Interdisciplinarity in Closed-Loop Supply Chain Management Research

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1 Introduction

Closed-loop supply chain (CLSC) management has evolved to be a mature area of supply chain management in its own right. Guide and Van Wassenhove (2009) describe how this research began with focusing on tactical and operational issues such as the disassembly of products or shop-floor control and coordination, and later started addressing issues pertaining to the entire reverse supply chain such as product acquisition, supply-chain contracting and incentives. Recently, the literature has begun studying issues at the intersection of other disciplines, drawing on concepts from industrial ecology, studying marketing issues such as the pricing and positioning of new and remanufactured products, etc. It is clear that the research in closed-loop supply chains is moving in an interdisciplinary direction. This is of great value, as the "messier" problems in industry tend to require an interdisciplinary approach.

At a recent workshop[1], invited industry participants[2] shared the issues that they face in closing the loop in their business context. These questions were then grouped primarily along the areas of Industrial Ecology, New Product Development, Marketing, and Economic Development, and discussed by small groups of workshop participants. This chapter builds on these discussions to present some existing research that is relevant to the questions posed, and is therefore necessarily interdisciplinary. A number of open research directions are also presented. We hope that describing industry problems and the current state of the art will prompt researchers to close existing gaps in the literature and increase the practical impact of closed-loop supply chain management research. Table 1 provides a list of teaching material that has significant closed-loop supply chain content and that is at the interface of the above-mentioned areas, to aid in broadening instruction related to CLSC management.

This chapter is organized as follows: In §2, we provide short case studies based on each industry participant to provide an account of their closed-loop supply chain activities and the problems they currently face in managing these operations. In §3, we identify the common threads running through the issues raised by these discussions and provide insights from the

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[2]John Wuichet, Installation Management Command, Southeast Region; Eric Nelson, Interface Americas; A.B. Short and Pat Robinson, MedShare International.

existing literature. We conclude in §4.

2 Case Studies

2.1 Interface, Inc.

Interface, Inc., is the world's largest provider of commercial carpet tile. It is well recognized for its attempts to be an environmentally sustainable enterprise with the ambitious goal of zero environmental impact by 2020 (Toktay et al. 2006). This is a particularly challenging goal, as the inputs into carpet production are primarily oil-based, and reycling remains elusive, with 5 billion square yards of carpet deposited in U.S. landfills each year. Here, we focus on two interconnected elements in their roadmap to sustainability - closing the loop and redesigning commerce. The proof of concept at Interface would be the Evergreen Services Agreement (ESA), whereby carpet would be leased, not sold. With operating lease agreements, carpet would remain in the ownership of Interface and reclaimed carpet could be recycled, diverting it from the landfills. This practice of leasing, rather than selling, has been claimed to be an environmentally superior strategy for decreasing virgin material use, reducing waste generation and closing the loop (Fishbein et al. 2000). The ownership of off-lease products would also provide the manufacturer with an incentive to utilize the residual value of these products. This is the rationale that prompted Interface to introduce ESA as part of their sustainability strategy as early as 1995. However, ESA was not successful. The main reason for its failure was the inability to recover value from used carpets as there was no viable technology to separate the face fiber from the backing, nor to recycle the face fiber consisting of Nylon 6,6 in the case of Interface; see Toktay et al. (2006) (pp.23-24) for a detailed discussion.

Interface's search for a way to close the loop was finally rewarded when they were introduced to an Italian company that manufactured machines to split leather to precise specifications (Ferguson et al. 2008). The technology was customized for the carpet industry to separate backing from face fiber, and to remelt the material back into pellets that could be fed back into the manufacturing process thanks to the very low levels of contamination achieved. Interface acquired this recycling process and introduced it as Re-Entry 2.0 in 2007. So far Interface has one facility in Georgia, but as this recycling process is a simple, low-footprint process, Interface is considering opening 19 such recycling facilities around the

country to process 450 million lbs of reclaimed carpet per year (Nelson 2008).

At this juncture, some of the questions faced by Interface, Inc. are as follows:

1. How does Interface responsibly expand its carpet recycling operations? Should they use one centralized facility, build many smaller facilities across the U.S. or license the technology? What are the environmental and economic implications of these choices?

