Coordination in Closed-Loop Supply Chains

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An Introduction to Closed-Loop Supply Chains

1.1 Introduction

Against the background of scarce resources and increasing consumption worldwide, the awareness and realization of product reuse are essential. This is reflected not only by the increased environmental awareness of customers but also by the legislative pressure to develop environmentally friendly products and processes. However, taking back products can also be seen as a chance for companies to gain additional economic benefits instead of only a burden. Due to the reuse of materials or components obtained from returned products, money can be saved. Furthermore, giving used products a second life offers companies the chance to earn additional profits by entering new markets. Accordingly, the consideration of reverse product flows can be separated into the waste-stream and the market-driven perspectives (Guide and Van Wassenhove, 2001, 2009). From a waste-stream perspective, companies passively accept the return of products and try to conduct reprocessing activities at the minimum costs. From a market-driven perspective, in contrast, companies strive to maximize their profits by remarketing reprocessed returns. This research project draws on and contributes to the value-added perspective.

The chosen focus on the value-added stream is driven by the fact that nowadays more and more products with remaining value are being returned. The management of these return flows represents an opportunity to obtain additional benefits that should not be disregarded. For example, hardly used consumer returns in the electronics sector increased by 21% from 2007 to 2011 (Bower and Maxham, 2012). This development is attributed to the increasing importance of e-commerce, a trend that is expected to grow further. In Germany alone, e-commerce sales of physical goods increased from € 18.3 billion in 2010 to € 39.1 billion in 2013 (Bundesverband E-Commerce und Versandhandel Deutschland, 2013). Another type of returns is so-called end-of-use returns: products that have lost their value for a certain customer segment but are still functional and may be of use to another customer segment. This phenomenon is especially observed in fast-moving industries with short product life cycles, such as the IT sector. These return types are of course not new, but due to the given market developments, they require special attention nowadays. As both kinds of product returns are still of value, these return flows should not be seen only as a cost factor. On the contrary, the returned units should be seen as an opportunity to generate additional profits.

In the literature, the consideration of reverse flows started in the late 1990s. The first focus was on operational issues, such as the disassembly of returned products. The research centered on one actor optimizing one reverse flow activity. Since then, research in this field has evolved towards a more process-oriented perspective. This means that no longer is only one activity considered exclusively, but the interaction of several activities along the reverse supply chain (SC) is considered. Consequently, no longer does only one actor need to be taken into account, but potentially multiple, independent actors. In the last years, the scope has been further extended to a holistic perspective. Not only reverse but forward and reverse SC processes are considered jointly. Due to this, the traditional forward SC is extended by the reverse flow of products and information as well as by financial flows. Therefore, in addition to the members of a traditional SC, actors are required that are responsible for reverse-flow-specific processes like collection, grading and disposition, reprocessing, and reselling. These processes can be conducted by traditional SC members, as well as by new parties.

One of the major challenges in Supply Chain Management (SCM) is to match supply with demand. According to Tsay et al. (1999), SC-wide optimality is achievable if all the decisions are made by a single decision maker who has access to all the available information. Usually the outcome of such centralized decision making is used as a benchmark that can be achieved by the coordination of SCs. To achieve coordination, explicit decisions need to be made by the actors involved. Unfortunately, these decisions often do not comply with the actors' own objectives. Additionally, actors require certain information to be able to make the necessary decisions. Unlike the case of a centralized decision maker, not all the actors in a common SC have access to all the available information. Both unaligned incentives of the involved actors and information asymmetry are known to be major obstacles to SC coordination (e.g. Cachon, 2003; Chen, 2003).

The challenge to match supply with demand needs to be faced in a Closed-Loop Supply Chain (CLSC) as well. Similar to the situation in a traditional forward SC, it can be expected that information and know-how are scattered between various members of a CLSC. Furthermore, actors have their own incentives, and decision making is usually decentralized. In comparison with traditional SCM, further complicating factors need to be considered. First is the heterogeneity of the returned products and the resulting increased uncertainty with respect to the supply side. The heterogeneity and uncertainty of the supplies originate from the usage phase of the customer, during which only little or no information is transmitted to other CLSC actors. Second, according to Guide and Van Wassenhove (2009), the complexity with regard to "designing, managing and controlling CLSCs" (p.12) increases due to the number of actors involved.

Consequently, the consideration of decentralized CLSCs raises several, consecutive questions that we want to address in this thesis:

1. **What are the potential coordination needs in a CLSC environment?**

2. **What are the appropriate coordination mechanisms?**

The following section provides an introduction to CLSC actors and the processes relevant to this thesis. Subsequently, an illustrative case is introduced (Section 1.3). Based on the learnings taken from the business case, we state the more explicit research questions for this thesis in Section 1.4. We close this chapter with an outline of the thesis (Section 1.5).

1.2 Closed-Loop Supply Chain Processes and Actors

In a CLSC setting, the traditional forward SC is extended by the reverse flow of products and information as well as by financial flows. The main processes of such a CLSC are depicted in Figure 1.1.

We consider a forward SC consisting of three major processes: a product needs to be developed and designed, produced, and finally delivered to the customers via various distribution channels. The end point of the forward SC is the customers' acquisition and use of the product.

The reverse flow of products starts with the customers' decision to return their products. These products are acquired by the reverse SC and need to be collected.

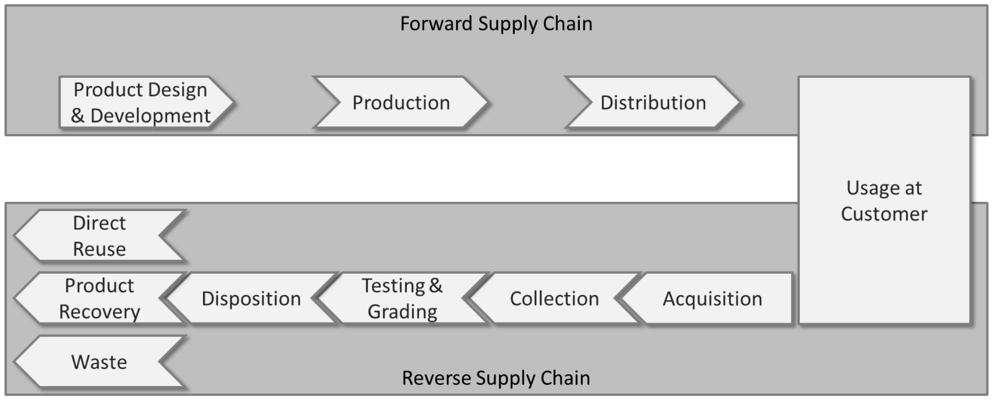


Figure 1.1: Common Closed-Loop Supply Chain Processes

Collection can be designed in multiple ways: directly from the customer, from collection points such as retailers, or via mail services (Aras et al., 2010). During the usage phase, customers handle their products in various ways. This is why the condition of returned products - and thus the quality of reverse SC supplies - is particularly heterogeneous. This makes the testing and grading of returned products necessary to obtain quality information. Depending on the reverse logistics network design, these processes are conducted either before or after the products are transported to the reprocessing facility. While the advantage of the first, decentralized option is that transportation costs for worthless products can be saved, it is accompanied by the implementation costs of decentralized grading resources (Fleischmann et al., 2000). Based on the grading outcome, what to do with a product of a given quality has to be determined - that is, the disposition decision has to be made. A common categorization of the available reprocessing options was introduced by Thierry et al. (1995). They distinguish three groups of disposition options: direct reuse, product recovery, and waste. Depending on the chosen disposition option, reprocessed products are reintroduced into the forward SC on a product, component, or material level or discarded.

These additional processes of the reverse SC are conducted by the Original Equipment Manufacturer (OEM), retailers, or third parties (Fleischmann et al., 1997). This has two impacts. First, potentially there are more parties involved in CLSCs than in traditional SCs, which increases the complexity involved in managing CLSCs efficiently (Guide and Van Wassenhove, 2009). Second, the possibility to integrate forward and reverse SC processes is limited (Fleischmann et al., 1997).

Furthermore, customers take an important role by linking the forward and the reverse SC. They no longer represent the demand side only, but additionally act as suppliers. As the users of the products that are potentially returned, customers are the origin of the most frequently mentioned challenging characteristic of reverse flows: the uncertainty with regard to the quality, quantity, and timing of product returns, the supply of reverse SCs (Guide and Van Wassenhove, 2009).

1.3 Reverse Logistics at SC Service Group: An Illustrative Case

To highlight the relevance of coordination aspects in a CLSC context, we present an illustrative case. In particular, material is presented that is based on a master thesis project in collaboration with an Asset Recovery Center of the SC Service Group[1] located in Germany (Tschan, 2011). The Asset Recovery Center is part of the Contract Logistics division of SC Service Group.

In the following, we first provide information on the SC Service Group and the Asset Recovery Center. Afterwards, the considered reverse SC of which the Asset Recovery Center is part, is described in more detail. This includes an introduction to the actors involved in the SC as well as a description of the current reverse flows.

