the end of 2000 Less than 1/3 of the 1996 level by the end of 2005 Less than 1/10 of the 1996 level after January 2006 **Mercury** (except LCD, instrument panel precision equipment, headlamps, fluorescent cabin lamps): zero use after the enforcement of the ELV recycling law **Hexavalent chromium**: zero use after January 2008 **Cadmium**: zero use after January 2007
Numerical target for the entire auto industry	Overall ELV Recycling rate	85% in 2002 and after 95% in 2015 and after
	Landfilled waste	3/5 of the 1996 level in 2002 and after 1/5 of the 1996 level in 2015 and after

JAMA represents the automobile industry and is involved in formulating collective actions as an industry organisation, so it is likely that their Voluntary Action Plan sets guidelines for development of new recovery technology. The central focus of the plan is to improve ELV recycling rate, targeting the compliance of the standards set by *the ELV Recycling Law*. The improvement of ELV recycling rate is to be achieved by measures in both upstream and downstream of vehicle life cycle described below:

(1) Design and development stage in the upstream phase of the product cycle. This includes:

- Improving recyclability and parts reusability (including disassembly)
- Reduction and removal of hazardous substances
- Design that leads to appropriate processing of airbags and CFCs
- Assessment of recyclability

(2) ELV recovery and processing stage in the downstream phase of the product cycle. This includes:

- Reusing parts
- Improving ELV recovery processes
- Expansion of application of recycled materials
- Information provision

At design and development stage of new vehicles, improving recyclability is supported by design efforts including use of recyclable materials, design for easy disassembly, and identification of material. Furthermore, by conducting pre-assessments of recyclability promoted in the plan, designers can evaluate the extent to which improvements in design lead to enhancement of recycling rate before a vehicle is actually recycled with design improvements focused on facilitating recycling of ASR. The plan also supports reusing of parts, and developing new applications for recycled material. Information provision of vehicles to business entities in reverse supply chain (i.e. dealers and dismantlers) also facilitates a higher level of ELV recovery.

Another focus of the voluntary action plan is the reduction and removal of hazardous materials in vehicles. Hazardous materials designated in the Voluntary Action Plan are the following four: lead, mercury, hexavalent chromium and cadmium. The plan set numerical reduction targets of these substances, though *the ELV Recycling Law* does not mandate the reduction of such materials. These four substances are regulated by *the End-of-Life Vehicle Directive* in European Union (EU *ELV Directive*) which was enforced in 2000 (Gerrard and Kandlikar) and it is likely that JAMA's Voluntary Action Plan matches regulation in EU *ELV Directive*. In what follows we describe manufacturer actions aimed at technological innovations as proposed in the JAMA action plan both in the upstream and downstream phases of the product cycle. We also examine what manufacturers are doing beyond the action plan.

3.4.2 Upstream innovations in the product cycle

The following is the measures in the upstream of product cycle for higher recycling rate that were identified from automobile manufacturers' environment/sustainability reports.

Improving Recyclability

Efforts of improving recyclability at design and development stage are being made by all manufacturers (Daihatsu 2005; Honda 2005; Mazda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005). The focus is put on plastic material, which takes up one third of ASR on the weight basis as shown in Table 3.3 (METI 2003b), but likely does much more on the volume basis and occupies the final disposal sites.

Table 3.3 Composition of ASR (Example)

Source: METI

Plastics	33%
Urethane	16%
Fibre	15%
Iron	8%
Rubber	7%
Glass	7%
Wire harness	5%
Non-ferrous metal	4%
Paper	3%
Wood	2%

More detailed measures for the use of recyclable materials are the following: at least five manufacturers unify types of plastics materials rather than using composite materials that are more difficult to separate and recycle. For example, an instrumental panel made with three layers of different plastic consisting of polyvinyl chloride, polypropylene form and alkyl benzene sulfonate was replaced with layers of thermoplastic olefin and polypropylene (Honda 2005). Separation of different layers is not needed after this change. In the same line, thermoset plastics are replaced with thermoplastics, which is easier to recycle (Nissan 2005, Toyota 2005). At least two manufacturers develop more environmentally lower-impact plastics such as bioplastics and use natural material aiming at the use of carbon-neutral material (Mazda 2005, Toyota 2005). Use of *recycled* plastics is also promoted by all six manufacturers (Daihatsu 2005; Honda 2005; Mazda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005). The original material can be ASR or other vehicle parts such as bumpers, or material from other industry such as polyethylene terephthalate drink bottles, food containers and paper.

Disassembly and Sorting

All manufacturers claim to be making efforts at design for easy disassembly (Daihatsu 2005; Honda 2005; Mazda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005). This includes adoption of vehicle structures that enable easier disassembly, reduction of numbers of components, and reduction of number of connecting points. Efforts for material identification are being made by at least four manufacturers (Honda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005) and one manufacturer claims that they adopt international part coding standard for rubber and plastic materials.

Reduction of hazardous materials

All six major manufacturers have plans to reduce the designated four substances of concern (SOC) in their agenda (Daihatsu 2005; Honda 2005; Mazda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005). In addition to the four SOC, at least four manufacturers state that they are making efforts to reduce HFC 134a, CFC-substitute coolant used in air conditioners, which has high global warming potential (Honda 2005; Mazda 2005; Mitsubishi 2005; Nissan 2005). Other hazardous material subject to removal and reduction include polyvinyl chloride (PVC), antiflame agents, other additives in plastic materials, sodium azide in airbags, and volatile organic compounds (VOC) in indoor materials. The use of International Material Data System (IMDS) to manage the use of hazardous substances was limited to at least two manufacturers (Mazda 2005; Mitsubishi 2005), with only one manufacturer reporting progress in reduction of hazardous materials throughout the supply chain.

Facilitating airbag recovery

In response to mandated responsibilities by *the ELV Recycling Law*, most manufacturers claim that they are designing airbags that can be processed more easily at the end of life (Honda 2005; Mazda 2005; Nissan 2005; Toyota 2005). At least three manufacturers develop on-board, central deployment connectors, and this is likely to be the suitable technology for effectively and appropriately processing airbags at the end of life by dismantlers.

Pre-assessment

Most manufacturers claim to have their own systems to evaluate recyclability of vehicles (Daihatsu 2005; Honda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005). These include simulation systems that can simulate recycling rate and costs, "3R evaluation" systems that can assess design improvements that can lead to improvements in recovery, and LCA-based assessment and management systems. These tools help vehicle designers to enhance recyclability and other environmental performance of their products.

3.4.3 Downstream innovation in the product cycle

Manufacturers have the following measures to improve recovery of ELVs in the downstream of product cycle.

Production and sales of "Recycled" parts

At the ELV recovery and processing stage, at least five manufacturers branch out into sales of "recycled" parts, which include reused parts and rebuild parts[22] (Daihatsu 2005; Honda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005). Reused parts are parts taken from ELVs, quality-inspected and cleaned before resale. Rebuild parts are ones taken from ELVs, disassembled, cleaned, quality-inspected, repaired where necessary, and reassembled with worn components replaced. Usually, both reused and rebuild parts have limited warranty (APDSI 2003). Traditionally, dismantlers and used part dealers are the main players in the used automobile part market, but manufacturers are entering this market with their brand names such as Toyota's "Ecolo parts", "Nissan Green Parts", and "Honda Recycle Parts". Nevertheless, it is not certain whether manufacturers' involvement in the used automobile part market increases overall usage of used parts. Because used parts have traditionally been distributed by part dealers and dismantlers, it may merely shift sales channels of used parts from such part dealers to manufacturers unless supply of used parts is increased. As we discuss later in this chapter, other factors such as consumer acceptance of used parts and quality of used parts may be more influential to more widespread usage of used parts.

Research and development of dismantling processes

Research and development of dismantling processes and techniques, a business originally done by dismantlers, is an approach which at least four manufacturers are taking (Honda 2005; Mazda 2005; Nissan 2005; Toyota 2005). Research and development is aimed at appropriate and effective dismantling techniques that lead to compliance of the standards and enhancement of recycling rate of ELV. Collection of fluids, airbag deployment, removal of wire harnesses, and collection of glass are among foci of research and development. Some manufacturers have developed equipment and tools for dismantling, and provide dismantlers with expertise gained through research. This research and development supports more efficient dismantling of ELVs.

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[22] The term "recycle parts" is used in the industry to refer to such parts. In this thesis I use "recycled parts" to refer to "recycle parts." Recycled parts do not mean parts from recycled material, and they should be distinguished from material recycling.

Development of ASR recycling technology

Manufacturers' responsibility to meet the standard of ASR recycling rate forces them to pick recyclers with superior technology or develop technology themselves. To keep the consumers' expense low, manufacturers also need to pick a technology that is cost-effective. There seems to be no single decisive technology for recycling ASR at the time of writing this and recyclers compete in their technology to be picked by manufacturers. Major ASR recycling technologies include the following, and they are typically used in combination (Tanaka and Onishi 2005). The details of these technologies have been well documented (JMF and JAIE 2004).