2. Can Interface use recycling as a means to create economic development in local communities?

3. How should Interface's current manufacturing strategy be adapted in the face of the recycling opportunity?

4. Given that reclaimed carpet has some residual value now, is the reintroduction of the leasing program a good business strategy for Interface?

2.2 Army Installation Management Command

The Army has initiated a Sustainability Planning Process with a 25-year goal setting framework, and a 5-year development plan overseen by the Army Installation Management Command (IMCOM). IMCOM's primary role is overseeing all facets of installation management including construction, barracks and housing, food management, etc. In this capacity, they handle the large variety and quantity of end-of-use and end-of-life streams generated in Army installations. Below we discuss three projects developed by IMCOM-SE that aim to close the material loop and reduce the installations' environmental footprint.

IMCOM is working to close loops within local economies surrounding the installations by collaborating with external stakeholders. As such, the focus is on products for which there is manufacturing activity in the region. For example, furniture jobs are down 20% in North Carolina (where Fort Bragg is located) since 2007, while the on-site construction and demolition landfill cannot accept furniture, imposing a higher off-site disposal cost on the Army. IMCOM promotes the design of furniture that is recyclable to achieve triple bottom line benefits: obtaining value recovery from waste, reducing environmental impact, and generating jobs for local economies surrounding the installations. Some associated challenges are incorporating the "buy local" concept into IMCOM's centralized purchasing process and giving manufacturers enough incentive to design and build such products.

IMCOM has explored servicizing, and in particular, leasing, as an environmentally preferred alternative for such products like furniture and mattresses. Some of the challenges

they face are finding an interested vendor, designing the right contract, and integrating into the purchasing-focused centralized procurement process.

IMCOM has also explored by-product synergies, where waste from one operation can be used as a raw material for another operation. Most installations occupy forested land that generates large quantities of timber harvest waste. Another large source of wood waste is demolition debris. Historically, timber waste was burned on the installations and demolition waste was landfilled, while bark fuel was purchased to run a central energy plant. Some installations now utilize their wood waste as fuel for the energy plant, which reduces disposal cost, fuel procurement cost and the number of smoke days. There could be several such synergies in IMCOM's operations, but the challenge lies in identifying and managing such symbiotic activities.

In this context, some of the questions faced by IMCOM are the following:

1. How can the Command encourage the design and availability of greener products?

2. The army procurement systems are becoming more centralized, but the disposal and recycling activities are carried out locally. Should closed-loop systems be pursued at the local or the global scale?

3. How can closing the loop best be leveraged to generate local employment opportunities?

4. What processes should be deployed to generate and manage by-product synergies?

5. Would leasing help to reduce costs and avoid end-of-life management? If so, should the Command lease directly from a manufacturer or through a third-party lessor? How should existing internal processes be redesigned to support such an endeavor?

2.3 MedShare International

Usable medical supplies worth $6.5 billion are discarded in the U.S. every year. Medshare International, an Atlanta-based non-profit humanitarian organization, collects unused medical supplies in the U.S. and distributes them to needy facilities in other parts of the world. While the main driver of MedShare is their humanitarian impact, since they divert waste from U.S. landfills, their operations also lend themselves to claims of environmental benefits. The ability to legitimately claim that environmental considerations are included in MedShare's recipient selection decisions has important ramifications for their business: Since MedShare depends on the philanthropic donations of individuals and foundations, and foundations

have strict guidelines on what types of projects are in line with their charitable objectives, the ability to demonstrate a sensitivity to the environmental impact of their operations can significantly increase the number of foundations to which MedShare can submit proposals. Thus, MedShare is interested in expanding their recipient strategy to include both humanitarian and environmental objectives, and to have a systematic procedure for doing so. Issues to take into account are the environmental impact of the additional transportation created by their operations, the usage rate of donated supplies, and the quality of disposal methods in the recipient country (Denizel et al. 2009).

Since MedShare operates on donations from sponsors, they are interested in figuring out whether they can be more effective by improving the cost efficiency of their collection operations (without increasing their environmental impact). One option is to partner with waste collectors, since they visit the same hospital facilities as MedShare. In addition, Medshare could integrate another facility or partner to re-sterilize the collected supplies that would otherwise have to be discarded. However, these partnerships may increase the operational risks and constraints for MedShare.