1.3.1 SC Service Group

Organizationally, the Asset Recovery Center (ARC in the following) belongs to Contract Logistics, which is one of five divisions of the SC Service Group. SC Service Group describes itself as a global multimodal provider offering end-to-end solutions for diverse industry sectors. In 120 different countries, SC Service Group has 30,000 employees, of whom 8,500 belong to Contract Logistics. This division is responsible for 18% of the group revenue and operates 3,000,000 m^2 of logistics surface area at 170 sites in Europe. It is a worldwide operating player that offers its customers reliability, flexibility, and agile flow management as key factors in its competitiveness.

Among other services, Contract Logistics offers reverse logistics activities. The reverse logistics services provided can be clustered into three main tasks: collection, reprocessing, and reporting. One of the seven European technical centers responsible for reverse logistics services is the ARC, which we present here in more detail.

Besides general logistics activities, the focus in the regarded location is on reverse logistics activities - a focus that has grown historically. SC Service Group has been active in Germany since the late 90s, the period in which a strategic partnership with an OEM of IT hardware was established. A reverse logistics contract was added

[1]Company name changed by the author

to this partnership four years later. The contract covered the returns handling and dismantling of desktop PCs in Europe at the end of their leasing duration. Since 2009, the ARC has been a Microsoft Authorized Refurbisher, which means that this facility is allowed to install the operating system Windows on recovered desktop PCs.

Originally, the ARC was located on the OEM's site. To develop its high-tech sector further, the company recently opened a new facility. The newly opened recovery center has about 21,000 m^2 of storage space and satisfies the highest security standards. ARC's workforce of about 200 employees offers services ranging from collection, data wiping, recovery, and remarketing over dismantling for spare parts to recycling. Due to certified process standards, both compliance with environmental regulations and data security can be ensured. Services are not offered exclusively to OEMs but also to other customers, such as independent leasing companies. Furthermore, the portfolio of returned products has expanded over the years. Now, besides desktop PCs, end-of-lease returns include notebooks, screens, printers, and servers.

The IT hardware sector is often the focus of reverse logistics research for several reasons. First is the economic perspective. The IT hardware sector is characterized by price competition, short product life cycles due to increasing innovation speed, and the usage of scarce resources. As technology allows for the reuse of products as a whole or their components on the one hand and IT hardware contains valuable elements such as rare earth metals on the other hand, reverse product flows have become increasingly attractive. Furthermore, the need for the establishment of reverse SCs in the IT sector is fostered by legislation as well as customer expectations of sustainability.

1.3.2 The Asset Recovery Center and its Reverse Supply Chain

Let us now turn to the considered reverse SC and the description of reverse flows. We organize our description analogous to a framework introduced by Guide and Van Wassenhove (2009). In order to structure reverse SC activities and to show interdependencies, the authors introduce the process flow perspective and identify three subprocesses of reverse SCs:

1. *Front End*, meaning the supply of returned products,

2. *Engine*, meaning reprocessing activities,

3. *Back End*, meaning the remarketing of reprocessed products.

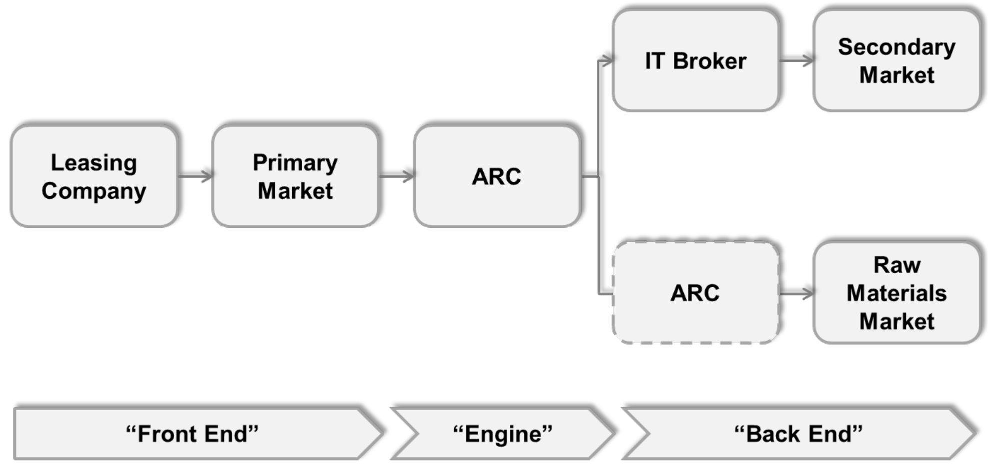


Figure 1.2: Physical Flows of Leased IT Equipment and Actors Involved

In our case, the actors involved are assigned to the subprocesses as follows (cf. Figure 1.2). ARC acts as a service provider offering reprocessing services and therefore represents the reverse SC's *Engine*. ARC is commissioned by companies to conduct the required reprocessing activities. Here, we talk about end-of-lease IT hardware that needs to be reprocessed. Both the companies leasing IT hardware to the primary market and the primary market users belong to the *Front End* as they supply ARC with returned products. Reprocessed units need to be resold. In the considered reverse SC, IT brokers are responsible for remarketing activities of reusable products. Raw materials are resold to the raw materials market directly by ARC. Thus, the *Back End* is represented by ARC, IT brokers, the secondary market, and the raw materials market.

We now address each of the three above subprocesses in more detail. OEMs or independent leasing companies lease IT hardware to their customers. The leasing of IT hardware is a common business concept, especially in the case of business customers. From the lessor's perspective, leasing provides the advantage of extending a product's life due to successive leasing or reselling of returned units. Another advantage for lessors can be seen in the possibility of establishing close relationships with customers, which preferably result in subsequent deals. On the downside, lessors have to consider technological obsolescence and thus loss in value of the original products. Customers may benefit from leasing due to the flexibility obtained to update equipment frequently and for accounting purposes. At the end of the determined leasing duration, the lessor commissions ARC with collection and reprocessing activities. The ownership of the returned products remains with the lessor, and ARC acts as a service provider.

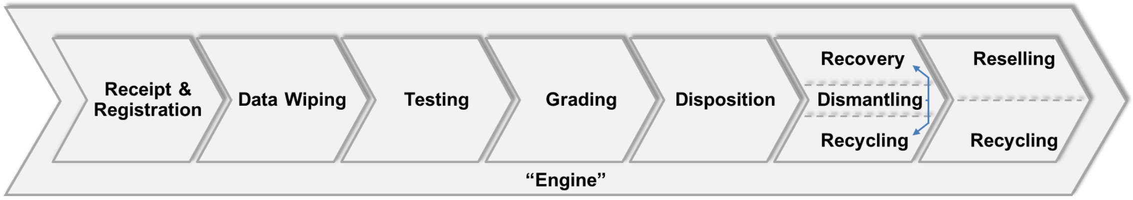


Figure 1.3: Process Steps at the Asset Recovery Center

According to the requirements of ARC, the transportation of returned units from primary customers to ARC should not take longer than five days, starting on the day when ARC receives the mandate. The primary customers are spread all over Europe, the Middle East, and Africa. To collect end-of-lease IT equipment, ARC distinguishes two collection concepts. Either it is collected directly from primary customers' location or customers take their end-of-lease units to a central collection point, from which ARC picks them up. Besides transportation, collection services include all the organizational issues and the supply of the required containers. ARC receives about 450,000 units annually from 33 different countries.

The process steps conducted by ARC are shown in Figure 1.3. All the processes that are described in the following in more detail are certified by different DIN ISO certificates.

Once products arrive at ARC, the serial numbers as well as product and model types are registered in a SAP system. Furthermore, TÜV SÜD certified irreversible data wiping is conducted, and everything that may allow the identification of former users is removed. Subsequently, returned products are tested by means of special software on operability and configuration. Based on the outcome of the testing procedure, the returned products are sorted into different input quality classes. ARC schedules two days to complete these processes (registration, data wiping, testing, grading) for a whole batch that arrives at its facility.

Next, ARC makes the disposition decision. On a high level one can distinguish three disposition options:

- Recovery
- Dismantling for spare parts
- Recycling

The disposition decision is based on the payments received for reprocessing activities and the costs, which depend on the both condition of the returns and the disposition option. About 80% of the returned products that arrive at ARC are worth recovering and reselling on the secondary market. In the case of recovery, input-quality-dependent reprocessing steps are conducted to bring the returns to an output quality level that can be resold. ARC distinguishes different output quality levels, for example depending on the technology standard. The required recovery activities include cleaning, repair, installation of software, asset upgrading, and packing. To conduct recovery activities, ARC schedules a total of five days for the completion of one batch.

On behalf of its customers, ARC sells recovered IT equipment to an established group of IT brokers, who are then responsible for remarketing activities. Reprocessed products are sold in batches, rather than in individual units. When creating these batches, several aspects need to be considered. Brokers are interested in batches that include many homogeneous products. This is due to the savings in transportation costs as well as the experience that homogeneous batches can be sold more easily to secondary customers. From the seller's perspective, the depreciation of recovered units during the waiting time to achieve a certain amount of products needs to be considered. Furthermore, the broker's reselling network and its saturation need to be taken into account when thinking of the amounts within a batch. Currently, ARC arranges fixed prices for certain output quality levels with the brokers with whom they usually work. Commonly, the batches include about 200 units. Furthermore, it is ensured that all the recovered equipment is bought by one of the brokers in ARC's network.