(1) Fractionation and separation of material
(2) Vitrification
(3) Non-ferrous metal refining
(4) Gasification and utilisation of synthetic gas
(5) Energy recovery by incineration or gasification
(6) Making pelletised fuel

Two manufacturer groups have been formed for collaboratively improving ASR processing: the TH team (Toyota, Honda and six others) and ART team (Automobile shredder residue Recycling promotion Team; Nissan, Mazda, Mitsubishi and nine others.) Both teams use their own criteria to designate outsourced recyclers and final disposal sites. Some manufacturers are also involved in developing in-house ASR processing technology or are doing so in close collaboration with recyclers. Toyota has developed and demonstrated a gasification-based energy and material recovery system with a cast metal company (Toyota 2005). Nissan processes 5,500 tonne of waste containing ASR and other waste from their factory every month in their own incineration plant (Nissan 2005). Steam gained through this process goes back to manufacturing process in the same factory.

A prospective ELV recycling route in addition to above is to create scrap iron by processing ELV hulks in an electric furnace without shredding. This technology seems appealing in that it eliminates generation of ASR, but it requires a strict pre-treatment to keep copper content in the hulk to be very low. Manufacturers in ART are keen on adopting the technology, and seeking ways to realise its use in collaboration with dismantlers (Tanaka and Onishi 2005).

Expansion of application of recycled material

Material recycling is only meaningful if there is a demand for recycled materials. Expanding application of recycled material is important in that it creates more demand for recycled material. All manufacturers are engaged in developing application of recycled material in some ways (Daihatsu 2005; Honda 2005; Mazda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2005). Manufacturers' efforts at expanding application include recycling glass to ceramic material, developing soundproof material from foam material in ASR, recycling bumpers into bumpers or other car parts, and developing alternative fuel from plastics in ASR.

Information provision

Finally, at least five manufacturers are engaged in information provision for better ELV management in the form of providing dismantling manuals, car structure information to dismantlers, and assisting dealers to comply with *the ELV Recycling Law* (Daihatsu 2005; Honda 2005; Mazda 2005; Nissan 2005; Toyota 2005). Traditionally, automobile manufacturers had little participation in ELV recovery processes, but the communication between artery industry (manufacturers) and vein industry (dismantlers and other ELV recovery business entities) is increasing.

3.4.4 Beyond the action plan

Measures beyond the action items set by the voluntary action with regard to the improvement of ELV management include the following (Daihatsu 2005; Honda 2005; Mitsubishi 2005; Nissan 2005; Toyota 2003, 2005).

(1) Reduce in vehicle design stage
(2) Longer-life design
(3) Recycling hybrid vehicle batteries

'Reduce' is located at the top of recovery hierarchy (Graedel and Allenby 2003) although it is not listed on JAMA's voluntary action plans. At least four manufacturers incorporate reduce into their design goals (Daihatsu 2005; Honda 2005; Mitsubishi 2005; Nissan 2005). Reduce encompasses multiple aspects of design: reducing resource use, number of parts, number of types of materials and number of integration of parts. In the same line, at least two manufacturers among them are making efforts to make parts smaller and lighter (Honda 2005; Mitsubishi 2005). These efforts apparently lead to the reduction of ASR and may bring other benefits such as improving transport efficiency of vehicles and making disassembly process easier.

At least three manufacturers target design for longer life. Longer-life design reduces replacement of parts and increases reusability of parts at the end of life (Honda 2005; Mitsubishi 2005; Nissan 2005). Parts subject to longer life design include lighting that does not need replacement, anti-stain body panels and longer-lived consumables such as engine oil, coolant, oil filter and automatic transmission fluid. Although making parts live longer can have effects on part reuse, there is little data on overall effects of longer life design on the used car parts market and the life cycle of vehicles.

Compatibility between improved recyclability and advances result in major technological platform change might be a challenge. At least two manufacturers are making efforts to establish collection and recovery systems of nickel-hydrogen batteries used in hybrid vehicles (Honda 2005; Toyota 2005). One manufacturer claims that the recyclability of their hybrid vehicles is no less than that of conventional gasoline vehicles because of usage of highly recyclable materials and the battery recycling system (Toyota 2003).

3.5 The impact of the Japanese *ELV Recycling Law* on Reuse and Remanufacturing

3.5.1 Life cycle under the law

Technological change taking place in the automobile industry under *the ELV Recycling Law* will improve recycling rate of ELVs toward standards set by the law. In Chapter 2, we characterised the current life cycle outcome of automobiles as 'diversified' because the life cycle outcome comprises multiple different life cycle scenarios: product reuse through second-hand market and export before the end of life, part reuse, material recycling and energy recovery at the end of life. Here we ask, how might *the ELV Recycling Law* affect life cycle outcomes other than recycling such as reuse and remanufacturing?

Table 3.4 summarises action items taken by automobile manufacturers under *the ELV Recycling Law* and end-of-life recovery option(s) which each item is most likely to result in. Life cycle options before the end of life, such as product reuse through second-hand market and export, will be discussed later.

Table 3.4 Auto manufacturers' action items under *the ELV Recycling Law* and possible change in end-of-life recovery options of automobiles

Note: It is hard to claim that 'reduce' efforts, reduction of hazardous substances and pre-assessment lead to a specific end-of-life recovery option, although these measures surely contribute to reduction of environmental impacts. Therefore no recovery option was picked for these actions in this table. Multiple recovery options are ticked for some action items. For example, 'design for longer life' provides possibilities for remanufacturing and reuse. However, this table only indicates possibilities of recovery options induced by innovation, and actual recovery options may be determined by other factors.

Action items by automobile manufacturer for ELV management	**End-of-life recovery option supported by the action**			
	Remanu-facturing vehicles	**Part reuse**	**Material recycl-ing**	**Energy recovery**
1. Design and development of new vehicles				
'Reduce'				
Reducing resource use, number of parts, number of integration				
Making parts smaller and lighter	✓	✓		
Design for longer life				
Improving recyclability of new vehicles			✓	
Use of recyclable material	✓	✓	✓	
Design for easy disassembly			✓	
Identification of material				
Prevention of diffusion of hazardous substances				
Safety in processing (reducing hazardous material)				
Reduction of lead				
Appropriate processing of airbags			✓	
Easier processing of airbags on board				
Assessment				
Pre-assessment				
2. ELV recovery and processing				
Reusing parts: sales of reused and rebuilt parts		✓		
Improvement of ELV recovery processes				
Technological development to improve recycling rate			✓	✓
Expansion of application of recycled material			✓	
Information provision (car structure etc.)		✓	✓	
Recycling hybrid vehicle batteries		✓	✓	

Life cycle outcomes emphasized by technological innovation is higher level of material recycling and part reuse. Energy recovery is also an option counted in the recycling rate to meet the standard set by *the ELV Recycling Law*, but is not actively pursued. Although some efforts in the design and development of new vehicles may provide possibilities for remanufacturing, there is no coordinating effort in the ELV recovery stage. As a result, remanufacturing vehicles is not pursued. ASR, which accounts for about 20% of an ELV, will be further recycled by the efforts of design change toward easier disassembly and separation, and improved ELV recovery processes. More thorough elimination of copper from ELVs and processing hulks in an electric arc furnace, for example, has a potential to achieve higher recycling rate. Percentage of part reuse may increase by the efforts in design and promotion of sales, but this is also contingent on demand. It is unlikely that other life cycle options, such as remanufacturing of vehicles, will emerge as a result of *the ELV Recycling Law* alone.

Technological change for better ELV management indicates that great emphasis is put on the goal of higher level of material recycling. It is likely that innovation taking place under *the ELV Recycling Law* is leading the automobile industry to focus on material recycling at the end of life. The remaining of this chapter will discuss if and how ELV legislation can further move the life cycle of automobile up the recovery hierarchy (i.e. remanufacturing and reuse).

Currently, only 20-30% of car parts on a weight basis are recovered as used parts and resold for replacement and spare (Tanaka and Onishi 2005). Given the possibility of huge reduction of environmental impacts of reuse (in a broad sense, including remanufacturing), it seems that wider reuse of automobile parts merits consideration. Reuse of automobile parts can be in the form of remanufacturing of vehicles (meaning reintegrating used parts into newly manufactured vehicles, or assembling 'remanufactured' models) or part reuse (including remanufacturing and rebuilding of parts) for replacement or spares as presently conducted. Nevertheless, there is no case of remanufacturing of vehicles found; no used parts from ELVs are reintegrated into newly manufactured vehicles, nor 'remanufactured model' composed of used parts exists. We will review the possibilities of remanufacturing vehicles and wider part reuse in sequence below.