MedShare currently has two locations in the U.S. One is on the east coast, in Atlanta, and the other is on the west coast, near San Francisco. Transporting supplies to these two central facilities is a major expense and contributes to their carbon footprint. On the other hand, there are economies of scale associated with a central facility. In addition, as shipments to each recipient are based on inventory at only one facility, centralizing the inventory provides a broader array of products for the recipients to choose from. The question for MedShare is whether to utilize a distributed or centralized approach as they continue to grow.

In summary, some of the questions faced by MedShare International are as follows:

1. How should MedShare measure the relative environmental impact of different potential recipients?

2. How can MedShare balance its dual objectives of humanitarian and environmental benefits?

3. Would partnering with medical waste collectors or other organizations improve the economic and environmental performance of their collection process?

4. How should Medshare expand to other communities or countries?

3 Relevant Interdisciplinary Research

The above case studies highlight that although each one of these organizations is very different, the main issues they are grappling with have common threads at the interfaces with the following research areas: industrial ecology and supply chain management, identifying and managing by-product synergies, designing and implementing product-service systems, developing and marketing greener products, and creating economic development opportunities by closing the loop. In this section, we will provide some insights on questions including, but not limited to, the specific ones discussed in the case studies. Our goal is not to provide an exhaustive review of the literature pertaining to each question, but to highlight different interdisciplinary approaches to such questions through a limited, but representative subset of the literature.

3.1 Industrial Ecology and Supply Chain Management

The main tenet of industrial ecology is to take a systems view and consider holistic analyses that focus on multiple attributes of a system (for example, different dimensions of environmental impact). Due to this perspective, research in the industrial ecology domain considers the environmental impact through the entire product life-cycle. Since as the product goes through the different stages of the supply chain, it also goes through different phases of its life cycle, existing approaches in industrial ecology and closed-loop supply chain management are complementary in nature. This synergy is reflected in recent interdisciplinary research which addresses environmental issues using tools from both domains. For example, Faruk et al. (2002) describe a framework that firms can use to assess the environmental impact of their entire supply chain. Rosen et al. (2001) discuss different supply-chain contracting mechanisms that can be used by firms in the computer industry to incentivize their suppliers to improve the environmental quality of their products. Rock et al. (2006) conduct a case study of Motorola's global supply chain to analyze if the internal environmental standards are adopted by its suppliers in other countries. In this section, we will focus exclusively on literature that draws on both domains and considers both the profitability and the environmental performance of closed-loop supply chains.

Subramanian et al. (2008) develop a decision support tool using a mathematical programming model for a profit-maximizing manufacturer to capture environmental considerations such as sustainable product design, management of emission allowances and loop-closing

activities such as recovery, remanufacturing and disposal along with traditional operational considerations such as capacity, production and inventory.

Matthews et al. (2002) assess the economic and environmental implications of the centralization of inventory and warehousing. Although increased centralization reduces the inventory level and the number of warehouses, and consequently reduces inventory and warehousing costs and the environmental impact of warehousing, it increases the costs and environmental impact of transportation. Based on a case study of the spare-parts inventory at U.S. Department of Defense warehouses, they find that since spare parts have low demand, there are both significant economic and environmental benefits from centralization. Although these insights may only hold for low-demand products, their analysis provides a framework that can be used to investigate any product category and various design and location decisions arising in the management of closed-loop supply chains.

Quariguasi Frota Neto and Bloemhof (2008) examine the economic and environmental implications of closing the loop by recovering, remanufacturing and selling computers and mobile phones. They use the concept of eco-efficiency, which is defined as economic output per unit of environmental impact. Since consumers discount remanufactured products, the remanufactured product price (economic output) is generally lower than the new product price. Remanufactured products are nevertheless more eco-efficient (with energy consumption as the environmental impact measure), because the energy consumption associated with remanufacturing is far lower than that associated with producing new products.

Geyer and Jackson (2004) study "supply loops": end-of-life strategies that divert waste and replace primary raw materials in forward supply chains. Using examples from the construction industry, they argue that such supply loops can not only result in environmental benefits but also help firms reap economic benefits. However, firms need to take into account that a component may be reused only a finite number of times due to technical constraints and enjoy market demand only for a limited time. The main insight for firms is that they need to align recovery decisions such as collection and remanufacturing rates with such product characteristics (Geyer et al. 2007).