If a given return is not worth recovering, it is dismantled and the reusable parts are sorted out and stored. About 110,000 reusable parts, such as graphics cards or storage components, are obtained annually from dismantling. These reusable parts are used as spare parts in the recovery process. Everything else is recycled. In the case of ARC, this amounts to a volume of about 3.5 t per year. The composition of the materials actually included is not specified further.

We now turn to the back end of the reverse SC shown in Figure 1.2. Depending on the disposition decision and successive reprocessing activities, two redistribution channels are distinguished: reselling and recycling. We start with the reselling channel. As mentioned above, ARC uses authorized IT brokers instead of selling directly to secondary end customers. A common role of such IT brokers is to buy recovered equipment and resell it to the secondary market. Motivated by the decreasing margins that are achievable on the secondary market, lately, more and more IT brokers have extended their business portfolio. One method is to offer service packages including the installation of IT hardware and support issues. This represents an offer that is especially attractive to smaller companies that do not employ special IT staff. An alternative extension to the IT broker business is to conduct reprocessing services. Hence, they become direct competitors to reverse logistics service providers such as ARC.

Here, IT equipment is returned after the end of the leasing duration of usually three years. This results in considerable depreciation in the IT hardware sector, and reprocessed IT hardware cannot be sold "as new". According to Atasu et al. (2008), reprocessed products are attractive to the functional and green customer segments. While functional-oriented customers value the function of a product over its newness, the main driver of environmentally conscious customers to buy reprocessed products is waste reduction. Therefore, the focus is on functional and green customers. Furthermore, the market consists of private and business customers; in the case of the latter, the company size plays an additional role. According to ARC, the recovered units are resold exclusively to business customers by the IT brokers.

The recycling of materials represents the second redistribution channel. Products that are not worth recovering and their parts that cannot be used as spare parts are recycled. ARC sorts these components according to 83 different materials and sells them directly to the raw materials market. IT hardware contains valuable elements, such as gold, silver, and copper, as well as different rare earth metals. As the value of these materials is expected to increase in the future, the recycling of IT hardware is seen as a profitable option.

In this chapter, we introduced an example of a reverse SC for end-of-lease IT equipment by focusing on the reverse logistics service provider ARC. We provided an overview of how the processes work at ARC and how it is linked to other actors in the considered reverse SC.

Why does this setting attract our attention? First, the SC structure described extends the previous literature by specifically addressing the role of a service provider responsible for the reprocessing activities. Second, we consider a reverse SC consisting of multiple, independent decision makers. Therefore, the described business case represents an interesting basis on which to deduce the coordination needs in a CLSC context.

1.4 Identified Research Needs

In Section 1.3, we introduced a service provider responsible for reprocessing activities and the reverse SC of which this service provider is part. Due to the decentralized setting, we concluded that there is a necessity to analyze CLSCs with regard to potential coordination obstacles. The vast spectrum of decisions that may be considered in this context offers diverse research opportunities. Our choice for the focus of this thesis is inspired by the major distinction between traditional SCs and CLSCs: the heterogeneity of the supply side. The Heterogeneity of supplies originates from the customers and their usage and return behavior. Hence, the link to the customers represents one research project of this thesis. Further, the heterogeneity of the supplies make the choice of appropriate reprocessing activities a necessity for profitable reverse SCs. Thus, the disposition of returned products is another research project. Both aspects are of special interest as they are CLSC-specific, and therefore open up the possibility to provide new insights to the research on coordination in SCs.

The Case of the Disposition Decision

In the business case introduced, two actors are directly affected by the disposition decision: the lessor and ARC. Currently, the lessor pays ARC to conduct reprocessing services and receives the revenues that are achievable on the secondary and raw materials markets. These revenues in turn depend on the output quality level achieved. This means that the lessor's achievable revenues depend on ARC's disposition decision. As we face a decentralized SC, this raises the question of whether a coordination need exists with respect to the disposition decision.

This becomes even more interesting against the background of the distribution of information on returns. Due to the chosen business model to lease IT hardware to primary customers, the uncertainty with respect to the timing and quantity of returns is relatively limited. However, quality uncertainty remains. In the current setting, only primary customers and ARC have knowledge of the actual quality of returns. The lessor, who owns the products and has to pay for reprocessing services, is not able to observe the actual quality of its end-of-lease IT equipment. This is because end-of-lease units are transported from primary customers directly to ARC (cf. Figure 1.2).

While previous research on reverse or CLSC coordination needs focuses on the OEM perspective (Savaskan et al., 2004; Savaskan and Van Wassenhove, 2006; Atasu et al., 2013), the setting described here offers a new perspective that is becoming more and more important. The increasing importance is due to two major factors. First, companies focus on core competences, such as research and development, and outsource the actual production. Consequently, they often lose know-how and are not able to establish profitable reprocessing activities. Second, growing numbers of leasing companies that are not OEMs are entering the market. These companies are not involved in any production processes and therefore are not able to conduct reprocessing activities on their own. Therefore, the reverse SC structure observed in the business case is representative of other cases as well and worth addressing in greater detail. We investigate the coordination of the disposition decision in Chapter 3 and address the following research question:

How can the disposition decision be coordinated in the case of reverse SCs consisting of multiple, independent actors?

The Customer Interface

The first research focus is supported by the fact that the information asymmetry concerning the condition of returns may cause SC deficiency. As users of potential product returns, customers commonly have exclusive knowledge about the condition of products. Furthermore, end users have decision power regarding when to return a product, if they intend to return it at all.

The value of information on the aforementioned uncertainties present in CLSCs is analyzed by several authors (Ferrer, 2003; Ferrer and Ketzenberg, 2004; Ketzenberg et al., 2006; De Brito and Van der Laan, 2009). However, the focus of previous research, as well as the focus of industry practice, is on the operational aspects of CLSCs (Guide et al., 2003), which take these uncertainties as exogenous. Besides the market demand and technical feasibility of reprocessing activities, Geyer and Jackson (2004) and Guide and Van Wassenhove (2009) identify the limited access to supply and supply information as major obstacles to efficient reverse SCs. Since then, three different concepts (which we will introduce later on) to reduce supply uncertainty have been developed.

However, to the best of our knowledge, no research exists on customers and the effects of their decisions on CLSCs' process from a SC coordination perspective. To close this gap, we address the following research question in Chapter 4:

Taking a holistic CLSC perspective, what are the needs for coordination at the customer interface?

1.5 Outline of the Thesis

This thesis consists of five chapters. Chapter 1 represents the basis on which both the research aim of this thesis and the actual research questions addressed in subsequent chapters are motivated. In Chapter 2, we embed this research focus into the previous literature. An in-depth analysis of the identified coordination requirements is provided in Chapters 3 and 4. We conclude this thesis in Chapter 5 by recapitulating our results and pointing out future research directions. In the following, we summarize the content of these chapters in more detail.

Chapter 1 is composed of four parts. In our introductory section, we highlight the necessity to focus on decentralized CLSCs and the resulting research goals of this thesis are stated. Subsequently, we provide an overview of the actors involved in such a decentralized setting and the processes that are of relevance. The first contribution of this thesis is the introduction of the ARC business case. On the one hand, the case is a contribution to the literature itself, and on the other hand, we derive concrete research needs based on the decentralized setting.

Chapter 2 provides an overview of the previous research on coordination both in a forward SC context and in a CLSC context. Based on the comparison of managerial requirements observed in the business case and the academic literature, we identify gaps that are addressed within the further analysis chapters of this thesis.

In *Chapter 3*, the coordination of the reverse-SC-specific process step "disposition" is addressed. To this end, we compare the introduced business case setting with our benchmark, a central decision maker. We see that the current setting results in a suboptimal CLSC solution. To overcome this SC deficiency, we develop a coordinating mechanism. Beyond the analysis, we provide a numerical example to illustrate our insights.

CLSCs are characterized by heterogeneous supplies with respect to quality, quantity, and timing. The increase in supply uncertainty originates from the customer's use phase, which in many cases is a kind of "black box" for the other actors in CLSCs. In *Chapter 4*, we address customer decisions and identify the coordination needs resulting from these decisions. Furthermore, we discuss the adaptability of existing mechanisms to the coordination requirements at the customer interface.

Finally, in *Chapter 5*, we summarize our findings and present the directions for future research.

Chapter 2

Coordination of Multiple Decision Makers - Structuring the Field

In this chapter, the identified coordination issues considered in this thesis are embedded into the previous literature. Coordination has been studied extensively in traditional SCM; therefore, we start this review with an overview of the literature on coordination issues in the case of multiple, independent decision makers in forward SCs (Section 2.1). The aim is to provide an overview of the developed coordination mechanisms on which we can build in our analysis chapters (Chapters 3 and 4). Subsequently, we review the previous literature on coordination in CLSCs (Section 2.2) and highlight our contributions to this research stream.

2.1 Coordination in the Forward Supply Chain Literature

Unaligned incentives as well as information asymmetries of the parties involved in decentralized SCs are identified as major obstacles to efficient SCM. Therefore, coordination "is perceived as a prerequisite to integrate operations of supply chain entities to achieve common goals" (Arshinder et al., 2011, p.44). The goal of coordination commonly is to achieve SC-wide optimality with respect to profit maximization or cost reduction (Tsay et al., 1999). Coordination takes a central role in the management of SCs and spans multiple directions (Ballou et al., 2000). On the one hand, one has to distinguish between intra-organizational and inter-organizational coordination. While the first concerns the coordination of activities like logistics, accounting, and marketing within one organization, the latter concerns the coordination of legally independent organizations. On the other hand, one can distinguish between vertical and horizontal coordination - coordination along the SC or coordination between organizations at the same stage of the SC.

