Contracting and coordination in closed-loop supply chains

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Introduction

"Coordination" has become a key concept in much of the modern literature on supply-chain management. The notion of a "supply chain" inherently involves multiple independent decision-makers. These decision-makers can be a single company's geographically dispersed warehouse managers, a company's different departmental managers, or different firms, vertically aligned to form a supply chain or competing horizontally each within their own respective supply chain. In such a context of decentralized and independent decision-making, outcomes will rarely be "optimal" for the entire supply chain unless there is some degree of coordination between the decision-makers actions. In general, the starting point for much of what happens in supply-chain management, whether in academia or in practice, is the objective of achieving greater coordination between parties. This can be done in several ways, including formal contracts or informal mechanisms to realign incentives or to encourage more information sharing, or by changing the physical or economic nature of the product or the system.

It is also clear, though, that there are many reasons why such coordination may be difficult or impossible to implement. Parties may have fundamentally conflicting incentives, or no party may be large or powerful enough to impose a coordinated outcome, and some parties may hold private information that they are unwilling to share but that could help others make better decisions. Many such problems have recently been studied for unidirectional or "forward" supply chains, and several general lessons about design and operation of such supply chains can be drawn.

With the recent emergence of product take-back laws in Europe and the ever-increasing tendency of customers worldwide to return products for whatever reason, many supply chains are becoming inherently bi-directional. Ideally, many (though not all) of these returns can be fed into a supply chain again, either back into the original supply chain from which they originated (such as when products are reused or remanufactured), or into another supply chain (such as when they are recycled to a lower-grade product). The ideal notion often espoused by some is that of a "closed-loop supply chain". Though clearly some chains are not and will never be truly "closed-loop", we will use that terminology to refer to any supply chain that encompasses flows of products that have been surrendered by the original customer.

The presence of such additional flows, whether they feed back into the original supply chain or are recycled or disposed of separately, further complicates the already tough challenge of achieving coordination in supply chains. In this chapter, we review what is known about coordination and contracting in forward supply chains, extrapolate these learnings to managing reverse flows, and then examine how these lessons may be affected by the presence of reverse flows. Our objective is obviously not to provide a full review of the supply-chain management literature (for that, see Tayur, Ganeshan and Magazine 1999), but rather to examine the ways in which forward and reverse flows interact.

In this chapter, we first identify several key reasons why closed-loop supply chains are emerging worldwide, as these will directly affect the coordination challenges faced and remedies available. Then we review various aspects of supply chains that could, in principle, be coordinated upon. After that, we review existing literature on (forward or unidirectional) supply chains, to see what can be learned about designing and managing such supply chains. In each case, we extrapolate these lessons to reverse flows and also examine how these lessons change in the presence of a reverse supply chain.

Many reasons to think about Reverse Logistics

Supply chains come in many shapes and sizes, each with their own specific requirements. A company's *supply chain strategy* defines the set of customer needs that it seeks to satisfy through its products and services. By ranking the customer's top priorities with respect to product price, quality, variety and time to market, a company defines its strategic position relative to the competitors. For example, Walmart's supply chain operations emphasize low cost and high variety in the grocery business, while Dell aims to provide high product customization and responsiveness to its customers at reasonable prices. For any company to be successful there needs to be consistency between, on the one hand, the customer's priorities which the firm chooses to emphasize and, on the other hand, the type of capabilities designed into a product/service supply chain and its operating principles. In other words, there should be *a strategic fit* between what the supply chain operations are designed to be good at and how the firm wants to compete with its products in the market (Chopra and Van Mieghem 2000, Porter 1996). In this respect, decisions regarding the design and the operating principles of reverse logistics channels should also be coordinated with the existing capabilities of forward supply chain structures.

The concept of *strategic fit* can be formulated in a general framework, which links the reverse logistics channel decisions to the overall business plan of a company and to existing forward supply chain capabilities. The linkage can be established based on the answers to the following three sets of questions:

- What is the firm's desired strategic positioning for its reverse logistics operations?
- Given the positioning of the reverse logistics operations, what capabilities are required from reverse logistics processes in terms of cost, flexibility, quality and

time? Do the present capabilities in the forward supply process complement the desired capabilities from reverse logistics operations?