These frameworks and insights are valuable to entities like Interface and Medshare, who are interested in incorporating both cost and environmental considerations in designing their closed-loop supply chains. Nevertheless, such applications are not common, and there is an opportunity to both do proof-of-concept on industry problems and to develop frameworks that are specific to reverse (rather than forward) supply chains.

3.2 By-Product Synergy and Industrial Symbiosis

By-product synergy is a process by which wastes can be converted into marketable commodities, and industrial symbiosis is the exchange of wastes, by-products and different forms of waste energy among closely situated firms in an industrial complex. In their seminal paper, Ehrenfeld and Gertler (1997), describe the benefits and challenges involved in managing opportunities for by-product synergy and industrial symbiosis using the example of the industrial district of Kalundborg, Denmark. Although the benefits of by-product synergy and industrial symbiosis are well recognized, there are several managerial challenges associated with benefiting from them (see Anderson and Mackenzie 2006 and Lee et al. 2009 for related teaching cases). The initial challenge is the identification of such opportunities: Since they are not the main focus of the business, employees have no incentive to identify or champion such causes. Even if such opportunities are identified, finding reliable markets for by-products may be difficult. Since they require long-term commitment and there is considerable uncertainty in their success, investing and implementing in such opportunities is also difficult.

There is little research literature on how a business can maximize the economic and benefits from by-product synergy and industrial symbiosis. Lee (2009) considers a firm operating in a competitive setting, where it can convert a waste stream into a marketable by-product. If the sale of the by-product is profitable enough, it may incentivize the firm to generate more waste, which will promote greater production of the base product and increase consumption. Thus, the net environmental impact of such opportunities could potentially be negative and a firm needs to be careful about claiming an environmental benefit when it implements such by-product synergies. Interesting avenues to explore are how to price by-products when there is uncertainty in both supply and demand for them, and how to incentivize employees to identify and manage by-product synergies.

3.3 Product-Service Systems

A product-service system is defined as a product and a service combined in a system to deliver consumer needs and reduce environmental impact, typically by displacing new production or increasing usage efficiency (Baines et al. 2007). Primary examples of product-service systems are servicizing, renting, leasing, sharing or pooling through membership schemes. Offering maintenance, take-back or disposal services are also considered to be part of product service

systems. In this chapter, we focus on these systems from a profit-maximizing firm's point of view. A recurring theme in this stream of literature is that such product-service systems do not necessarily yield superior environmental outcomes. The interested reader is directed to Mont (2004), who provides a detailed discussion of other aspects of these systems.

An interesting example of servicizing is for the consumption of indirect materials such as solvents or hazardous catalysts in the chemical industry and to a lesser extent in the electronics and automotive industries. A buyer would like to reduce his consumption of such indirect materials, but the supplier has an incentive to sell a larger volume and will not invest in reducing the consumption. Using examples from industrial practice, Reiskin et al. (2000) describe how the traditional supplier-customer price-based relationship can be transformed to where the supplier does not sell, but provides these indirect materials as a service. This might provide the supplier with an incentive to reduce consumption. Corbett and DeCroix (2001) study contracting schemes for sharing savings from such servicizing opportunities in a supply chain, where both the supplier and the customers can benefit from dematerialization. They show that such contracts can increase the supply chain profits but at the expense of increased consumption, which leads to environmentally inferior outcomes.

Leasing is a strategy that has long been used with the goal of maximizing firm profits. Recently, the industrial ecology literature has promoted leasing as environmentally superior to selling (Hawken et al. 1999, Fishbein et al. 2000, Lifset and Lindhqvist 2000, Robert et al. 2002). The rationale is that since the firm maintains ownership of the off-lease products, it has an incentive to refurbish and remarket the product, which helps extend its useful life, divert waste from landfills and displace new production. However, some argue that if manufacturers have control over off-lease products, they will prematurely dispose of them to reduce cannibalization and lead to environmentally worse outcomes (Lawn 2001).