In the following, the mechanisms to achieve coordination are introduced. The mechanisms found in the previous literature address either settings in which coordination is hampered due to unaligned incentives (Section 2.1.1) or settings suffering from both unaligned incentives and information asymmetries (Section 2.1.2).

2.1.1 How to Coordinate Actions in Decentralized Supply Chains

To achieve optimal SC performance, certain actions are required. However, these SC optimal actions often conflict with actors' individual objectives. To match the individual objectives with the SC objective, contracts defining transfer payments have been introduced. In the following, we review the mechanisms coordinating the order decision in SCs with unaligned incentives, under the assumption that there is no information asymmetry between the actors involved. We close this section with an overview of the extensions to this basic setting.

Mechanisms to Achieve Supply Chain Optimal Order Quantities

In the most basic setting for which contracts are developed, two risk-neutral actors and a one-period time horizon are assumed: a single upstream party sells a product to a single downstream party, which faces the so-called newsvendor problem. In a newsvendor setting, the demand for a certain product is stochastic and only one ordering opportunity exists well in advance of the actual selling season. Products can be used to satisfy the demand of one selling season only. Thus, the trade-off between the risk of ordering too much and the risk of ordering too little has to be considered when determining the optimal order quantity. "Optimal" is hard to define here as the demand is uncertain. A usual performance measure is the expected profit.

The analyzed SC consists of a supplier and a retailer. In the basic setting, it is assumed that both actors have access to all the relevant information. Although common in practice, a wholesale price contract does not coordinate this setting due to double marginalization. Incentives are needed to make the retailer order the SC optimal quantity[1] q°. It is shown that this can be achieved by several contracts: buyback, revenue-sharing, quantity-flexibility, sales-rebate, and quantity-discount contracts. Cachon (2003) provides an excellent overview of SC coordination with contracts. The following introduction to the aforementioned contracts coordinating

[1]Notation is taken from Cachon (2003)

the basic setting is based on this commonly cited chapter. Thereby, we focus on the general, underlying mechanisms. For a more detailed analysis of contract structures, we refer the interested reader to Cachon (2003).

Buyback and revenue-sharing contracts are proven to be equivalent in the basic setting. Under a *buyback contract*, the supplier charges a wholesale price w_b per unit, but additionally a second parameter is part of the contract: a certain amount b is paid per unsold unit at the end of the selling season, with $b \leq w_b$. Applying a *revenue-sharing contract* results in a reduced wholesale price $w_r \leq w$. In addition to the wholesale price, the retailer pays an agreed fraction $1 - \phi$ of his achieved revenue to his supplier. Hence, in both cases, the retailer is refunded in the case that the actual demand is below the ordered quantity, a mechanism that (Cachon, 2003, p.255) refers to as "downside protection".

A *quantity-flexibility contract* also works by the "downside protection" mechanism. However, the structure differs from the aforementioned contracts. A quantity-flexibility contract consists of two components: the wholesale price w_q, which is charged for each ordered unit, and a refund, which the retailer receives at the end of the selling season according to the following scheme: $(w_q + c_r - \text{salvage value}) * \min\{\text{leftover units}; \delta * q\}$, with contract parameter $\delta \in [0, 1]$. "Hence, the quantity-flexibility contract fully protects the retailer on a portion of the retailer's order whereas the buyback contract gives partial protection on the retailer's entire order" (Cachon, 2003, p.248). A further distinction is that in contrast to the buyback and revenue-sharing contracts, the quantity-flexibility contract is not assured to result in SC coordination under voluntary compliance.

One can distinguish between forced and voluntary compliance. While forced compliance assumes that exactly the amount ordered is delivered due to sufficiently hard consequences, under voluntary compliance the supplier delivers the amount that results in the maximum profits for him (but not more than the ordered quantity).

A *sales-rebate contract* consists of three parameters: the wholesale price w_s, the rebate r, and the threshold t. The retailer pays w_s as long as the ordered amount is below the threshold. If $q \geq t$, the retailer has to pay a reduced wholesale price $w_s - r$ for all the ordered units plus a rebate for the first t units and for all the unsold units above t. Here, so-called "upside protection" is given. For any unit sold above t, the retailer pays less than the production cost. A sales-rebate contract does not coordinate SCs under voluntary compliance.

Diverse *quantity-discount contracts* are proposed in the literature. In general, coordination can be achieved due to manipulation of "(...) the retailer's marginal cost curve, while leaving the retailer's marginal revenue untouched" (Cachon, 2003, p.254).

Extensions

The extensions to the basic model cover two directions: either the optimal order quantity is considered in different settings or an additional decision is taken into account.

Kouvelis and Lariviere (2000) introduce the alternative setting in which the set of transfer payments is not fixed but determined via internal markets after the relevant information has been revealed. The authors show that such internal markets coordinate the SC as well. Donohue (2000) introduces a setting with two ordering opportunities. Here, the optimal order quantity of the first order (before the early demand is observable) and the optimal second order quantity (after the early demand has been observed) need to be incentivized. Alternatively, the considered "one-to-one" SC structure is changed. Cachon (2003) describes and extends contracts for the optimal order quantity with multiple retailers ("one-to-many"). Cachon and Kök (2010) introduce a SC consisting of competing manufacturers and one single retailer ("many-to-one"). On this line, Li et al. (2013) analyze the contract choice in the case of competition between multiple retailers as well as between multiple manufacturers. Ha and Tong (2008) analyze the optimal contract design in the case of two competing "one-to-one" SCs. Recent research effort also points in two further directions: Feng and Lu (2013) introduce bilateral bargaining instead of the common Stackelberg game, and Chen et al. (2014) analyze the question of stability of contracts in the case of the involvement of risk-averse actors.

Furthermore, besides the pure consideration of order quantity, the coordinating contracts found in the literature jointly specify different parameters, like retail prices, time, or quality. We refer to Arshinder et al. (2011) for a summary.

In sum, three different contract types (*downside protection*, *upside protection*, and *quantity discounts*) are introduced to coordinate the basic setting (thus, making the retailer order the SC optimal order quantity). Some of these contracts are reported to coordinate extensions of the basic setting as well - either in their pure form or as combinations.

The contracts differ with respect to the cost of administration, the distribution/shifting of risk between the actors involved and the information required to choose the contract parameters. These factors may indicate which contract is the best match in different real-world situations and need to be checked when transferring the contracts to alternative settings.

2.1.2 How to Coordinate Actions and Pursue Information Transfer in Decentralized Supply Chains

An underlying assumption of the aforementioned models is that all the actors have access to all the available and required information. However, this is not always the case. Information with respect to the demand, exerted selling effort, inventory position, or inventory control policy that is in place (so-called "downstream information") and information with respect to cost structures, lead time, or capacity ("upstream information") may be scattered among diverse actors. Therefore, in the case of asymmetric information, besides the coordination of actions, the sharing of accurate information needs to be pursued (Chen, 2003).

In such settings, the idea of the agency literature[2] is often applied. Depending on whether the principal or the agent is offering the contract, the concepts of screening and signaling are distinguished. Besides contracts, collaborative initiatives to coordinate such SC settings are found in the literature. The following overview of the literature dealing with the exchange of information in decentralized SCs is structured accordingly.

Screening

The objective of screening models is to design contracts that provide incentives to gather the private information held by one SC entity. The action to coordinate is the order quantity.

Information asymmetry on an actor's cost structure represents one research direction within this stream. Corbett and De Groote (2000) consider a retailer's holding cost parameter that is unknown to the supplier. They derive the optimal quantity discount policy to make the buyer order the SC optimal quantities. Ha (2001) and Corbett et al. (2004) consider supplier-buyer relationships under information asymmetry with regard to the buyer's cost structure. Ha (2001) shows the optimality of "a cutoff policy on the buyers marginal cost to determine whether a contract should be signed" (p.43). The optimal cutoff level is affected by both the supplier's marginal costs and the buyer's reservation profit. Corbett et al. (2004) compare different contract types in the case of full and asymmetric information. One of their major findings is that the "value of information is greater under two-part contracts than under one-part contracts, and the value of being able to offer two-part contracts rather than one-part contracts is greater under full information than under asymmetric information" (p.558).

[2] An introduction to the principal-agent theory is provided by Kreps (1990)

Private demand information is the second research direction considered in the previous literature (e.g. Lariviere, 2002; Özer and Wei, 2006). Lariviere (2002) considers a SC consisting of a supplier and a retailer facing the newsvendor problem. The demand information is likely to be improved due to costly forecasting by the retailer. The supplier wants to induce the retailer to forecast and to share this information with him. However, the supplier cannot observe the retailer's forecasting activities. The authors examine and compare the performance of buyback and quantity-flexibility contracts in this regard. They conclude that the performance depends on the costs of forecasting. In the case of high forecasting costs, the quantity-flexibility contract is preferred (and vice versa). Özer and Wei (2006) show that a non-linear price capacity reservation contract results in credible information sharing and profit maximization. Ha and Tong (2008) consider two one-to-one SCs and analyze "how the incentive contracts change under different information structures in a competitive environment" (p.703).