- Given the positioning of the forward supply chain and its present capabilities and the desired capabilities from reverse logistics processes, how should the reverse supply chain be structured, and the product and pricing decisions in the reverse flows be coordinated with the forward supply system?

The current practice shows that a company can use its reverse logistics capabilities to increase its cost efficiency in manufacturing and in supplying products to the market, and also to enhance the value of its product to customers. We use these two dimensions to classify different types of product returns as they relate to the overall supply chain strategy of the firm. The extent of interaction between decisions on the forward and the reverse logistics channels highlights areas where coordination challenges may arise.

Reverse logistics capabilities can lead to more cost efficient operations either by reducing the life cycle costs of a product or by providing a means to make better decisions on the forward supply chains. Here are some examples of how reverse logistics can reduce costs. Table 1 summarizes the cost and value implications of reverse logistics activities and highlights areas for better supply chain integration. Below, a detailed discussion of for each type of reverse logistics activity is given.

Environmental Product Returns

Political concerns for the environment in Europe, in the US and in Japan have resulted in legislation dictating recycling of materials (e.g. chemical products, glass, paper, plastics, aluminum, lead) up to a certain percentage as they are disposed by the end consumers either directly, e.g. in the case of packaging, or indirectly, in the case of various products such as computers, TVs, automobiles, home appliances, cartridges and cameras (Krikke 1998).

For material suppliers, the strategic priority in managing the return flows evolves around cost efficient collection and recycling of materials and the attainment of scale economies. Some of the supply decisions, which require coordination with the reverse flows, are: capacity choices of virgin and recycled materials, degree of material recyclability and the pricing of the recycled and virgin materials (Martin 1982).

Cost-efficient reverse logistics is a strategic priority for product manufacturers in particular for products, which cannot be recovered in other forms of reuse. For instance, several car manufacturers have recently set up joint ventures with dismantlers to recycle the end-of-life cars in the most cost efficient way (Automotive News 2000). Since the cost efficiency of the recovery operations depends on the scale of the return flows, an important decision has been finding the right incentive schemes to stimulate the reverse flows from the end users. In this respect, the manufacturer faces the challenge of setting *the right salvage value* for used products, which reveals the consumer's valuations in a costless manner and avoids products ending up in other distribution channels (Purohit and Staelin 1994). The pricing decision of the salvage products also has implications for pricing decisions in forward channel. Several marketing papers have addressed this issue in the context of used cars (Levinthal and Purohit 1989).

Retailer Returns of Short Life-Cycle Products (Retailers/Distributors - Manufacturers)

For seasonal products with uncertain demand, allowances for product returns from retailers/distributors to manufacturers have been a popular means of improving coordination in forward supply chains. Research shows that return policies can improve supply chain efficiency by freeing the channel of obsolescent products, by reducing the cost of lost sales due to under stocking decisions by the retailers and by increasing the competitive strategic interaction at the retail level (Padmanabhan and Png 1997). The type of contracts is called *buyback contracts*. The manufacturer has to determine the buyback price of a leftover unit as a fraction of the purchase price of the product (Pasternack 1985). The buyback contracts in the reverse channels lead to more cost efficient operations by reducing the risks for retailers associated with short lifecycle (fashion) products.

Reverse logistics activities can also be a means to improve competitiveness of the product in the market by enhancing its value to consumers. Rather than being a means to reduce supply chain costs, reverse flows can lead to increases in demand as well. Here are some examples of such value creation.

Retail Return Allowances (Consumer - Retailer)

Most manufacturers and retailers have liberalized their return policies from consumers due to competitive pressure. The main drive has been to provide higher product value and to increase switching cost of consumers between suppliers. For several products, retailers can agree to take back merchandise at no cost to the consumers with or without replacement of a new product. One of the difficulties of managing this type of returns is the difference between the objectives of the manufacturers and the retailers. When the retailer wants to return an item, the two parties can disagree on the condition of the item, value of the item and the timeliness of the response. In most cases, the manufacturer or the distributor does not allow the retailers to return items and instead they give the retailer or the downstream partner a certain amount of *return allowance credit* and guidelines for proper disposal of the product. The main benefit of such a contract is that the manufacturer does not incur the handling costs of the returns. On the other hand, a disadvantage associated with this approach is that the products can end up in other distribution channels, which cannibalize the original product. The return allowance credits are sometimes subject to *ex-post* renegotiation of the contract if the retailer has sufficient channel power and the returns exceed the cap suggested by the manufacturer in the ex-ante contract.