3.5.2 Reintegration of parts into newly manufactured vehicles

Remanufacturing of entire vehicles is a viable life cycle option only when various conditions in different aspects of the product – product attributes, reverse logistics, after-market demand and recovery technology – are met. At the very basic level, availability of cores (products that are candidates for renewal) is a critically important factor for remanufacturing (Hauser and Lund 2003). In the case of Japanese automobiles, a core is available for remanufacturing when a user deregisters and disposes a vehicle. However, automobiles stay with consumers for a relatively long time, and the average usage period of a vehicle is over ten years and rising, as shown in Figure 3.2 (AIRA 2005b).

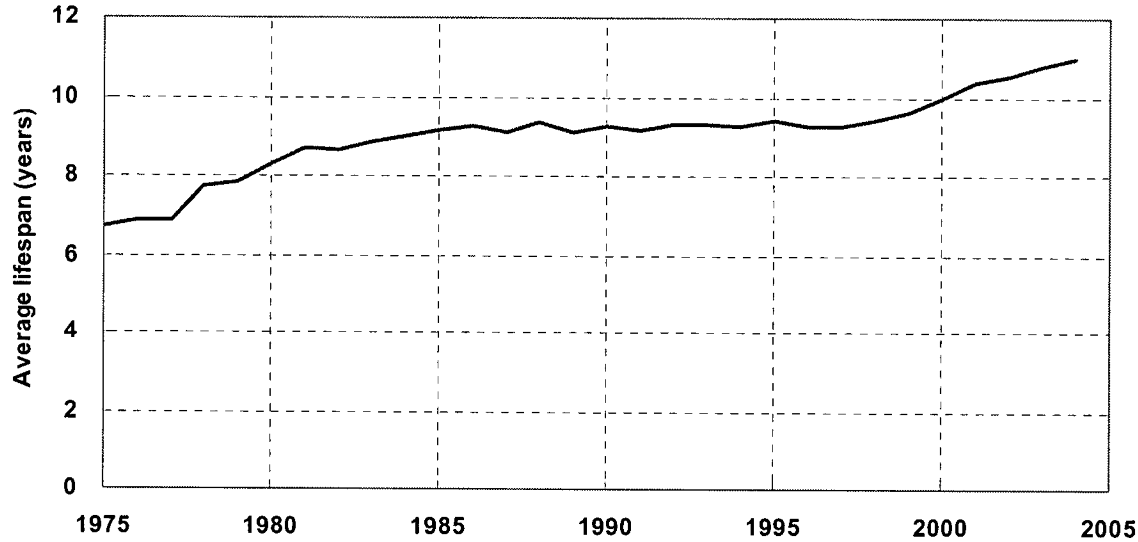

Figure 3.2 Average life span of passenger vehicles in Japan, 1975-2004

Passenger vehicles include regular vehicles (>2000cc) and compact vehicles (≤2000cc, and dimension criteria).
Source: Automobile Inspection and Registration Association

Some vehicles retire earlier than average, while others last longer. Accident rates and damage, driving patterns and levels of maintenance are among the factors that affect the life span of vehicles. Figure 3.3 shows temporal distribution of scraping rate of regular passenger vehicles and compact passenger vehicles (Kakudate, Kajikawa et al. 2002). A small peak in the third year is mainly attributable to commercial vehicles that retire at early age. This temporal distribution of scrapping rate determines the availability of cores, and reintegration of parts into newly manufactured vehicles is only possible while cores are available. With scrappage rates shown below, only 5% of cars after seven years of introduction retire for regular vehicles, and after five years of introduction for compact vehicles.

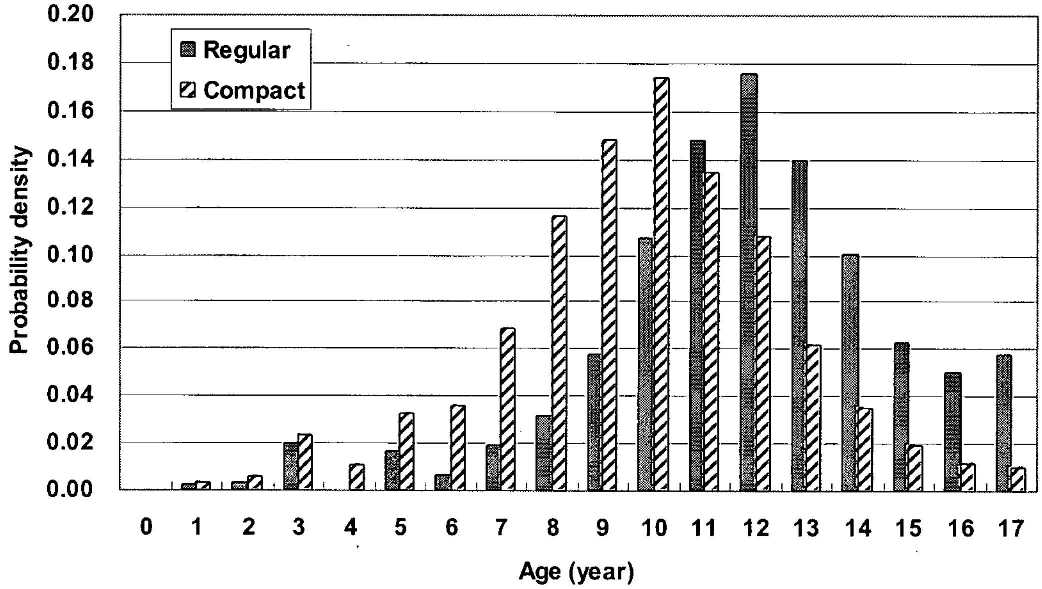

Figure 3.3 Temporal distribution of scrapping rate of regular and compact vehicles

Note: Compact passenger vehicles meet size-based criteria and have an engine less than 2,000 cc.
Source: Kakudate, Kajikawa et al. (2002)

On the other hand, most car models have a full model change every four to six years.[23] A full model change is a change of generations of a car, with major design change for body parts and internal parts (Kuruma de com 2005). There is little data on how many parts are common between generations. One survey respondent stated that this varied from model to model, but a recent new model has few parts from older generations' design with the exception of joint parts such as nuts and bolts. Another automobile manufacturer estimates such overlap between generations would not exceed 20% for the number of parts, including functional parts such as compressors and motors, and joint parts. Given that few parts are used common in the design of two generations of a model, a part must be supplied while the current generation is still being manufactured if reintegration of the part into newly manufactured vehicles is to be done, i.e. the period of manufacturing a model must overlap with the period in which cores are supplied. We will look into patterns in period of manufacturing a model.

Figure 3.4 and Figure 3.5 show sales patterns through full model change cycles for a popular regular passenger vehicle model and a compact vehicle model, respectively (JADA 2005). Although a full model change cycle is four to six years for most models, the annual sales are not uniform over a model period. The sales tend to boost right after a full model change takes place, and gradually diminish as the next full model change approaches. In the Japanese market this pattern is observed in most car models of regular vehicles and

[23] There are exceptions to this. A best-selling compact car, Nissan March's full model change cycle was ten years. In general, popular models with superior design can have a longer cycle of full model change.

compact vehicles alike. Figure 3.6 shows the annualised sales patterns of 11 popular models in one full model change cycle. Although the declining patterns slightly differ from model to model, the common pattern is that there is a decline in sales after four to six years of initial sales. On an average, the annual sale of an automobile drops to below 20% of it first year peak by the end of year 6.

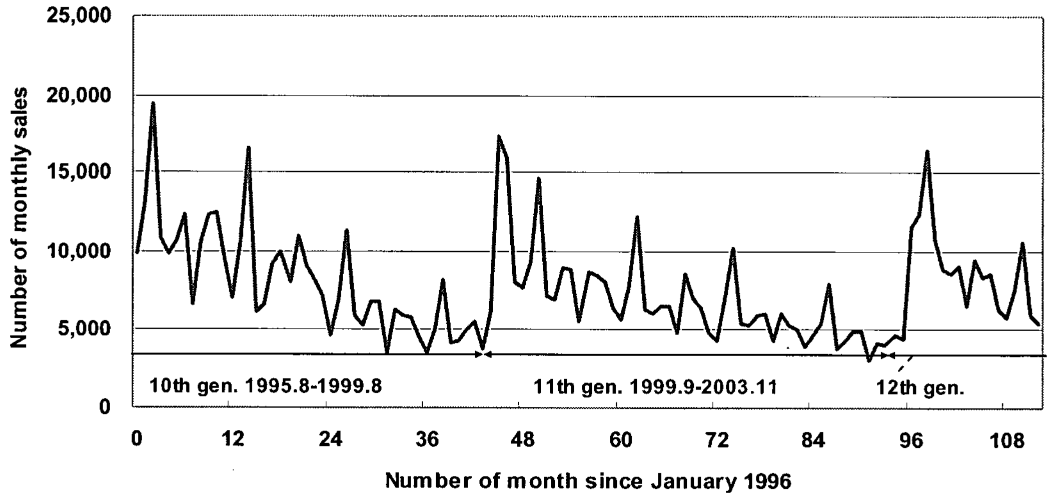

Figure 3.4 Car sales pattern through full model change cycles for Toyota Crown (Full size sedan)