Besides the aforementioned information on the demand and cost structure, the decision on exerted selling effort is usually known only by the responsible actor, that is, the retailer. Higher selling effort, thus increased demand, is beneficial to both actors but only costly to the retailer. An intuitive solution is to share the costs occurring between the two actors, but the actual effort may be hard to monitor by the supplier and sometimes not only one supplier benefits from the retailer's selling efforts. Thus, direct transfer payments are not possible (Porteus and Whang, 1991). Cachon (2003) shows that buyback, revenue-sharing, and quantity-flexibility contracts result in less effort than is SC optimal, whereas a sales-rebate contract leads to too much effort. A combination of the sales-rebate and buyback contracts can solve this problem and result in the optimal SC effort, but as many as four different parameters are required to implement this combination. Besides this combined contract, the quantity-discount contract leads to SC optimal effort and order quantity decision. It is not only the demand that can be influenced by the exerted efforts. Several papers (e.g. Reyniers and Tapiero, 1995; Baiman et al., 2000) analyze the influence of the chosen effort on the resulting quality of the delivered products, whereas Wang and Shin (2013) consider the innovation effort and its effects on customers' product valuation.

Signaling

The objective of an informed entity in transferring its private information to an uninformed one is known as signaling. Interestingly, signaling is mostly used in the context of new product introduction (Chen, 2003). The models assume that manufacturers introducing a new product usually possess superior information on the market demand. This information is shared either with downstream SC partners, such as retailers, or with upstream partners, such as suppliers. Papers like Chu (1992), Desai and Srinivasan (1995), or Lariviere and Padmanabhan (1997) address signaling games between well-informed manufacturers and retailers. The underlying problem is to convince the uninformed retailer to carry the product, although this incurs costs and overstocks may not be returnable. With respect to upstream partners, Cachon and Lariviere (2001) investigate the issue that manufacturers need to convince their supplier(s) to build up sufficiently large capacities.

Coordination by Joint Decision-Making Initiatives

Joint decision-making initiatives represent another set of mechanisms to achieve SC optimal actions under information asymmetry (Arshinder et al., 2011). The basis of all of them consists of information and communication technology (ICT) tools. In the following, the most common initiatives are introduced, sorted by increasing collaboration effort and the degree of information sharing required.

Quick Response is an inventory management initiative that originates from the apparel industry. The underlying idea is that lead times are shortened and retailers can therefore order closer to the actual selling season and thus based on a better forecast. Nevertheless, certain actions, such as service level or volume commitments, are required to make both actors better off than without Quick Response (Iyer and Bergen, 1997).

Collaborative Planning, Forecasting, and Replenishment means that the SC partners share information and work closely together in their core SC business processes (Aviv, 2001). Among other benefits, increased sales, better service levels, and reduced capacity requirements are mentioned in the literature. A road map showing how to achieve these objectives is offered by the Voluntary Interindustry Commerce Standard Association (1999). Subsets of this standard set of technology-enabled business processes, like collaborative forecasting, are discussed in the literature as well (e.g. Aviv, 2001, 2007).

Vendor Managed Inventory (VMI) is a further technology-enabled mechanism to achieve optimal decision making within a SC. If VMI is in place, the timing and quantity of the reordering decision is shifted from the retailer to the supplier (Aviv and Federgruen, 1998). The basic requirement of a VMI system is that the demand and inventory information is shared within the SC. Furthermore, ICT is required to enable real-time and accurate transmission. A major advantage of VMI for suppliers is the possibility to overcome the bullwhip effect (Disney and Towill, 2003). On the retailer side, ordering and inventory monitoring cost savings are often highlighted. Mishra et al. (2009) argue that such savings are possibly realized already by the introduction of technology like electronic data interchange systems, hence looking for an alternative explanation for why retailers often "force" their supplier to install a VMI system. They show that the competition between suppliers of product substitutes is intensified by VMI. Retailers benefit from this increased competition, which the authors take as reasoning for the observed popularity of VMI among retailers.

Summarizing the literature on the coordination of forward SCs, Arshinder et al. (2011) state, "(...) literature has emphasized more on demand uncertainty, whereas supply uncertainty can be of equal concern in the era of globalization and outsourcing" (p.67). This circumstance may complicate the transferability of the developed mechanisms to a CLSC context, in which supply uncertainty represents a major challenge. Nevertheless, the mechanisms introduced in this section may be useful as a starting point and can be drawn on in this thesis.

2.2 Coordination in the Closed-Loop Supply Chain Literature

The vast majority of the literature in CLSC research addresses technical and operational issues (Guide and Van Wassenhove, 2009). A common assumption is that the planning of the CLSC processes, such as scheduling and shop floor control, inventory management, or network planning, is undertaken by a central planner. Ferguson (2009) and Souza (2013) provide recent reviews of previous publications in this literature stream.

The focus of this section is on the literature modeling the issues arising from multiple, independent decision makers in CLSCs with non-aligned objectives. Thierry et al. (1995) are among the first to transfer the necessity to take multiple decision makers into account in a CLSC setting. Studying the product recovery management of an international copier manufacturer, BMW, and IBM, one of their key findings is that it is important to cooperate with other organizations in one's reverse (or even better closed-loop) SC. According to the authors, cooperation opportunities include working with companies that specialize in product reprocessing activities as well as joint product redesign.

In line with Savaskan et al. (2004), we distinguish two "clusters" of resulting research efforts on the strategic interaction among CLSC actors. We start with the literature on the reverse channel structure for collection and the literature on false failure returns. Both coordination issues occur *ex post*, that is, they are related to the after-usage phase. Finally, we address product-design-related issues, which occur *ex ante*.

Reverse Channel Structure for Collection

The general idea of this research stream is to obtain a detailed understanding of the implications that a manufacturer's reverse channel choice has for forward channel pricing decisions and for the collection rate, specifically how the profits are affected. To make collection economically beneficial, it is assumed that the production of new products is cheaper in the case that returned products are used instead of new supplies. Linked to this assumption, it is assumed that returned products are of homogeneous quality.

Savaskan et al. (2004) consider a two-echelon SC consisting of a single manufacturer and a single retailer. The manufacturer can choose between three different reverse channel structures: (1) the manufacturer collects returns directly from customers, (2) the retailer is responsible for the collection, and (3) a third party is commissioned with the collection of product returns. These decentralized settings are compared with a central decision maker in terms of wholesale price, retail price, product return rate, and total SC profit. All the settings are modeled as Stackelberg games, with the manufacturer as the Stackelberg leader.

The analysis shows that in the case that prices are sensitive to changes in the unit production costs, the best option is to choose the retailer to collect used products. This choice results in the highest collection rate, the lowest retail price, and thus the highest sales volumes. This consequently results in the best SC profit in a decentralized setting. Furthermore, it is shown that the profits of both actors, manufacturer and retailer, increase in comparison with the alternative settings. The authors explain their result in the following way. The amount of potentially collected products is limited by the sales volume of the first period. As the retail price affects the sales volume, it is seen as the main driver in this model. In the case that a retailer takes into account the future benefits from the collected products, he is able to decrease his retail price. Due to the lower retail price, the sales volume increases, from which the manufacturer benefits as well - hence, he is able to offer a decreased wholesale price to the retailer. This effect is observable only to some extent in the case that the manufacturer collects the products. Again, the production costs are lowered due to the usage of returned products, but these savings will not be transferred completely in terms of a reduced wholesale price. This problem is known from traditional SCM coordination as double marginalization (Spengler, 1950). The third-party option is the least preferred one as again the double marginalization problem arises. Additionally, the SC profits are decreased due to the payments for the collection activities of the third party. Furthermore, the authors show that as a result of the introduction of a two-part tariff, the retailer collection setting leads to SC optimal profits, obtained by a central planner. However, this assumes complete information on the costs as well as the demand.

Savaskan and Van Wassenhove (2006) extend the above model of a single manufacturer-retailer dyad by incorporating competing retailers. The authors analyze five different reverse channel structures: on the one hand, decentralized settings with (1) no collection at all, (2) returns are collected directly from the manufacturer, (3) retailers being responsible for the collection; and on the other hand, two centralized settings with (4) direct collection and (5) indirect collection via retailers. Using a game theoretic modeling framework, they provide insights into how wholesale prices and the retailer's intensity of competitive behavior are affected by the reverse channel structure. In the case of competing retailers, the manufacturer's optimal choice depends on the product under consideration. In the case of consumer products, that is, when retailers compete on prices, the indirect, retailer collection is the best option. If the retailers cannot affect the prices, or only to a small extent, manufacturer collection is preferred.

Atasu et al. (2013) provide another extension to the model of Savaskan et al. (2004) by incorporating volume-dependent costs. Depending on the environment in which a company operates, two different collection cost structures are distinguished. A company faces either economies of scale in the collection cost, for example due to the quantity discounts of a mail provider, or diseconomies of scale, which relate to settings in which more distant (thus more expensive) customers need to be reached to increase the collection volume. Similar to the result of Savaskan et al. (2004), retailer collection is the manufacturer's optimal choice in the case that the retailer is incentivized to increase the sales volume. This is achieved either due to the above scale effect in investment costs or due to economies of scale in collection costs. Otherwise - such as in the case of diseconomies of scale - manufacturer collection is preferred. Again, third-party collection is always dominated. While this differentiation according to costs is not too surprising, the major contribution of this paper is to show that the analysis of the collection cost structure is of importance for the optimal reverse channel structure choice.