Agrawal et al. (2009b) compare leasing and selling from the manufacturer's point of view to identify conditions under which leasing can be both financially and environmentally superior from a life-cycle perspective. They find that manufacturers would find it profitable to lease only if they face a lower disposal cost than the consumers. Commercial carpeting, while durable, does not lend itself to reuse and only some of the material can be recycled. Thus, by committing itself to collecting and (partially) recycling the carpet, Interface effectively increased its disposal cost significantly relative to local landfilling by its customers. Consequently, it is not surprising that despite originally being championed at the highest levels of the company, the leasing program was phased out.

Agrawal et al. (2009b) also find that even if a leasing firm does not prematurely dispose off-lease products, it may still have an incentive to produce a larger quantity of products, which negates any reduction in the disposal impact. The main message for firms considering promoting or adopting leasing programs for improving their environmental performance is to carefully consider the disposal cost scenarios, the product durability and the environmental impact over the entire product life-cycle.

Membership or pooling schemes such as car-sharing services can be environmentally beneficial as they may induce consumers to participate in these schemes instead of buying new products, thereby leading to lower consumption and production. However, Bellos et al. (2009) study membership schemes in the context of transportation and show that membership schemes may lead to inferior environmental outcomes where they induce consumers who would otherwise use lower-impact substitutes such as public transport to join such schemes.

Olivia and Quinn (2003) is a case study based on Interface's Evergreen Leasing program that highlights the managerial challenges associated with its implementation. The main insight from the literature discussed above is that a firm implementing such a product-service system needs to be careful before claiming environmental superiority. This is of importance to Interface in the context of the revival of the Evergreen Leasing Program and to IMCOM in its efforts to promote leasing as an environmentally superior procurement strategy.

There are several open questions regarding such systems. One direction for future research is whether an OEM should lease directly to consumers or sell to a third-party lessor who would lease to consumers. Another question is how to manage conflicts with existing dealer networks while introducing such new systems. Can the inclusion of ancillary services such as maintenance help increase the attractiveness of such options for the consumers? Finally, more research is needed to investigate the appropriate design of lease terms to achieve both economic and environmental benefits.

3.4 New Product Development

The literature in new product development and innovation has studied problems such as quality choice, product line design and component commonality. These issues are relevant in the closed-loop supply chain context, albeit with complementary considerations such as the role of green consumers and the effect of take-back legislation. Here, we focus on the managerial challenges associated with new product development in the closed-loop supply chain

context, most of which are nicely captured in Vietor and Murray (1995), a case study describing Xerox's attempts to align its design strategy with its recovery strategy. A discussion of the engineering design aspects is the subject of Chapter 4.

Chen (2001) studies the design problem for a firm where the conventional and environmental attributes of a product conflict with each other and the market may consist of traditional and green consumers. They show that a firm's design problem critically depends on the legislative (presence of regulation) and market conditions (population of green consumers). They show that in the presence of government policies such as stricter environmental standards, the firm's design and marketing strategies may change, resulting in inferior environmental outcomes. Subramanian et al. (2009) analyze a firm's component commonality decision in the presence of recovery and remanufacturing operations. They show that ignoring remanufacturing operations at the product design stage can have a detrimental impact on a firm's profitability. This stream of literature emphasizes the importance of product design in leveraging the benefits from closing the loop.

An important consideration in the design and introduction of new products is the presence of take-back legislation (see Chapter 3 for an in-depth discussion of this type of legislation). Plambeck and Wang (2009) study the impact of e-waste legislation on new product introduction and find that "fee-upon-sale" type of legislation decreases the rate of new product introduction, and consequently, the quantity of e-waste, but does not provide firms the incentive to design products for recyclability. They also find that e-waste legislation that imposes a "fee-upon-disposal" does not reduce the rate of introduction and e-waste, but leads to firms designing products for recyclability. Atasu and Subramanian (2009) analyze the effect of legislation on designing products for recyclability. They find that individual producer responsibility programs offer higher incentives for recyclable product design as compared to collective responsibility programs.

In the absence of legislation, the benefits from designing for the environment depend on the presence of green consumers. Ginsberg and Bloom (2004) discuss different types of consumers and their preferences regarding green products. They say that somewhere around 15-46% of consumers are interested in some form of green product. However, only a very small fraction (at most 5-10%) of these consumers would spend more to buy a "greener" product. Moreover, not all industries or products enjoy an already existent consumer population who are willing to pay a premium for greener products. In such a setting, the question is how a firm or a policy-maker can encourage the growth of such consumer segments to support the

development of environmentally superior products.