Source: Japan Automobile Dealers Association

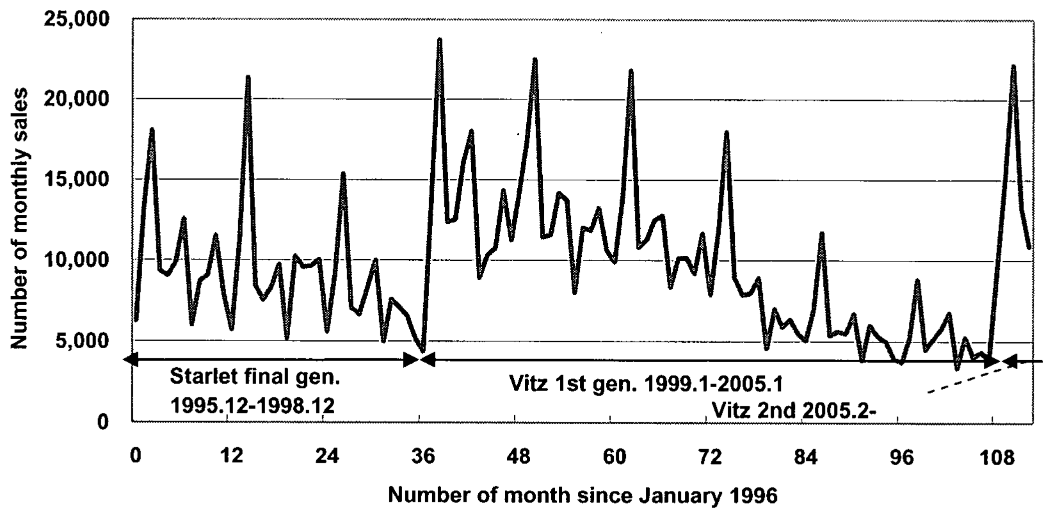

Figure 3.5 Car sales pattern through full model change cycles for Toyota Starlet/Vitz (Compact car)

Note: Starlet was renamed to Vits, but regarded as the revision of Starlet. Data on the 108th month (January 2005) is missing

Source: Japan Automobile Dealers Association

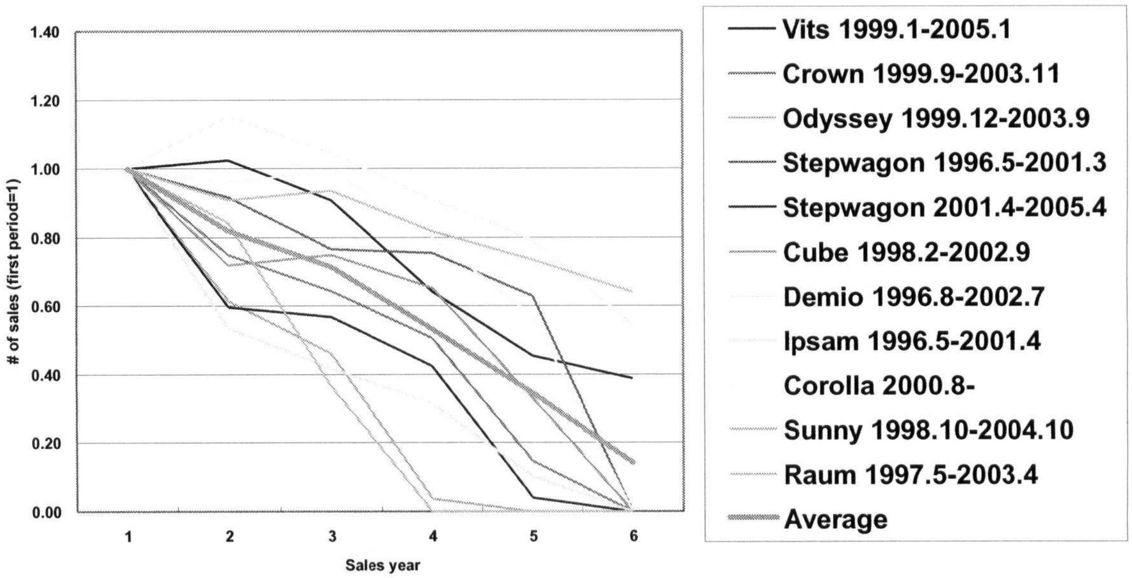

Figure 3.6 Car sales patterns of 11 models in one full model change cycle

Source: Japan Automobile Dealers Association

Figure 3.7 and 3.8 show the average relative sales rate of the regular vehicle and compact vehicle models respectively and the scrapping rate stretched over time.

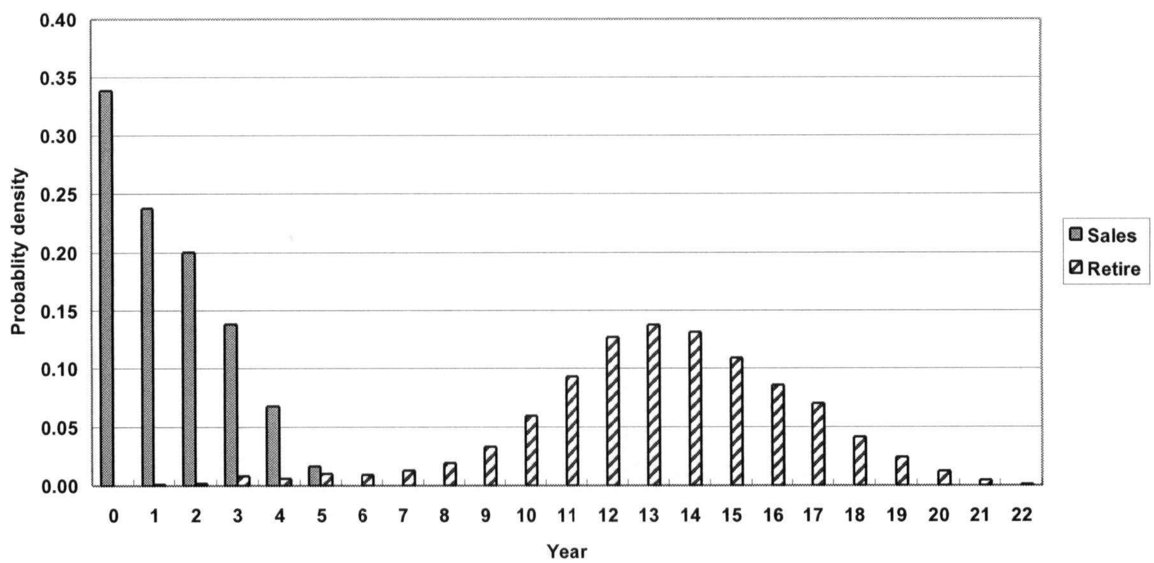

Figure 3.7 Sales pattern in one full model change cycle and scrapping rate for regular cars

Sales data are average of six regular car models in Figure 3.6, retirement distribution is based on data in Figure 3.3 and the data of distribution of sales of the six models.

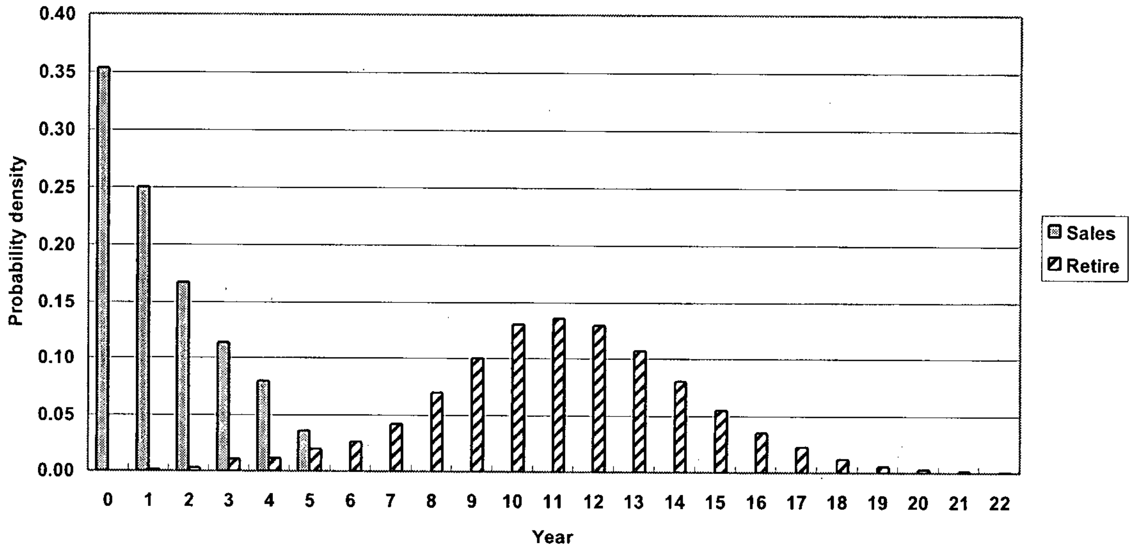

Figure 3.8 Sales pattern in one full model change cycle and scrapping rate for compact cars

Sales data are average of five models in Figure 3.6, retirement distribution is based on data in Figure 3.3 and the data of distribution of sales of the five models.