Karakayali et al. (2007) focus on a CLSC setting motivated by the automotive industry. OEMs are often obligated by law to fulfill certain recycling targets. However, due to disappointing experiences, they tend to outsource these activities. To model this decision, a SC consisting of a collector and a reprocessor is considered. In contrast to the aforementioned papers, the authors include heterogeneous qualities of returned products. The collecting actor decides on the quality-dependent acquisition price for the used products. The reprocessing actor decides on the amount of products that are remanufactured, pays a transfer price to the collector, and determines the reselling price. The authors analyze how the pricing decisions of agents responsible for the collecting or processing of end-of-life product returns influence the collection rate. As a benchmark, they introduce a central decision maker responsible for both collection and reprocessing. Two decentralized settings are compared with this benchmark: either the collector or the reprocessor is modeled as the Stackelberg leader. It is shown that a two-part tariff consisting of a quality-dependent unit wholesale price and a fixed payment coordinates both decentralized settings.

False Failure Returns

While the aforementioned models address returns that have been used by customers for a longer period of time, Ferguson et al. (2006) consider false failure returns, that is products that are returned by customers although they do not have any functional or cosmetic disfunctionalities. According to the authors, most returns of this type could be avoided due to increased sales efforts. However, these efforts need to be taken by the retailers, while the manufacturer benefits from them as he can save the costs incurred by the reverse flows. To coordinate the setting, the authors introduce a target rebate contract. This means that the manufacturer pays a certain amount per unit of false failure return below a target value to the retailer. Due to the payment, the retailer has the incentive to exert sales effort, thereby decreasing the amount of false failure returns and thus the decreasing reverse SC costs for the manufacturer.

Product Design

A precondition of the above considerations is the reusability of a product. Reusability is a central product design decision and is related to further CLSC processes and actors. The production of reusable products usually is more expensive than the production of a single-use product (Debo et al., 2005). However, reusable products can be recovered at lower costs than the initial production costs (e.g. Ferguson, 2009). The most fundamental question that has to be answered is whether reusability of a product is profitable.

Debo et al. (2005) address this question under the assumption of heterogeneous customers. Customers differ from each other in terms of high and low degrees of willingness to pay for a new product as well as heterogeneity with respect to the willingness to pay for reprocessed products - whereas new and reprocessed products are substitutes, but reprocessed products are valued less than new ones. As key drivers of an increasing reusability level, the authors identify decreasing reprocessing costs as well as decreasing incremental costs associated with producing a reusable product instead of a single-use one. Besides costs structures, the choice of reusability is driven by the customer structure: "the optimal remanufacturability level is the highest for medium levels of market heterogeneity. For markets with high concentrations of customers on either the high end or the low end, the optimal remanufacturability level is low"(p.1200). Hence, knowledge of the customer structure is central when determining attributes like reusability.

The coexistence of new and reprocessed products is briefly covered by the authors. The focus is consequently on the special role of new products. Their results indicate that the "practice of focusing on the profits obtained from new and remanufactured products separately can be counterproductive, and that considering the total product line as part of the same profit center may lead to higher profitability for the firm"(p.1201).

The reusability potentially offers the opportunity for independent reprocessing companies to enter the market. Therefore, competition with independent reprocessors also needs to be considered when deciding on the level of reusability. In this regard, the authors find that the key drivers for the introduction of a reusable product remain. However, the level of reusability decreases with the number of competitors.

Geyer et al. (2007) analyze several aspects that potentially influence the cost savings obtained from reprocessing activities besides the product design. Their result highlights the necessity to consider simultaneously the production cost structure, collection rate, product life cycle, and component durability. This is a very complex task that - according to the authors is possibly an explanation for why many OEMs avoid closing the loop.

To summarize, it can be stated that the research on coordination in CLSCs is still in an early stage. We contribute to this stream of research in multiple ways:

- Due to the introduction of a business case the necessity of coordination in the CLSC context is highlighted.

- The literature on the optimal reverse channel structure is extended by our analysis of the coordination of the disposition decision in a decentralized CLSC.

- The analysis of the customer interface adds a new layer to the research on the coordination of CLSCs. Customers as the origin of supply uncertainties are analyzed in more detail and the effects of their decisions on CLSC processes are considered from a coordination perspective.

Chapter 3

Coordination in Closed-Loop Supply Chains - The Case of the Disposition Decision

So far, the foundations for coordination issues in CLSCs have been laid. In this chapter, we focus on one specific coordination aspect: the coordination of the reverse-SC-specific process step *disposition* and related decisions. The main driver of this focus is the business case introduced. We consider a decentralized reverse SC consisting of a lessor and a service provider that conducts the reprocessing activities of end-of-lease returns. The disposition decision affects the profits of both actors involved. However, the essential information for the disposition decision - the information on the actual quality of the returned products - is available only to the service provider. Hence, decentralized decision making and scattered information between multiple SC members raise the question of appropriate SC coordination with regard to the disposition decision. Furthermore, the coordination of the disposition is of interest as there is no obvious corresponding process step in a traditional forward SC. Specifically, we address the research question raised in Section 1.4:

How can the disposition decision be coordinated in the case of reverse SCs consisting of multiple, independent actors?

The chapter is structured as follows. In Section 3.1, a review of the relevant literature on the disposition decision is provided, followed by the statement of assumptions and the notation used (Section 3.2). The actual analysis of the identified coordination need starts with the introduction of our benchmark - following the standard SCM literature, we use a central decision maker who owns all the relevant information (Section 3.3.1). The current business case setting is analyzed in Section 3.3.2. As it is shown not to be optimal, a coordinating strategy is developed in Section 3.3.3. We illustrate the aforementioned settings in terms of an example (Section 3.4) and conclude with a discussion of the assumptions and future research directions (Section 3.5).

3.1 Literature Review - Disposition Decisions in Closed-Loop Supply Chains

The main distinction between reverse SCs and traditional ones is the uncertainty on the supply side with respect to the quantity, timing, and quality of returns (Fleischmann et al., 2010). This is why the inbound processes, namely product acquisition, grading, and disposition are of special interest in CLSC settings. In our business case, we identified a potential SC deficiency with respect to one of these inbound processes: the disposition decision. In this chapter, we characterize the disposition decision (Section 3.1.1) and provide an overview of the previous literature on the disposition decision (Section 3.1.2).

3.1.1 Characterizing the Disposition Decision

The objective of the disposition decision is to choose the most suitable disposition option for returned products of a certain category. In the following, we summarize the commonly distinguished categories of return flows and disposition options. In the section on objectives, we state the basis for the choice of the most suitable disposition decision.

Categories of Return Flows

Heterogeneity of supplies makes it necessary to assess the condition of returned products to be able to determine a suitable disposition option (Guide et al., 2000). However, to some extent, information on the quality of supplies can be gathered even without actually assessing the returned products. This is due to the different kinds of return flows that exist. Three different categorization schemes of reverse flows can be found in the literature. Thierry et al. (1995) are the first to mention return types and their inherent different characteristics. Using the terminology of Guide and Van Wassenhove (2009), three return types are distinguished: consumer returns, end-of-use, and end-of-life. Consumer returns are products that are returned by end customers due to dissatisfaction within a short period of time after the purchase. This return type is usually hardly used and requires quick reintroduction into the market. End-of-use returns, such as leasing returns, are often attractive for a second usage phase, whereas end-of-life returns are usually worn out and outdated with respect to their technology. Guide and Van Wassenhove (2001) propose a distinction between waste-stream and market-driven flows. Alternatively, Rogers et al. (2002) introduce a categorization according to the origin of the product flow. Based on information from the Global Supply Chain Forum, they distinguish five different return flows: consumer returns (including returns due to defects as well as commercial return policies), marketing returns (from a forward SC actor), asset returns (transportation equipment, such as containers), product recalls, and environmental returns.

Different return types and/or origins of return flows have an impact on the condition of returned products. Nevertheless, both the availability and the actual quality are uncertain ex ante.

Disposition Options

Next, we come to the clarification of possible disposition options. Thierry et al. (1995) are the first to provide an overview of observable disposition options. The authors divide the different options into three groups: direct reuse, product recovery, and waste. This common categorization is used in the following to describe the diverse disposition options described in the previous literature in more detail. Figure 3.1 provides a summarizing overview.

Let us start with the *direct reuse* options. Returned products that are in an "as new" condition, for example consumer returns, can usually be resold directly or after repacking. These products are sold for the original or a discount price. Depending on the condition of returned products, further direct reuse alternatives are to sell the products via an outlet to a secondary market or to donate them (Rogers and Tibben-Lembke, 1998).