Trade-In Offers and Product Acquisition (Consumer to Distributor/Manufacturer)

Manufacturers such as Dell, Xerox, HP or Compaq frequently use trade-in programs to stimulate new product sales by providing cost effective replacement options to their customers. Trade-in offers are also popular for white goods and automobiles. A trade-in offer includes a rebate for the old product and in some cases an upgrade price for the new product. The customer can trade in either the manufacturer's own product or a product of a different manufacturer, as long as it is in sufficiently good condition. The used product that is returned to the manufacturer can be disposed, recycled or remanufactured depending on the product's condition. Research in economics looks into how trade-in offers can be used as a price discrimination mechanism for first and repeat buyers (Van Ackere and Reyniers 1993, 1995). Fudenberg and Tirole (1998) present a detailed analysis of trade-in offers in a monopoly market with and without second-hand markets. The paper shows that the rental outcome can be replicated with a trade-in offer. Several issues associated with this type of product returns remain open for study, such as: who in the channel should set the trade-in offer? How should the trade-in offer account for uncertainty in the product's condition? How do trade-ins affect the competition in the market?

Warranty Claims (Retailer to Manufacturer/Supplier)

A warranty is a contractual obligation incurred by a manufacturer (vendor or seller) in connection with the sale of a product. In broad terms the purpose of the warranty is to establish liability in the event of a premature failure of an item or the inability of the item to perform its intended function. Producers, to increase market demand and to enhance product reputation, mostly use warranties as a marketing tool. However, the cost consequences have been more severe than marketing gains. In particular, in the auto industry and in electronics, warranty claims constitute a large part of the product life cycle costs.

	Types of Reverse Logistics Activities	**Decisions Involved**

COST REDUCTION	• Environmental Product Take-Back • Buybacks for Short Life Cycle Products	• Capacity Choice • Product Pricing • Information Sharing • Product Introduction Timing
PRODUCT VALUE CREATION	• Return Allowances • Trade-In Offers • Warranty Claims	• Used-Product Pricing • Information Acquisition and Sharing • Quality Choice

Table 1: Supply Chain Implications of Reverse Logistics Activities

Aspects of supply chains, which require coordination in closed-loop supply chains

We have seen that reverse logistics can occur both for cost-efficiency reasons and to increase the product's value to customers. To analyze the role of contracting and coordination in managing such reverse flows, we now turn to several key lessons, which have emerged from existing supply-chain literature. The basic premise is, in many cases, that coordination is beneficial for the entire supply chain. Ideally, coordination should occur for all activities throughout the supply chain, from product design through manufacturing, logistics, marketing, managing return flows, and recycling or disposal. In this section, we review the various aspects of supply chains, which require coordination and the lessons that emerge from existing literature in each of these areas.

The literature on supply-chain management frequently emphasizes the existence of three key flows, each of which can occur in forward and reverse directions:

- flows of physical goods, typically from upstream to downstream, but increasingly including reverse flows;
- flows of information, about inventories, demands, forecasts, etc;
- flows of money, representing purchase or lease payments, buyback agreements, etc.

Understanding and managing each of these flows is important to supply chain success. Clearly, there are interactions between them, and the notion of "coordination" of supply chains typically requires managing all three flows at once. For instance, changing the financial flow in order to accelerate the information flow in order to improve the physical flow.

In this section, we identify the various aspects of each of these flows that require coordination and the types of contracts that are or could be used to enhance that coordination. In the next section we discuss learnings from the supply-chain management literature on each of these coordination issues.

Physical flows

Broadly speaking, coordination of physical flows requires agreeing on quantities, timing, and place of product deliveries. In closed-loop supply chains, forward physical flows now generally induce future reverse physical flows, for which the same coordination issues arise. In both cases, availability of appropriate capacity levels for manufacturing, disassembly, remanufacturing, transportation, collection, etc, also needs to be coordinated upon. Several aspects of product design itself can also require coordination between parties in the system: for instance, the number of reuse cycles for which the product is designed (Geyer and Van Wassenhove 2000), or when product design affects ease of remanufacturing.