While car sales of a generation typically end in six years, cars sold in this period last up to 20 years after the initial sales. As shown in figures 3.7 and 3.8, overlapping periods for sales and retirements represent of the time-window for reintegrating parts from ELVs into newly manufactured vehicles of the same generation, assuming that there is no time gap between manufacturing and sales. These periods barely overlap for both regular vehicles and compact ones. Consequently, there are few used automobile cores available when a model is being manufactured. Most cores only become available after the manufacturing of the model has ended and new generations are already in market. Furthermore, even between full model change cycles, there are minor changes and 'facelifting' that further reduce commonality of parts between generations. Among various factors, the relationship between the short full model change cycle (4~6 years) and the longer usage time (average 11 years) alone makes it very difficult, if not impossible, to reintegrate used parts into newly manufactured vehicles.

3.5.3 The possibility of a 'remanufactured model'

Although parts from ELVs cannot be reintegrated into newly manufactured vehicles, some parts are still usable at the end of life. If reusable parts cannot be reintegrated into new vehicles of the same model, it may be possible to fully use parts to the end of their physical lives by assembling 'remanufactured models' like copiers, or as used parts for replacement, repair and spare for existing vehicles. The former is currently not taking place. Below, we will explore reasons why 'remanufactured models' are not assembled and whether possibility of such models exists.

In the previous section, we claimed that availability of cores is a critically important factor for remanufacturing, and that it is a constraining factor of reintegrating used parts into newly manufactured vehicles of the same model. In addition to physical availability and quantity of cores, the quality aspect of cores is also important. Let us revisit the framework of factors and life cycle outcomes formulated in Chapter 2. Table 3.5 shows the potential necessary conditions for remanufacturing, derived from the case studies of consumer products in the Japanese market. The columns on the right show whether copiers – a successful example of remanufactured product – and automobiles meet these conditions.

Table 3.5 Potential necessary conditions for remanufacturing

Note ✓: meet the condition ×: does not meet the condition ?: not sure

Potential necessary conditions for remanufacturing	Copiers	Automobiles (hypothesis)
Product Attribute		
Lifetime of parts must be longer than average lifetime per user	✓	?
Design for disassembly and separation	✓	✓
Slow technological changes vis-à-vis period of usage by a single user	✓	×
High degree of management of usage	✓	×
Reverse logistics		
Established collection and recovery systems	✓	✓
Controlled ownership and feedback	✓	×
After market demand		
Demand for remanufacturing	✓	?
Demand for used components	✓	✓some parts
Recovery technology		
Disassembly	✓	✓
Diagnosis	✓	?
Cleaning	✓	?

Several of these criteria: the product lifetime, the degree of 'management' during use, the presence of adequate 'reverse logistics', and 'recovery technology' influence the quality of available cores[24]. In successful examples of remanufacturing such as copiers and disposable cameras, these conditions help secure the quality of cores to a level that makes remanufacturing feasible.

We are not aware of any statistical data on remaining lifetime of parts from ELVs in Japan, or even whether there are appropriate diagnosis techniques to determine the remaining physical lifetime of parts. An industry organisation we surveyed states that data collection is underway collaboratively by research institutes, universities and industry organisations. It is likely that remaining lifetime of parts will vary to a considerable degree because conditions of ELVs from which parts are taken vary depending on level of maintenance, usage pattern and other factors. Therefore, while quantitative analysis of remaining lifetime of parts from ELVs cannot be done at present, there are some indicators that give us insight into the quality of parts from ELVs.

[24] Some conditions also have to do with physical availability and quantities of cores at the same time.

Car parts in new cars are usually warranted for five years or up to 100,000 kilometres driven, by automobile manufacturers, according to an industrial organisation surveyed. Recycled car parts, including those sold by automobile manufacturers, usually have shorter warranty period or distance driven. For example, a major used car part dealer provides warranty for six month at best, three month or one month, depending on the condition of parts. There are part dealers who offer longer warranty than this, but never as long as those for new parts (APP 2005; Nissan Sapporo 2005). There is a significant difference in warranty periods of new parts and those of used parts, and this gap may be an indication that the quality of used parts might be variable, and not as uniform and high as new parts.

How do some remanufactured products secure used products whose quality can be made to be as good as new parts? High quality of copier parts at the end of lease period of a single user can be attributed to a number of factors: usage pattern is highly predictable; lease-based business models ensure that manufacturers retain ownership and do frequent servicing through service contracts. This contributes to high quality of parts and low variations in conditions of products at the end of lease period. Automobile manufacturers do not have ownership or any other means to manage their product at their discretion once a product is sold to a user.

Leasing, a business model which helped copier manufacturer manage their products considerably, is not a popular option for automobile in Japan. An estimate shows that only 3.7% of total registered vehicles are leased in 2004, and an overwhelming majority of them are commercial use (YRI 2005). The market scale of leased cars for individual users, although increasing, is currently negligible level.

There is little evidence that the consumer expense for ASR, airbags and CFCs, defined by *the ELV Recycling Law*, provides incentives for the use of leased cars over purchase of cars. The consumer expense under *the ELV Recycling Law* is about 1% of the new car price for compact cars, and less than 1% for regular cars. Although other factors are also involved, the experience with *the Home Appliance Recycling Law* shows that the consumer expense needs to be at least a few percent of new product price for a leasing market to emerge. Overall, it is likely that automobile manufacturers do not have the means to manage their product to a degree that is required for remanufacturing after sales, although quantitatively evaluating the degree of management remains difficult. Our survey revealed that at least four automobile manufacturers think that remanufacturing vehicles is not viable, and three pointed to the difficulty of quality assurance of parts taken form ELVs as a major reason of the difficulty.

Vehicles retire 11 years after sales on average, and some even stay in service for longer. Although it is difficult to define and quantify the rate of technological change, technological obsolescence is likely to take place in this long period of usage. One manufacturer pointed that automotive technology advances every year and reusing old parts can hinder the achievement that would otherwise be made by technological advance, i.e. reduction of carbon dioxide emission. Even copiers whose lease period is three to five years, which is much shorter than that of automobiles, suffer from technological obsolescence (Saito and Yoshioka 2005). Remanufactured copiers comprising reused parts from previous generation models cannot meet the energy consumption standard and cannot be designated as a green product by *the Green Purchasing Law*. Automobiles, whose life span is much longer than those of copiers, has a lower chance of overcoming technological obsolescence, unless the technology used for automobiles does not change for at least a decade. Even if a 'remanufactured model' can be assembled, it is questionable if such technologically obsolete car would meet the needs of the time.

The above analysis only captures generic aspect of automobiles. There may be niche segments in the market that may have more desirable attributes for remanufacturing. For example, taxis, commercial vehicles and public-sector vehicles may have different driving patterns and management practices than individual car users. However, as a whole, the enforcement of *the ELV Recycling Law* ensures that ELVs are appropriately recovered, but does not help redirect life cycle of automobiles toward remanufacturing.

3.5.4 The possibility of wider reuse of parts

Currently, the fraction of parts recovered as 'recycled parts' accounts for 20 to 30 percent of ELV weight. and consist of parts for reuse that are quality-inspected and cleaned, and rebuilt parts that are disassembled, cleaned, quality-inspected, repaired and reassembled. Parts taken from young ELVs (less than five years) are mainly resold as repair parts for damaged vehicles, while parts taken from mid-age and old vehicles (five years or older) are resold as replacement parts for worn or failed ones. Parts from mid-age and old vehicles are also exported (Takeuchi 2004). The domestic market scale of recycled parts is estimated as 106 billion yen (US$ 964 million) in 2003 (YRI 2004) and rising as shown in Table 6. (APDSI 2003; YRI 2004). Although the numbers are on the rise, recycled parts only account for about four percent of the total repair parts in 2002 (METI 2002). It is likely that there are constraining factors of part reuse both on the supply and demand sides.