Product recovery covers disposition options that require "(...) a value-added operation that restores a used product to a common operating and aesthetic standard, and where the core geometry of the product is preserved" (Souza, 2012, p.150). Commonly three disposition options are related to this group: repair, refurbishing, and remanufacturing. These disposition options differ from each other in terms of the degree of disassembly and the achieved quality level of the recovered product. To repair a product, limited disassembly is usually required and due to a lower quality level than a new product, repaired products cannot be sold "as new". In contrast, remanufacturing requires complete disassembly and inspection of the original product to assure the quality standard of new products. Refurbishment is seen to be in

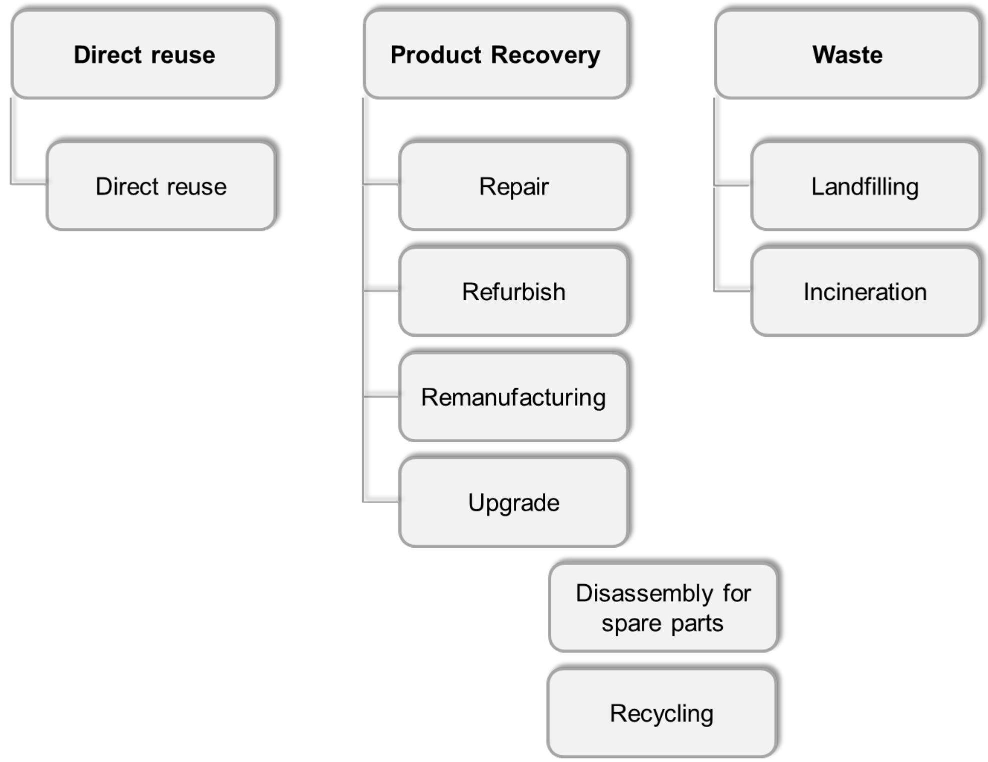


Figure 3.1: Categorization of Disposition Options (based on Thierry et al., 1995)

between these two options. In addition to the aforementioned recovery alternatives, Galbreth et al. (2013) recently addressed the option to include component upgrades to cover technological innovations that evolved during the use phase of the product.

The disposition option disassembly for spare parts can be located *in between product recovery and waste*. In contrast to the aforementioned recovery options, in this option only a minority of components are reused. These components are, depending on their inherent quality standard, used in the aforementioned recovery processes (Thierry et al., 1995). In addition, Ferguson et al. (2011) observe that spare parts can also be sold directly to customers. All other parts are disposed of in some form. Recycling is another disposition option found in the literature. This is the recovery of the materials of which a returned product consists. As in the case of disassembly for spare parts, some materials are reintroduced in the forward SC, whereas others are disposed of - but on a material instead of a component level.

In the literature, there are two disposition options that match Thierry et al. (1995)'s *waste* category: incineration (i.e. energy recovery) and landfilling.

Objectives

We introduced the choice of the most suitable disposition option for returned products as the objective of the disposition decision. This makes a definition of "most suitable" necessary. The criteria can be summarized by the *Triple Bottom Line* (Elkington, 1997):

- *People*, meaning social impact
- *Planet*, meaning environmental impact
- *Profit*, meaning economic goals

Although the focus of market-driven CLSCs is usually on profit maximization, the prioritization of different aspects may vary depending on the decision maker (Souza, 2012). Furthermore, multiple obstacles hamper straightforward decision making, based on profit considerations. Besides the aforementioned supply uncertainties, Fleischmann et al. (2010) as well as Souza (2012) highlight the following complicating factors that should be taken into account to enable a good disposition decision to be made:

1. *Demand uncertainties.* These includes uncertainties with respect to the demand for reprocessed products as well as differences in the demand for the multiple components a returned product consists.
2. *Long-term perspective.* Considering a long-term planning horizon, not only uncertainties but also predictable fluctuations in the demand and supply increase the complexity. The currently achievable profits of a returned unit need to be compared with its potential future value, assumed that it is put into stock.
3. *Opportunity costs.* Choosing one disposition option means withholding a returned unit from another option.
4. *Capacity utilization.* Related to the previous factor: depending on the condition as well as on the chosen disposition option, the capacity requirements vary. This may affect future decisions due to capacity limits.

Guide and Van Wassenhove (2009) introduced two views on CLSCs: they can be seen either from a return type perspective or from a disposition perspective. By combining the two views, the authors identify common return type-reprocessing pairs, which are shown in Table 3.1. However, this allocation provides only a first

Return Type	$\xrightarrow{\text{most suitable}}$	Disposition Option
Consumer Returns	$\rightarrow$	Direct Reuse
End-of-Use	$\rightarrow$	Product Recovery
End-of-Life	$\rightarrow$	Waste

Table 3.1: Return Type-Reprocessing Pairs (based on Guide and Van Wassenhove, 2009)

guideline. As described above, the finally chosen disposition option depends on a variety of influencing factors, such as the actual condition of returned products, the aforementioned complicating factors, and the objective of the responsible decision maker.

3.1.2 Models of the Disposition Decision

Now, we come to the review of the literature on the activity "disposition". The literature comprises the strategic, tactical, and operational planning levels, which are often interrelated. Nevertheless, we use these planning levels as guidance to structure the following review.

Strategic Disposition Decisions

According to Fleischmann et al. (2010, p.110), disposition decisions on the strategic level circle around three questions: "When, where, and based on which information (...)?".

Guide et al. (2005) as well as Guide et al. (2006) cover a commercial returns context and analyze of the question whether it is beneficial to centralize or decentralize the location of the disposition decision. According to the questions stated by Fleischmann et al. (2010), this decision can be considered a strategic one. However, it is necessary to mention that, depending on the reversibility of the initial investments, it can also be of a tactical nature.

Guide et al. (2005) analyze Hewlett-Packard's reverse SC of consumer electronics. The original reverse SC includes an outsourced repair service, to which all returns are directed. This outsourced service is identified as a bottleneck, increasing the reprocessing times of the reverse SC. In time-sensitive industries such as the one considered, this represents a serious dysfunction. The authors recommend introducing minor in-house repairs as an alternative to the regular outsourced repair service. A multi-period network-flow model is used to determine the volumes of returned units that should be handled in-house or sent to the outsourced service, respectively. The return quantities as well as the demand fluctuations are assumed to be known in this model. Uncertainty exists with regard to the quality of the returned units.

Although the authors take into account an additional actor responsible for repair services, they still assume that all the relevant decisions, like which returned product should be directed to which reprocessing activity (thus the disposition decision), are made by the product owner, Hewlett-Packard.

Based on two case studies, Guide et al. (2006) propose the introduction of a network design, in which the retailer is responsible for the sorting of product returns. Due to this structure, commercial returns that are in the same condition as new products can be restocked faster than in the case of a centralized disposition decision. In their analysis, the authors do not include incentives to be paid to the retailer for extra activities, such as sorting. Only products that are in an as-new condition can be resold directly.

This means that, in contrast to our setting, in the described case the retailer would be paid only for activities that are observable by the OEM. Thus, this setting does not give rise to a coordination issue with respect to the disposition decision.

Tactical and Operational Disposition Decisions

The literature on the disposition process on the tactical and operational planning levels covers the introduction of decision rules and the actual determination of optimal disposition choices. An underlying modeling aspect is the amount of distinguishable disposition options. According to Fleischmann et al. (2010), either a simple distinction between two options, such as a value-adding one and disposal, is made or multiple disposition options are distinguished. The number of considered disposition options depends on diverse factors, such as the product type, the technological possibilities of the company, or the modeling limitations. Commonly, the determination of the disposition choice is based on contribution margins (Ferguson, 2009). An exception is Guide et al. (2008), who use a queuing approach to determine whether a returned product should be remanufactured or salvaged immediately. The following review of decision support models found in the previous literature is structured according to Souza (2012), who suggests clusters based on the included (degree of) uncertainties.

Assuming information on seasonal fluctuations of supply and demand volumes, Kleber et al. (2002) determine disposition decision rules on a medium-term level. Their analysis is based on the assumption that all returns have the same quality and the demand can be satisfied by remanufacturing as well as new production.