Information flows

The information flows required in supply chains are manifold, including short-term and long-term demand forecasts, actual orders, inventory availability throughout the system, etc. In closed-loop supply chains, information about quantities, timing and quality of returns is also useful in coordinating. Increasingly, as a result of producer responsibility laws and product stewardship actions, information about use and disposal of products also needs to flow between all parties in the system, and even to external parties such as consumer groups and regulatory agencies.

Financial flows

Financial flows consist of purchase price, lease payments, service payments, etc, but, in the case of closed-loop supply chains, also include buyback clauses, disposal costs, and other end-of-use costs. While pricing for the original product is relatively straightforward, designing contracts specifying conditions under which the product will be taken back after use is more challenging, as the quality of the product is unknown and often difficult to observe. Yet, as Guide and Van Wassenhove (2001) argue, appropriate financial incentives are an important way of managing the physical return flow.

Lessons from literature on forward supply chains and interaction with reverse supply chains

Perhaps the most important general lesson that can be drawn from the supply-chain management literature is that all three flows (physical, information, and financial) must be managed in conjunction with one another to obtain the desired performance. In this section, we examine some specific instances of such interaction between these three flows: we summarize prescriptions from existing literature on how contracts can be used to improve the interaction between the three flows, how these lessons can be extrapolated to reverse flows, and how the combined presence of forward and reverse flows affects the received wisdom in the field. It is obviously not our intention to provide a complete review of the literature on supply-chain contracting; for that, see for instance Tsay, Nahmias and Agrawal (1999).

The basic premise in most cases is that coordination is beneficial for the entire supply chain. However, there are many reasons in practice why such coordination may be hard to achieve. In this section, we review the obstacles standing in the way of achieving coordination, and the recommendations that have been made to overcome these obstacles.

Aligning incentives

Incentive conflicts can take many forms. Below we review some of the most common occurrences: pricing, inventory decisions, capacity planning, investments in process improvement, and the effects of competition.

Pricing: perhaps the most common incentive problem in supply chains is that known as "double marginalization" (Tirole 1988), referring to the situation where a manufacturer sells a product to a retailer who then sells to a final market. Both manufacturer and retailer add a markup to their sales price (the double margin), causing the final price to be higher and final demand to be lower than would be the case if both firms were vertically integrated. A simple solution to the double marginalization problem is to allow two-part pricing. If the manufacturer can charge a fixed fee (such as a franchise fee), he will set his wholesale price equal to his marginal cost, hence increasing demand, and will set the franchise fee high enough to recoup his profits. Corbett and Tang (1999) show how such more flexible contracts can indeed lead to better coordination, even when the manufacturer does not know the retailer's cost structure.

Many other incentive problems are similar in nature. Cachon and Lariviére (2000) study reusable products, such as videotapes for rental, and show how reducing the price at which the tape is sold to the rental store will induce the rental store to stock more tapes, hence increasing rental income for both parties.

A recurrent pricing issue in reverse flows is the use of buyback contracts, as discussed earlier. One consequence of the double marginalization effect is that retailers will hold less safety stock than optimal (assuming that stockout penalties exceed holding costs) when demand is uncertain; to overcome this, Pasternack (1985) and others have shown how buyback contracts can help retailers overcome their fear of over-ordering.

Closed-loop supply chains often consist of even more parties, hence further increasing the scope for double marginalization or related effects. However, it also introduces mechanisms for more flexible pricing without having to resort to two-part or more complex pricing schemes. For instance, Savaskan (2000) shows that the presence of a reverse channel can in fact eliminate the double marginalization problem in the forward channel. In a related study, Savaskan (2000) also shows that a manufacturer can use the payments in the reverse flows to price discriminate between retail outlets with different market sizes.

Inventory control: incentive problems also occur in inventory management, such as lot sizing or safety stock decisions. Cachon and Zipkin (1999) show how a manufacturer and a retailer setting inventory levels independently will generally not achieve the system optimal outcome. They also show that tracking inventory in a more appropriate way (using echelon inventory rather than local inventory) brings them closer to the system optimal outcome, and that simple linear transfer payments can lead to full coordination. Corbett and de Groote (2000) and Corbett (2001) show how lot sizing and safety stock decisions can be suboptimal if the party making the decision does not internalize all associated costs; they also conclude that appropriate assignments of ownership and corresponding costs of inventory (eg. implementing consignment stock or not) can improve coordination.