Table 3.6 Estimated market scale of 'recycled' automobile parts in Japan

YRI: Yano Research Institute
METI: Ministry of Economy, Trade and Industry
APDSI: Auto Parts Distribution Strategy Institution

Year	**Estimated market scale (billion yen/US$ million)**			**Source**
	Reused parts	**Rebuilt parts**	**Total recycled parts**	
1998	68.0 (US$618M)	9.0 (US$82M)	77.0 (US$700M)	YRI
2001	85.0 (US$773M)	10.5 (US$95M)	95.5 (US$868M)	YRI
2002			83.0 (US$755M)	METI/APDSI
2003	92.0 (US$836M)	14.0 (US$127M)	106.0 (US$964M)	YRI
2005 and after (projection)			150.0~200.0 (US$1,364M ~1,818M)	YRI
2010 (projection)			300.0 (US$2,727M)	METI

On the supply side, 'production' of recycled parts is restricted by the generation of ELVs, Although the number of retiring vehicles every year may be estimated to some degree, increasing number of exported ELVs and increasing average period of usage of automobiles are possible factors of uncertainty affecting availability of cores from which recycled parts are taken (YRI 2004). Types of automobile parts are also highly diverse because parts vary depending on manufacturer model and year of manufacturing. This diversity of automobile parts makes matching of supply and demand difficult. A part dealer needs a large inventory of parts if they aim to meet all demand. In many cases this is not economically practical. To overcome matching difficulties, part dealers network with each other to share inventories (YRI 2004). Dealers in a region communicate with each other from the early stage of business, and nationwide and regional networks have commanded a large share of the recycled part market since the mid-1980s. Since the 1990s, information technology and computerised networks have further improved accessibility of parts, enabling holding large volume of information and real-time access to the state of inventory (Takeuchi 2004). As of 2002, 20 networks consisting of 500 individual dealers account for 80% of the recycled part market share (YRI 2004). As of 2003, despite the use of computerised information systems, only 40% of demanded parts are estimated to be available, and there seems to be room to improve the supply capacity of automobile part dealers (APDSI 2003).

Establishing quality is also important factor on the supply side for attracting users. Recycled parts are not parts just taken from ELVs, but are ones repaired, cleaned and reconditioned. They need to reach a quality level that makes recycled parts to be more economical alternative to new parts. Some part dealers develop their own testers to effectively inspect parts (Tanaka and Onishi 2005), while others obtain ISO9002 quality management system certification to prove their efforts for quality (Takeuchi 2004).

On the demand side, consumers' level of acceptance of used parts is an important factor. Recent study shows that potential demands for recycled parts are high but that the lack of information provision and communication among suppliers, users (dealers and repair shops) and end users (car owners) is constraining the use of recycled parts (METI 2002). In particular, recycled parts are poorly recognised by individual end users. Guidelines on quality assurance and quality information provision were set toward wider use of recycled parts in 2002 by the Ministry of Land Infrastructure and Transport (MLIT 2002). This guideline helps users (repair shops) make right decision on selecting parts and end users better understand the nature of recycled parts.

By alleviating these constraining factors both on the supply side and demand side, the market scale of recycled parts is expected to grow up to two to three times the current size (YRI 2004). Even so, the market share of recycled parts out of the total repair and replacement parts will be around 10% of all parts, and it is likely that wider use of recycled parts does not cause drastic change in automobile life cycle outcomes.

3.6 Summary and conclusion

The direction of technological change observed in automobile manufacturers under *the ELV*

Recycling Law suggests the following trends in innovation: increased level of recycling, supported by eco-design efforts, improved ELV recovery processes, and improved information provision; and removal of toxic substances (lead, cadmium, mercury, hexavalent chromium and others.)

It is likely that innovation both in design and development, and in ELV recovery will have synergistic effects that lead to higher ELV recovery rate targeted at 95% by 2015 and to the elimination of toxic substances from new vehicles. Favoured life cycle options remain recycling and part-level reuse. Remanufacturing vehicles is unlikely to emerge as a viable life cycle outcome from ELV legislation alone. Drastic change in business models, and the speed of technological change, would be required to enable remanufacturing vehicles. Moreover, *the ELV Recycling Law* does not contain mechanisms to discourage export of ELVs. Consequently, exports from Japan are likely to be on the rise as a result of the law. Export of ELVs increases the overall lifetime of an automobile on the one hand. On the other, it may simply move the ELV disposal problem offshore and diminish incentives of improved recycling and recovery options within Japan.

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Chapter 4: Implications for North America

4.1 Introduction: implications for North America

In the previous chapters, I emphasized that formulating product life cycle design and strategy including formulating appropriate business models and life cycle options is contextual, i.e., appropriate life cycle strategy for a product can vary depending on technical, market and regulatory factors. This section attempts to draw some implications from Japanese experience of legislating ELV recycling for North America (the United States and Canada) where the landscape around ELV management is somewhat different.

4.2 ELV management and surrounding conditions in North America

Below I characterise ELV management in North America and compare it with that in Japan in terms of the following key aspects: scale of ELV generation, state of ELVs, ELV management practices, disposal costs and illegal disposal, ELV legislation, and after-market.

4.2.1 Scale of ELV generation

Statistical figures for ELVs in North America are not available and estimation techniques are typically used to calculate the ELVs generation rate. The average number of ELVs in the United States is estimated at 11.0 million per year in 1990-1996, and 13.3 million per year based on 1990-1998 data considering increasing number of retired trucks in recent years (Staudinger and Keoleian 2001). In Canada, approximately one million ELVs were generated in 1996 (Griffith, Gearhart et al. 2001), which adds up 12 to 14 million of ELVs generated per year in North America. Japan's ELV generation rate is approximately five million per year.

4.2.2 State of ELVs

Vehicles in North America have longer life span and are driven for longer distances. The estimated median lifetime for 1990 model passenger vehicles in the United States is 14 years (Staudinger and Keoleian 2001) while the average usage period of passenger vehicles in 2004 is 11 years in Japan (AIRA 2005). The estimated average distance driven is 200,000~300,000 kilometres in the United States while it is approximately 100,000 kilometres in Japan (Takeuchi 2005). One can assume that longer usage period and longer distance driven would lead to more deterioration of parts and less chances of part reuse; however, parts for reuse is no less widespread in the United States than in Japan. This will be discussed later in this chapter.

4.2.3 ELV management practices

The major processes of ELV management in North America are very similar to those in Japan, though there are some differences in treatment of ASR (Staudinger and Keoleian

2001). The first point of ELV treatment processes is dismantlers where parts for reuse and remanufacturing are taken, fluids are collected, and tires are removed. The remaining hulks are sent to shredding facilities where hulks are torn into small pieces. After the shredding process, ferrous metals and non-ferrous metals including aluminium, stainless steel, copper, brass, lead etc. are separated and sent to recyclers. Finally remaining ASR is landfilled without pre-treatment in municipal or industrial landfill sites except in the state of California where ASR is designated as a hazardous waste. According to the analysis of actual ASR, the major composition of ASR is plastic which accounts for 37% (Staudinger and Keoleian 2001). Although analysis items differ, there are some differences in the composition of ASR between North America and Japan, shown in Table 4.1 (METI 2003b).

Table 4.1 Composition of ASR (Example)

Source: Japan-METI (Table 3.3), North America-adopted from Staudinger et al. (converted into dry basis composition, original moisture content was 15%)

	Japan	North America
Plastics	33%	37%
Urethane	16%	
Fibre	15%	
Iron	8%	
Rubber	7%	10%
Glass	7%	15%
Wire harness	5%	
Non-ferrous metal	4%	
Paper	3%	
Wood	2%	
Other materials		29% (dirt, metal fines and others)

4.2.4 Disposal costs and illegal disposal

The primary goal of the Japanese ELV Recycling Law is to lessen burdens on increasingly scarce landfill sites and prevent illegal dumping of ELVs. The risk of running out of capacity of landfill sites in North America is not likely to be as an imminent factor as in Japan. Assuming that the landfill cost reflects the scarcity of landfill sites, there is a substantial gap in scarcity between the United States and Japan. The average landfill cost in the United States in 1998 was $34 per tonne with the wide variation from $10 in Wyoming to $65 in Vermont (Staudinger and Keoleian 2001). This cost applies to ASR except in the State of California where ASR is considered hazardous solid waste. On the other hand, in Japan the cost of landfill is approximately 30,000 yen (US$272) per tonne in 2001 in metropolitan area (METI 2003a). The scarcity of landfill sites is still likely to be a weak incentive for mandating further recycling of ASR in North America.

Illegal dumping is a larger problem in North America than in Japan. Approximately 6% of all ELVs in the United States are abandoned in an improper manner (Staudinger and Keoleian 2001). In Canada, although national figures are not available, in British Columbia, 9% of ELVs are abandoned on roads and highways (Environment Canada 2003). Release of vehicle fluid (fuel, engine oil etc.) and air conditioner coolant into the environment is the primary concern with regard to illegally disposed ELVs.