Andrews and DeVault (2009) use a multi-heterogeneous-agent simulation to analyze the interactions between firm strategies, government policy and consumer preferences and study the emergence of green markets using an application to hybrid cars. Their insights are useful for different stakeholders: Firms can innovate to create greener products either as a response to or in anticipation of government regulation. However, green markets will not emerge unless there are enough green consumers. Thus, innovation by firms is necessary, but not sufficient; the presence of green consumers is also important. They find that governmental intervention such as bans on environmentally inferior products or taxes only help preserve niche-green markets. The only way for such markets to grow and for green products to go mainstream is through cost parity. This implies that in order to increase the availability of recyclable products, entities such as IMCOM may benefit from joining groups such as the "Buy Recycled Business Alliance" which would help to increase demand for recycled products and help achieve economies of scale leading to cost parity with ordinary products.

There are several open questions for future research. One such question is whether it is profitable to design products for modularity so that it is easier to reuse them and maximize value recovery. Another is the trade-off between the ability to innovate and the ability to benefit from returned cores in subsequent generations.

3.5 Marketing

The profitability of closed-loop supply chains depends on the market acceptance of recyclable, refurbished or remanufactured products. Marketing such products poses several challenges for a firm. Remanufactured products may potentially cannibalize the demand for the firm's new products. Thus, the joint positioning and pricing of new and remanufactured products is a key problem faced by the firm. We point the interested reader to Chapter 2 for a detailed discussion of the trade-offs involved. In this section, we will focus on the literature that studies the effect of consumer perceptions of remanufactured and refurbished products on a firm's closed-loop strategies.

Consumers may have quality and reliability concerns regarding remanufactured products, which may lead to a lower perceived value, which may in turn inhibit their market acceptance or profitability. This has extensively been used as a modeling assumption in the literature (Debo et al. 2005, Ferguson and Toktay 2006, Debo et al. 2006, Atasu et al. 2008).

Recent research efforts have validated this assumption through experimental and empirical analyses. Guide and Li (2009) conduct eBay experiments using a consumer product (a power tool) and a commercial product (internet router) and find that on average, remanufactured products are purchased at lower prices than new products. They also find little overlap between bidders for the consumer product, but greater overlap for the commercial product. Thus, a commercial product firm should be more careful about the cannibalization of its new products by its remanufactured products. Subramanian and Subramanyam (2009) use purchase data from eBay and show that the price differential depends on the seller reputation and the product category (see Chapter 8 for more details). Agrawal et al. (2009a) conduct an experiment using Apple iPods and find that the subjects have a lower willingness to pay for remanufactured products and that they have a higher perceived value for an OEM-remanufactured product as compared to a third-party-remanufactured product.

The presence of remanufactured products may raise quality issues concerning the firm's new products: "...Just where are the refurbished iPhones coming from? Is Apple getting enough returns so they can resell them..." (CNET 2007). Existing literature in marketing has established that consumers' perceptions spill over between different products sold under the same brand (Sullivan 1990, Rangaswamy et al. 1993, Erdem 1998). Since remanufactured products are functionally and physically the same as the new product, one may expect consumer perception of the new product changing in the presence of its remanufactured counterpart. Indeed, Agrawal et al. (2009a) establish that the presence of remanufactured products has a significant impact on the consumers' perceived value for new products. They find that the presence of OEM-remanufactured products lowers the value of new products, but the presence of third party-remanufactured products increases the value of new products. This result implies that while selling remanufactured products, an OEM should alleviate consumer concerns regarding quality or reliability by providing more information regarding the remanufacturing processes or better warranties. The authors also show that when such consumer perceptions are taken into account, an OEM's optimal remanufacturing and preemption strategy may drastically change. The main insight from this stream of literature is that firms should first investigate the consumer perceptions for their product and manage their closed-loop supply chains accordingly.