Capacity planning: similar problems arise here as for inventory control, but with potentially even more serious consequences given the strategic nature of capacity decisions. Capacity is often built on the basis of long-term demand forecasts; these forecasts however are often generated for other reasons and need not be realistic, especially when the forecasters are not penalized for inaccurate (over optimistic) forecasts. Porteus and Whang (1991) show how contracts can be used to provide marketing managers with the incentive to forecast accurately and to exert the right amount of sales effort, and to provide manufacturing managers with the incentive to build the right amount of capacity. However, they also show that no "budget-neutral" scheme exists[1].

[1] Budget neutral means that the principal (ie. the owner of the firm) can implement the policy without spending extra money, i.e. the bonuses and penalties exactly cancel out, so the owner's budget is not affected.

The existing capacity planning models focus on conventional supply chain settings on the basis of long-term demand forecasts. In product markets where commercial returns are a large percentage of sales, capacity planning models should include not only the forecasts of sales but also of return flows

Process improvement: all parties can exert effort to improve the system, but, as before, generally do not internalize the full benefits of such improvements. A familiar problem in the economics literature is the "moral hazard" problem (see e.g. Holmström 1979), in which a principal obtains value from an agent's efforts, but cannot observe that agent's efforts directly and hence can only reward the agent based on indirect measures such as output. If the agent is risk averse, the system optimal outcome can be achieved simply by "selling the firm" to the agent, i.e., letting the agent incur all variable costs and benefits resulting from his effort, in exchange for a fixed fee paid to (or by) the principal.

What happens, though, if both supplier and customer can exert effort to achieve such improvements? Corbett and DeCroix (2001) study the case of suppliers of indirect materials such as solvents or other chemicals used in customers' processes but which do not become part of the final product. The customer wants to minimize usage of such chemicals, which is also desirable from a system-wide perspective, but the supplier will obviously not cooperate with such efforts as long as his profits depend on the volume of chemicals sold. Again, moving to a two-part contract (with a fixed component and a component that depends on volume) can improve coordination within the system, but can never lead to the system-wide optimal outcome. This is known as the double moral hazard problem (see Bhattacharyya and Lafontaine 1995, Kim and Wang 1998), and it has been shown that a contract, which is linear in consumption, is optimal for the supplier (Corbett, DeCroix and Ha 2001).

Competition: the role of competition in increasing efficiency of transactions is often ambiguous. On the one hand, allowing multiple suppliers to compete will generally lower the procurement price for the buyer. On the other hand, the literature has also frequently pointed out the importance of building more stable supply-chain relationships. Long-term relationships can approximate the vertically integrated outcome, which may yield larger benefits than the short-term benefits of allowing competition (Corbett and Karmarkar 2001).

In the reverse logistics context, Savaskan (2000) shows that when the retail outlets perform product take-back, the buyback payments from the manufacturers to the retailers can induce more intense competitive interaction between the retail outlets. Majumder and Groenevelt (2000) examine how third party remanufacturing can induce competitive behavior when the recycled products can cannibalize the demand for the original product.

Conclusion: the well-established general recommendation in designing supply-chain incentive mechanisms is to attempt to make all parties internalize the full system-wide costs and benefits associated with their decisions. This requires the ability to offer more complex contracts than pure spot-market volume-based agreements. This could include two-part tariffs instead of simple linear prices, or even more complicated "menus" of contracts from which the other party can choose the most appropriate. The presence of multiple flows of goods, for instance a forward and a reverse flow, can in itself be used as a way to implement more sophisticated contracts.

Perfect coordination through contracting is rarely possible in practice. Several common conditions will immediately lead to the coordinated outcomes being suboptimal from a system-wide perspective:

- If the party designing the contract (the principal) does not have full information about the other party (the agent).
- If the same contract must be offered to different agents without being able to perfectly price-discriminate between them.
- If the agent is risk-averse.
- If effort exerted by both parties (principal and agent) can influence the outcome.

Whenever any of these conditions are present, it may still be possible to implement the system-wide optimum, but the contracts required to achieve that would not be optimal from the principal's perspective.