4.2.5 ELV legislation

Currently, there are no national, provincial or state legislative frameworks in North America which is equivalent to the Japanese *ELV Recycling Law* or EU *ELVD* that mandates manufacturer responsibility for taking back all or parts of ELVs and sets recycling rate targets. In the United States, *the Automobile Recycling Study Act* of 1991 (HR 3369) is the only one piece of legislation ever introduced targeting ELV management at the national level, but this only focuses on 'studying' various aspects of ELV management instead of mandating responsibilities (Staudinger and Keoleian 2001). Nevertheless, ELV management activities have been constrained by other national- and state-level legislation regarding waste management. The national-level legislation includes banning the disposal of free liquid and lead-acid batteries in landfills. State-level legislation includes classification of ASR as a hazardous waste (in California), landfill management requirement regarding ASR disposal, landfill restrictions on mercury-containing devices, and scrap tire management (Staudinger and Keoleian 2001). In Canada, *the Environmental Protection Act*, Part V Regulation 347 is relevant to ELV management, but it is claimed not to be sufficient to ensure proper treatment of hazardous waste (RCO 1999).

As a result of the absence of EPR legislation and mandatory recycling standards, the recovery of ELVs are primarily driven by economic incentives, resulting in ferrous and non-ferrous metal recovery (RCO 1999). ASR is typically destined for landfill sites even with some restrictions from waste management legislation.

4.2.6 After market

Part reuse is more widespread in the United States than in Japan. In the United States, about 40% of parts for repair and replacement is supplied from recycled parts, while in Japan such parts only account for 3% (NGP 2005). The number of parts taken for reuse from a vehicle in the United States also outnumbers that in Japan: 42 items in the U.S. vs 23 items in Japan (NGP 2005). The difference in the number of parts taken for reuse from one car can partly be explained to differences in the level of 'disassembly' of a sold part. In the United States, parts are taken apart closer to the level of original parts. For example, door panel, door mirror, regulators, glass and door trim are all taken apart in the United States while in Japan a recycled door is sold with a mirror, regulator, glass, trims attached. Whether the level of disassembly affects matching rate is not well known, it is likely that demand for recycled parts is higher in the United States, leading to higher percentage of recycled parts in parts for repair and replacement.

4.3 Implications for North America for better ELV management

Market forces are the main drivers of recycling ELVs, and recycling efforts are focused on used parts, and ferrous and non-ferrous metals. Although the scarcity of landfill sites is not necessarily a pressing problem in a short run, release of hazardous substances in the ELV management processes and from illegally dumped ELVs is a serious concern in North America. For example, mercury from automobile components is likely to be the largest source of mercury emissions in the atmosphere, and measures are called for the problem (Griffith, Gearhart et al. 2001).

In the absence of national, state or provincial legislation for appropriate ELV management, some industrial organisations and municipalities are taking initiatives in appropriate management of ELVs. For example, British Columbia Automotive Recyclers in partnership with the city of Abbotsford developed an environmental code of practice to manage ELVs in an environmentally responsible manner (Environment Canada 2003). The code of practice ensures collection of mercury switches, removal of batteries, collection and recycling of fluids, and evacuation of air conditioning refrigerant, resulting in significant reduction of risks of contaminating groundwater.

Although local initiatives are making a difference, they are limited in that only 'end-of-pipe' approaches are used and no upstream efforts are involved. The experience of Japanese ELV recycling law suggests that technological innovation throughout the product chain is a part of solution for reducing ASR generation and release of hazardous materials. In particular, automobile manufacturer efforts in design and development stage are indispensable to improve recycling rate and effectively reduce ASR and hazardous material output. In a long run, more stringent and across-the-product-chain measures than the current local voluntary initiatives will be required, in particular, to mitigate the following potential risks:

- Soil and water contamination due to release of hazardous substances such as heavy metals and vehicle fluids due to inappropriate ELV management processes and illegally disposed ELVs.
- Release of ozone-depleting and/or high greenhouse potent air-conditioner refrigerant through inappropriate ELV dismantling processes.
- Atmospheric emissions of hazardous substances such as mercury from electric arc furnaces, shredding process and scrap yards due to inappropriate ELV management processes.

In general ex-post environment management is more costly and requires more energy than prevention, and this applies to ELV management as well. There is no need to wait until ELV-derived environmental problems are more obvious. Better ELV management by involving manufacturers and optimising the entire product chain from the view point of product life cycle is desirable.

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Chapter 5: Summary and conclusion

5.1 Appropriate life cycle strategy for automobiles

Conventional 'end-of-pipe' approaches, that target processing waste at the end of pipe without providing feedbacks to upstream processes, is increasingly insufficient and ineffective in controlling the release of hazardous substances and waste output to the ecosphere. It is also inefficient in terms of controlling waste flow; upstream processes such as design and production are likely to have higher capability of controlling waste (Hosoda 1999).

Life cycle design provides an integrative product approach of designing a mix of product, processes, business model and life cycle options (MSTC 2004), and appropriate life cycle design leads to minimised waste flow. Theoretically, choosing life cycle options should consider the hierarchy shown in Figure 2.1 based on a comparison of environmental impacts between different life cycle options. In practice, life cycle outcomes are determined by an interaction of host of factors. Chapter 2 investigated such factors and the interaction of the factors by case studies of five products with different life cycle outcomes, and provided a framework in which four main factors including Product Attributes, Reverse Logistics, After-Market Demand and Recovery Technology are contributing to the formulation of a life cycle outcome. Elements of these four factors are affected by a further set of forces such as consumer preference, consumer pressure for social responsibility and EPR legislation. The framework implies that realising a life cycle option may require meeting large number of criteria on different aspects of the product. In other words, a life cycle option may be constrained by a set of factors that are beyond control of product design. A product designer may have the capacity to change a subset of product attributes, but may have little or no capacity to account for social infrastructure, consumer preference and other regulatory and market forces in the product design. Thus appropriate life cycle design is not necessarily possible at designer's discretion; rather an appropriate life cycle outcome emerges from the interaction of design with relevant external factors such as social infrastructure, consumer preferences and market forces. Figure 5.1 conceptually shows the important aspects of life cycle design and determinant factors.

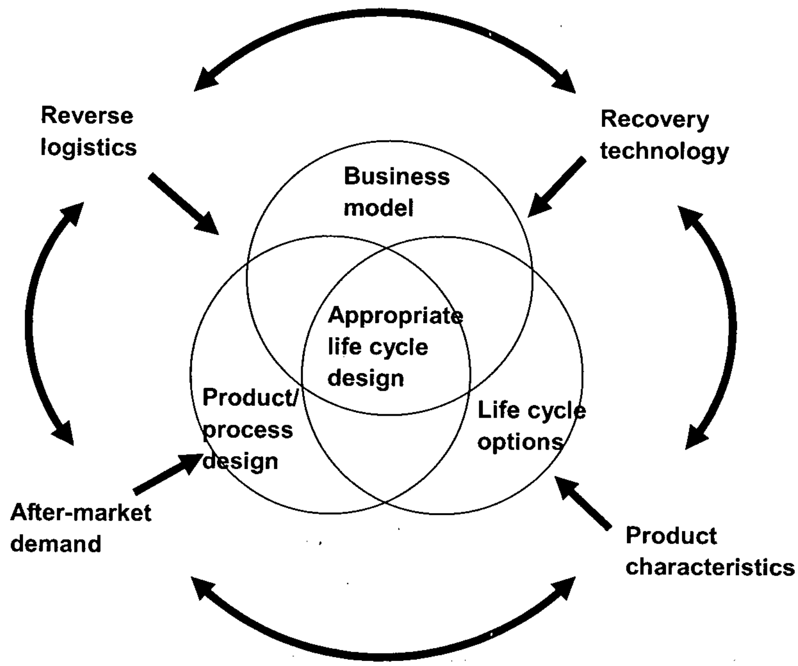

Figure 5.1 Important aspects of life cycle design and potentially affecting factors

Chapter 3 reviewed technological innovation with regard to ELV management under the Japanese EPR legislation, and provides an in-depth investigation of the appropriate life cycle outcomes for automobiles. Material recycling and limited part reuse are the currently favoured life cycle options for the Japanese automobile market. In other words, the Japanese automotive industry is optimising life cycle outcome of automobiles around material recycling and to some extent the reuse of parts. Technological advance under the EPR legislation is not likely to redirect automotive life cycle outcome toward automobile remanufacturing. The law also effectively promotes specific mandatory outcomes such as elimination of toxic substances. The second half of Chapter 3 discussed the possibility of automobile remanufacturing and wider reuse of parts, and concluded that the current product attributes, business models and market forces acts as deterrents to transforming life cycle outcomes of automobiles toward greater reuse and remanufacturing. The relationship between physical product lifetime and model change cycle driven by market forces makes it unrealistic to reintegrate parts from ELVs into newly manufactured vehicles. 'Remanufactured models' are also not feasible mainly due to inability to secure quality of used parts. Parts can be only used as repair or replacement for existing vehicles, and wider use of parts from ELVs to some degree is likely to be feasible. For above reasons, the current strategy oriented to material recycling is justifiable. However, this conclusion does not mean that remanufacturing vehicles is impossible: remanufacturing vehicles would require redesign of major aspects of automobiles such as lifetime, speed of technological changes, and recovery infrastructure. It would also necessitate drastic changes in external factors such as consumer preference. How these redesign and changes should occur is out of scope of this study, but such major redesign and changes around automotive industry is not likely to happen at least in a short run. EPR legislation is not likely to trigger such changes.