Recently, research has also focused on different information cues that can help to increase the perceived value of remanufactured products. Ovchinnikov (2009) conducts an experiment using Dell laptops where consumers are provided with the price differential between the new

and remanufactured products as a cue and studies their valuation for the remanufactured product. He finds that the fraction of consumers who switch from a new to a remanufactured product first increases and then decreases (inverted-U shape) as the discount on the remanufactured products increases. This provides some evidence that consumers may infer the quality of the remanufactured product based on the price. Quariguasi Frota Neto (2008) explicitly considers the role of the new-product price as a reference price and finds that using the new product price helps increase the consumers' willingness to pay for remanufactured products. Agrawal et al. (2009a) conduct an experiment to examine the role of information regarding the availability of remanufactured products on the consumers' perceived value for new and remanufactured products. They find that the perceived value of remanufactured products decreases with an increase in their availability. Thus, the firm may benefit from restricting information regarding the availability of remanufactured products. The main insight from this literature is that a firm can improve the acceptance and value of recovered products by using the appropriate marketing cues and strategies.

There are other marketing factors and cues that warrant further investigation. For example, while it has been recognized that the reputation of third-party remanufacturers has a significant impact on the perceived value of remanufactured products (Subramanian and Subramanyam 2009), the effect of OEM reputation on consumer perceptions is still unknown. More research is also needed on analyzing the impact of other factors on consumer perception, such as warranties and information regarding the source of cores used for remanufacturing.

3.6 Economic Development

A testament to the impact of closing the loop on economic development is the contribution of the remanufacturing sector to the United States economy. According to a 1996 survey conducted in United States, 79 different product areas were being remanufactured, employing 480,000 people and consisting of 73,000 different firms, which is comparable to other mainstream industries (see Lund 2001). Goldman and Ogishi (2001) argue that new activities from the diversion and reuse of waste can result in economic development in economically distressed areas. Smith and Keoleian (2004) use a life-cycle assessment model to analyze the environmental benefits of remanufacturing automotive engines. They also show that remanufacturing can also have social benefits either through additional employment opportunities or through greater affordability of the products for small businesses and consumers.

Leigh and Patterson (2005) discuss how recycling construction debris can not only result in environmental benefits, but also assist in economic development as such activities result in the creation of jobs for low-income, low-skilled residents. Leigh and Realff (2003) study the economic development potential of the recycling and reuse of computers in the state of Georgia. An interesting question they pose is whether end-of-life material flows can be designed to both promote economic development in the severely distressed areas of Atlanta and limit the environmental performance of collection. Using census and demographic data, they estimate the quantity of obsolete computers in households across the state. Taking existing electronics stores as collection centers, they compare two locations for placing a recycling network along the economic development and environmental dimensions. The "greenfield" location is a traditionally affluent section of the city, where most of the e-waste originates and which is closer to major transport routes, but is further away from sources of the low-skilled unemployed labor force. In contrast, the "greyfield" location is a traditionally industrial location that is further away from sources of e-waste but closer to the sources of required labor. They find that locating the recycling center in the greyfield location has lower environmental impact and also results in more economic development by being closer to the unemployed labor force.

The nexus of economic development and closed-loop supply chains has not been studied except for the above-mentioned papers and is a fertile area for combining the social and environmental benefits of closed-loop supply chains. Building robust statistical models for estimating the volume of used products that can be collected based on demographic statistics and on consumer behavior regarding recycling activities would help evaluate the potential for employment creation. Developing frameworks to incorporate information about characteristics of the work force in supply chain design decisions would also be valuable.

4 Conclusions

We hope that the case studies presented have highlighted the interdisciplinary nature of issues that closing the material loop raises. As evidenced by the (mostly recent) research using approaches from different disciplines, there is a growing recognition that challenges faced by industry to design and manage closed-loop supply chains cannot be solved by using a single approach or by only drawing from the knowledge base of one domain. Indeed, as discussed in this chapter, there are many opportunities that remain for us to collaborate

with researchers in other disciplines and help to increase the influence of our research on managerial practice.

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Table 1: List of Teaching Cases with Significant Closed-loop Supply Chain Content and Interdisciplinary Issues.

Product Design and Recovery	Vietor and Murray (1995)
Marketing of Refurbished and Remanufactured Products	Van Wassenhove et al. (2002) Rayport and Vanthiel (2003)
Economic and Environmental Benefits of Leasing	Olivia and Quinn (2003)
By-product Synergy Opportunities	Anderson and Mackenzie (2006) Lee et al. (2009)
Sustainability and Supply Chain Management	Plambeck and Denend (2007)