Information sharing

The notion that sharing information can lead to more efficient outcomes for an entire supply chain is intuitively clear. However, there are often many obstacles to full sharing of information. The technological hurdles are increasingly being overcome, but for many parties, information (for instance, about final market demand) still conveys power. Below we identify several different types of information and the ways in which sharing them can improve coordination within a supply chain.

Demand information: the distortion of final market demand as one moves further upstream is well-documented, and often referred to as the "bullwhip effect". The central notion is that, in any system where variability (or uncertainty) is combined with delayed response, amplification will occur. In the context of supply chains, this means that demand uncertainty coupled with a positive lead time to respond to changes in demand will cause those changes to be amplified further upstream. Lee, Padmanabhan and Whang (1997a,b) identify several main causes of this bullwhip effect, including:

- updating of forecasts based on customer orders rather than final market information;
- batching of orders, for instance due to transportation economies or fixed order costs;
- pricing variability, for instance that caused by periodic promotions;
- shortage gaming, for instance when limited capacity is allocated based on customer orders rather than true final market demand.

Another cause of amplification was identified in Corbett, Blackburn and Van Wassenhove (1999), who observed how total weekly order quantities were allocated in a seemingly random fashion between multiple suppliers, who therefore perceive much higher demand variability than is actually present in the final downstream market. Chen et al. (2000) demonstrate that centralizing all demand information does indeed reduce the severity of the bullwhip effect. Lee, So and Tang (2000) find similar results, especially when demands over time display significant positive correlation. By contrast, Cachon and Fisher (2000) find that the value of sharing demand information can be quite small, and that the main benefit from using information technology lies in accelerating physical flows rather than expanding information flows.

Sharing information about longer-term demand forecasts is also important. Porteus and Whang (1991) study the case where marketing and manufacturing managers need to coordinate capacity plans based on demand forecasts. Without putting the appropriate contracts in place, the marketing managers will have an incentive to exaggerate demand forecasts in order to avoid stockouts, potentially saddling the manufacturing managers with excess capacity. Porteus and Whang (1991) show that the owner of the firm can induce the marketing and manufacturing managers to take the optimal decisions, but that the owner cannot do so in a budget-neutral way. Cachon and Larivière (1999) examine the case of a supplier building capacity based on a customer's demand forecasts. They study a range of different supply contracts, and analyze which ones will lead the customer to forecast accurately. In their setting, firm commitments are not desirable for aligning incentives, but do convey information about the customer's demand expectations.

Inventory information: several authors have identified the importance of allocating inventory holding costs appropriately to all parties in a multi-echelon system. Clark and Scarf's (1960) original decomposition scheme for a two-echelon system already relied on making each party bear the holding costs associated with his "echelon" inventory, i.e. the inventory at that party's level and all levels downstream from there, where the holding cost rate is the value-added at that party's level. Cachon and Zipkin (1999), Lee and Whang (1999) and Chen (1998, 1999) provide further analyses of systems based on echelon inventories rather than physical (or "installation" inventory levels). Most of these policies therefore require each party to have full visibility of inventories at all levels in the system; Lee and Whang (1999) propose a system which can be operated with only locally available information (but which requires a central planner to design it), and Chen (1999) suggests a scheme based on "accounting inventory levels" which also allows decentralized control of the system, even when there are information delays. Chen (1998) finds that the optimal inventory policy based on installation inventory levels (hence using local information only) performs only slightly worse (between 0% to 9%) than the optimal policy based on echelon inventory levels.

Manufacturing systems with product returns have several unique operational characteristics, which make existing models of inventory control insufficient for these environments. These characteristics are: two exogeneous supply sources, time dependent availability of the remanufacturing source and stochastic manufacturing lead times. Van der Laan et al. (1998) develop both continuous and discrete time models of inventory control for hybrid systems with and without disposal of returned units. They model the uncertainy using a Coxian – 2 arrival process for used products and correlation between return and demand patterns. The information structure in this case is exogeneous to their model. Scenario analyses are provided to determine the effect of system parameters on the optimal inventory control policy. At a supply chain level, Toktay et al. (2001) develop joint forecasting and inventory control to determine the optimal procurement policy of a remanufacturable product. In their analysis the information structure is made endogenous to the problem formulation and is updated during the planning horizon.