5.2 Areas of further study

This study can be extended and strengthened by further exploring the relevant issues. Significant issues for further study are suggested as follows:

Strengthening the framework

As stated in 1.6, the case-study approach used in Chapter 2 has a limitation that it cannot capture every possible factor in every product, although it tries to have reasonable variations of different aspects of products. Examining additional cases may help test the validity and robustness of the framework formulated in Chapter 2, and in turn strengthen the framework.

Besides examining additional products, further analysis on the following topics may also help increasing robustness of the framework:

- Japan is a small island country of which 70% is human-uninhabitable mountain areas and the most of the rest is densely populated cities. How does this small and compact geography affect formulating a life cycle outcome?
- There may be significant differences in consumer perception of safety between automobiles and other products such as copiers. Is the significant perception of safety issue for automobiles a key factor affecting life cycle outcomes?

Policy analysis of Japanese EPR

Although EPR legislation and its effects is a focus of this study, policy analysis of Japanese EPR is not fully conducted. Japanese EPR legislation has a unique feature that major stakeholders involved in the product chain share responsibility and expenses for processing end-of-life products appropriately. It would be interesting to compare the Japanese scheme with European one which responsibility is more concentrated to producers, and to evaluate it in terms of policy analysis criteria such as efficiency, effectiveness (improvement of environmental quality), equity, transparency and administrative simplicity (Lave and Gruenspecht 1991). There is a growing concern that *the ELV Recycling Law* may trigger an increase in export of ELVs. While export of ELVs prolong life span of automobiles, it potentially leads to inappropriate management of ELVs overseas. Evaluating the net impacts of export of ELVs may also be an interesting research focus.

Spill-over effect of ELV management technology

How technology for better ELV management developed in Japan can spill over to other parts of the world, in particular, to North America which is a significant market of automobiles but lacks legislative initiatives for ELV management, can be an interesting issue. Evaluating spill-over effect would require in-depth analysis of the extent to which automobile technologies are being applied globally, the degree of benefits ELV management technology can bring vis-à-vis its cost.

Feasibility of automobile remanufacturing in niche market

The analysis on feasibility of automobile remanufacturing in Chapter 3 is based on data of the macro-level and generic automobile market in Japan. There may be automobile sub-market whose characteristics are different from generic automobile market, and potential of remanufacturing in such market may be greater than what was discussed in Chapter 3. For example, taxis, commercial vehicles and public-sector vehicles have different driving pattern and management practice than individual car users. It would be worth exploring the potential of automobile remanufacturing in such niche markets.

References

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Lave, L. and Gruenspecht, H. (1991) Increasing the Efficiency and Effectiveness of Environmental Decisions: Benefit-Cost Analysis and Effluent Fees, A Critical Review, *Journal of Air Waste Management Association* **41**(5) 680-693

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Appendix 1: Companies to which survey was sent

Copier manufacturers

Canon Inc.	http://canon.jp/
Fuji Xerox Co., Ltd.	http://www.fujixerox.co.jp/
Konica Minoruta Holdings, Inc.	http://konicaminolta.jp/
Ricoh Company, Limited.	http://www.ricoh.co.jp/
Sharp Corporation	http://www.sharp.co.jp/

(Alphabetical order)

Appliance Manufacturers

Hitachi, Ltd.	http://www.toshiba.co.jp/
Matsushita Electric Industrial Co., Ltd.	http://panasonic.co.jp/
Mitsubishi Electric Corporation	http://www.mitsubishielectric.co.jp/index_c.html
Sony Corporation	http://www.sony.co.jp/
Toshiba Corporation	http://www.toshiba.co.jp/

(Alphabetical order)

Appendix 2: Survey Questions

Copier Manufactures

(1) Technological changes of copiers
What are domains in which copiers' technological changes has been taking place in the last decade? Provide key words such as 'high speed' or 'saving energy.'

(2) The rate of technological changes
What are the rates of technological changes provided in (1)? How many years can major parts be used without design change in each domain of the technological changes?

(3) Influence of technological changes on design
To what extent do the technological changes affect product design? With regard to each domain, rate from 1 (influence is partial) to 5 (influence stretches to the entire product)

(4) Design lifetime of parts
Given that remanufactured copiers need to have parts across different generations, how many generations are parts expected to be used?

(5) Remanufacturing and innovation
It seems that gaining commonality of parts between generations and introducing new technology are not compatible. How do you overcome this problem?

(6) Acceptance of remanufactured products
Have remanufactured copiers been accepted smoothly by Japanese consumers? What are barriers to consumers' acceptance of remanufactured products, if any?

(7) Changes of acceptance of remanufactured products
How has the acceptance of remanufactured copiers changed?

Appliance Manufacturers

(1) Reasons for not conducting reuse and remanufacturing
It seems that the central strategy of appliances is material recycling. What are reasons that reuse and remanufacturing are not taking place? Provide them from major ones to minor ones.

(2) Possibility of reuse and remanufacturing
Is there possibility that home appliances shifts to reuse and remanufacturing in the future? If there is no or little possibility, what are major reasons?

(3) Evaluation of material recycling

Do you measure and evaluate energy required for material recycling? Provide any evaluation report that is open to public.

(4) Home Appliance Recycling Law
Has the design lifetime of designated appliance been changed since the implementation of the Home Appliance Recycling Law?

(5) Home Appliance Recycling Law
Has there been any other change in technological development by the Home Appliance Recycling Law?

Note: Communication with companies, including questions, was made in Japanese language. The above questions are English translation.

Appendix 3: Automobile manufacturers examined

Daihatsu Motor Co., Ltd	www.daihatsu.co.jp
Honda Motor Corporation	www.honda.co.jp
Mazda Motor Corporation	www.mazda.co.jp
Mitsubishi Motors Corporation	www.mitsubishi-motors.co.jp
Nissan Motor Co., Ltd.	www.nissan.co.jp
Toyota Motor Corporation	www.toyota.co.jp

(Alphabetical order)

Appendix 4: Survey questions to manufacturers

(1) What are parts that are commonly used among different models sold at the same period? Itemise typical ones.

(2) What percentage (quantity basis) do such parts account for among all automobile parts?

(3) What are parts whose design does not change before and after a full model change? Itemise typical ones.

(4) What percentage (quantity basis) do such parts account for among all automobile parts?

(5) Do you think it is practical to reintegrate used parts taken from ELVs into newly manufactured vehicles?

(6) If not, what are main reasons?

(7) I can find much information on "reuse" and "recycle" of 3R from your website. What do you do for "reuse" in design, development and manufacturing?

(8) Is "reduce" prioritised over reuse and recycle in your design guideline?

(9) Currently, 20-30% of ELVs (weight basis) are recovered in the form of used parts. What would be the maximum possible rate?

(10) What efforts do you make to realise (9)?

Note: Communication with companies, including questions, was made in Japanese language. The above questions are English translation.

Appendix 5: Automobile part dealers and industry organisations

Automobile parts dealer

JAPRA	http://www.japra.co.jp/mail.html
System Auto Parts	info@sap-net.co.jp
U Parts	http://www.u-parts.com/CompanyInfo/Company_top.html#

Industry organisations

Automobile Recycling Workshop http://homepage3.nifty.com/ariken/index.html

Japan Auto Parts Industries Association (JAPIA)

http://www.japia.or.jp/public/jsp/japia/g_index.jsp?contents=2

Japan Automotive Recyclers Association http://www.npo-jara.org/index.html

(Alphabetical order)

Appendix 6: Survey questions to industry organisations and automobile part dealers

(1) How many reusable parts can be taken from one new ELV (~5 years old), mid-age ELV (5~7 years old), and old ELV (7~ years old), respectively?

(2) How many theoretically reusable parts (that function properly, have long enough remaining lifetime and may need some cleaning and repair) would be taken from one new ELV (~5 years old), mid-age ELV (5~7 years old), and old ELV (7~ years old), respectively?

(3) What are remaining lifetime of recycled parts in the market?
   a. functional parts around engine
   b. functional parts around transmission
   c. functional parts such as pumps and motors
   d. electrical parts such as starters and alternators
   e. consumable parts such as brake pads and linings
   f. exterior parts such as doors, bumpers and mirrors
   g. interior parts such as seats and console panels

(4) Currently, 20-30% of ELVs (weight basis) are recovered in the form of used parts. What would be the maximum possible rate?

(5) What efforts do you make to realise (4)?

Note: Communication with companies, including questions, was made in Japanese language. The above questions are English translation.