As highlighted in the current research most of the complexity in reverse logistics comes from the inability to forecast product return patterns. In an exploratory study Kokkinaki et al. (2001) discuss the use of electronic marketplaces, which facilitate returns from end users and reduce the uncertainty in the timing and the quality of the product returns. Pooling and transaction cost benefits arise from using electronic markets for reverse logistics. There is a need to understand the exact benefits and the pricing mechanisms in these market environments for used products. The findings would certainly be useful to address issues related to design of reverse logistics systems.

<u>Other information</u>: many of the types of contract discussed earlier ideally require one party to have full information about all relevant parameters, such as both parties' cost structure. For instance, in Porteus and Whang (1991), marketing managers have private

information about demand, so the owner of the firm must give them an appropriate incentive in order to reveal that information truthfully. Corbett (2001) examines cases where one party has private information about stock out costs or holding costs. Both papers conclude that such private information leads to inefficiencies in the system. A central planner with full information would be able to avoid such inefficiencies. In the absence of such a central planner, it is clear why many parties in practice are extremely reluctant to share certain types of information, especially related to cost structures.

Such information asymmetries immediately arise in the case of closed-loop supply chains too. If collection and remanufacturing activities are outsourced to a third party, the original manufacturer will generally not know what the true costs are. A third-party subcontractor for remanufacturing has an incentive to overstate those costs, which would lead the original manufacturer to reduce the quantity of material remanufactured. Though arguments exist in favor of separating remanufacturing from the original manufacturer, the resulting information asymmetries will generally lead to efficiency losses in the reverse supply chain.

Supply chain structure

Supply chains are designed to meet various goals, depending on the product and market characteristics. Fisher (1997) characterizes two general types of products (functional vs. innovative), and two general types of supply chain (focused on cost and efficiency vs. focused on responsiveness). He argues that the supply chain structure should be aligned with the product/market characteristics. Intuitively, similar advice should carry over to the reverse side of a closed-loop supply chain. Virtually all supply chain design decisions come down to that basic distinction: how many layers should the supply chain have, who should the players be, what modes of transportation should they use, how should the network be designed and activities be allocated.

Interaction between product design and (reverse) logistics

Not only supply-chain design, but also product design, will affect the performance of a supply chain. This is well known, through examples such as the HP DeskJet (Lee et al. 1993): once the printer was redesigned to allow localization (ie., adding the country-specific power supply) at the local warehouse rather than in the central factory, inventories were reduced and logistics simplified. This same principle has been applied in many instances, under names such as "design for logistics", "postponement", "delayed differentiation", etc. Similarly, the notion of "design for disassembly" or "design for remanufacturing" or "design for environment" is increasingly well-established in the design world. For true closed-loop supply chains, one might expect both of these design concepts simultaneously to be important, which clearly requires coordination between the design teams, logistics parties (both forward and reverse), remanufacturers, etc.

Conclusions

Based on the current state of the literature on reverse logistics, we believe that there are two fundamental research questions that should constitute the basics of future research in this area.

- How can we use our learnings to date and the existing theory in forward supply chains to address issues faced in reverse logistics?
- How can the theory of reverse logistics help us improve our understanding of forward supply chain issues?

Because the forward supply-chain literature is more developed, we expect that many lessons from this area can be of value for closed-loop supply chains too, but the exact nature of the relationships between forward (or open-loop) and reverse (or closed-loop) supply chains still needs to be examined. For instance, with respect to pricing and demand management, we still need to understand better how lease terms and prices should be adapted for remanufacturable products such as copiers, taking into consideration the life cycle effects. What can economic theory tell us about the quality of remanufacturable goods, and how can we use this knowledge to improve the product acquisition process? Similarly, on the operational side, what can we say about the impact of uncertainty on a production line for recoverable products based on our understanding with JIT systems? How can we coordinate maintenance and remanufacturing decisions, in particular for high value products like medical systems? How do we decide on make/buy decisions in a reverse logistics context? What trade-offs exist if we allow third-party remanufacturing? What can transaction cost economics, agency theory or cooperative game theory tell us about the incentive issues in the reverse logistics channels?

The list of such research questions can easily be extended through critical thinking about reverse logistics as it relates to the overall supply chain strategy of a company. Hopefully this chapter will provide some food for thought in that direction.

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