Another set of models incorporates different uncertainties while assuming deterministic return volumes - an assumption that is suitable if reliable return forecasts are possible. An example of such a setting is leasing returns. On this line, Krikke et al. (1998) started a stream of research on the determination of the optimal disassembly strategy, taking into account the Triple Bottom Line. The authors consider two quality classes, in which the quality of sub-assemblies can be estimated from the condition of the returned "parent" product.

Denizel et al. (2010) also consider a deterministic return flow with uncertain quality of returns. In contrast to Krikke et al. (1998), the authors consider a longer time horizon. A multi-period linear program is developed that is used to determine the amount of returned units that should be graded, the number of these graded units that should be reprocessed, and the amount of returns that should be kept as inventory (either ungraded, graded, or reprocessed).

Considering uncertainty with regard to both supply quality and supply volume, the aforementioned paper by Guide et al. (2008) takes into account capacity utilization in the disposition decision. The authors introduce a short-term strategy consisting of two steps. First, the quality and the related processing time are observed. Second, the returned product is either remanufactured (in the case that the reprocessing time is below a determined threshold) or salvaged as it is. It is shown numerically that this strategy is superior to models that ignore the time value of money.

A further set of models analyzes the effects of supply as well as demand uncertainty on short-term disposition decisions. Inderfurth et al. (2001) are the first to introduce multiple disposition options, such as product recovery options and disassembly for spare parts in a stochastic environment. The authors develop a heuristic that determines the disposition based on mean demands. In contrast, Ferguson et al. (2011) use a profit-maximization approach. They highlight the parallels of this remanufacturing setting to revenue management problems. The underlying idea is that a limited amount of returned units can either be remanufactured and resold or be dismantled for spare parts. Reselling is seen as the more profitable option on a per unit basis, compared with disassembly for spare parts, but the demand for recovered products is more uncertain than the demand for spare parts. Based on a numerical study, the authors show that their approach outperforms the commonly used prioritization of high-margin disposition options.

Guo et al. (2014) consider a multi-period multi-part setting. The authors develop a stochastic dynamic program that covers two disposition options: dismantling for spare parts or remanufacturing, in which the demands for spare parts and remanufactured products are stochastic. The quality of supplies is assumed to be sufficient for both disposition options. Given the fact that the two disposition alternatives compete for the limited resource "returned units", the authors conclude that, depending on the inventory level of certain parts, remanufacturing is preferred to dismantling.

Besides uncertain supply and demand volumes, Karaer and Lee (2007) additionally consider the uncertain quality of supplies. They distinguish between disposal, remanufacturing, and direct reselling. As the latter two can be seen as substitutes for new production, the authors analyze the impact of the visibility of reverse flows on a manufacturer's inventory management.

Taking into account the uncertain product innovation rate, Galbreth et al. (2013) consider another kind of uncertainty. The authors assume identical quality levels of all returns and take into account two disposition options: remanufacturing and upgrading. Alternatively, new production is possible to satisfy the demand. They find that ignoring the innovation rates results in overestimation of the optimal amount of returns to be reused.

A common assumption of these models on the tactical and operational levels is that the product owner is responsible for the disposition decision. Hence, the product owner alone is considered. He chooses his most suitable disposition option and thereby manages his own profits. However, we observed a deviating setting in our business case in Section 1.3. In the considered SC, the profit of the product owner depends on the disposition decision that is made by a third-party reprocessor. Therefore, we consider the disposition decision from a decentralized SC perspective. We analyze whether the current SC structure results in any SC deficiencies and, if necessary, develop a coordinating strategy to induce reverse SC optimal disposition decision making.

3.2 Model Assumptions and Notation

Our analysis of the disposition decision considers a two-echelon reverse SC, consisting of a lessor (L) owning returned products and a service provider (SP) responsible for all reprocessing activities. Figure 3.2 summarizes the relevant material and financial flows. Furthermore, this figure includes the distribution of information as well as the notation used.

Products that are returned by primary customers arrive at SP's recovery facility in batches. This is the moment when our analysis starts. Thus, there is no more uncertainty with respect to the timing or quantity of returns. However, the products within a batch can be of different input quality levels, and these input qualities are

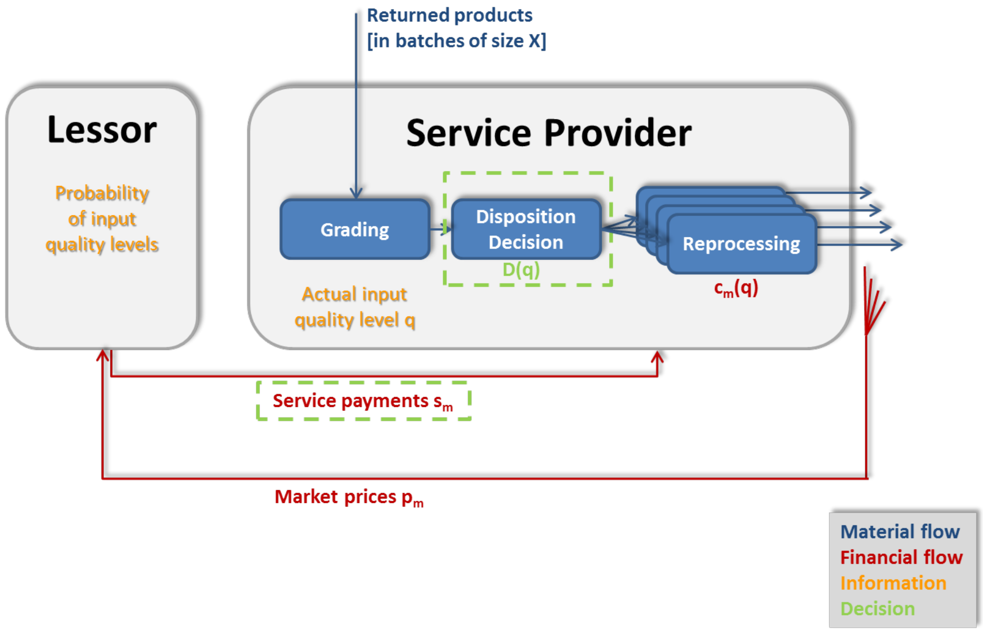


Figure 3.2: Considered Reverse Supply Chain

uncertain ex ante. Upon their arrival at the recovery facility, all the returned products are graded by SP. Through this process step, SP gains knowledge of the actual quality of the returned products. Next, the disposition decision has to be made. In line with our business case description (Section 1.3), several reprocessing alternatives are distinguished. Disposition options span from recycling, via dismantling for spare parts to recovery, including technological upgrades. Reprocessed units are sold on the secondary market. For each unit, the choice of the optimal disposition option depends on two factors: reprocessing effort and achievable revenues. Both of these factors depend on the product quality.

We consider two independent actors, each of whom is responsible for one decision of relevance to the considered context. L decides on the payments that he offers to SP for conducting the reverse logistics services. Based on these payments and the actual quality of the returned products, SP makes the disposition decision. According to the setting briefly introduced above, information on the actual quality is exclusive to SP. This raises the question of whether the decisions made in the current business case setting are reverse SC optimal.

Figure 3.3 provides a summary of the aforementioned sequence of events and decisions. In the following, the notation used is introduced and the assumptions are stated.

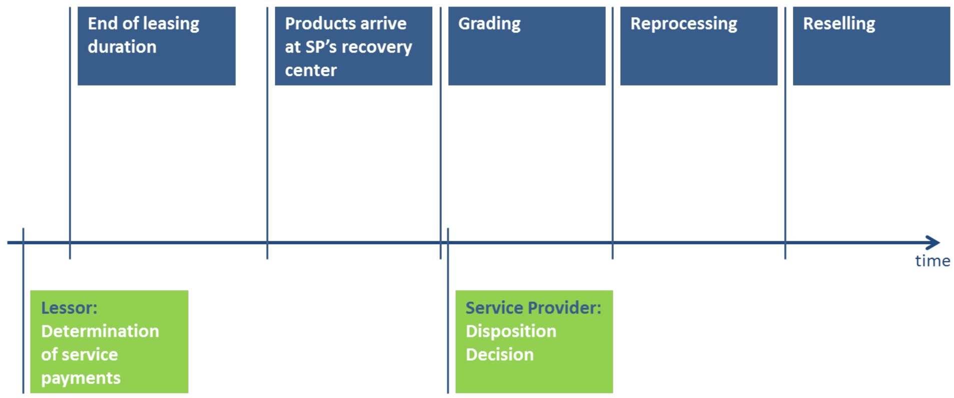


Figure 3.3: Sequence of Events and Decisions

ASSUMPTION 1. *Returns arrive at the reprocessing facility in batches of size X. Each unit within a batch has an individual input quality level $q \in [0; Q]$.*

Depending on the handling of a product during the customers' usage phase, the input qualities of the returned products vary. In our model, the value of q increases the lower the input quality level of a returned product is. A return of $q = 0$ is a product that is "as new". The worst input quality level of a returned unit is Q.

ASSUMPTION 2. *Returned products can be reprocessed to multiple output quality levels $m = 1, \ldots, M$.*

Multiple output quality levels $m = 1, \ldots, M$ are achievable, where $m = 1$ means that a return is reprocessed to the highest standard achievable on the secondary market and $m = M$ means that a product is recycled. Our analysis does not explicitly include a disposal option. However, M represents a default option for the worst input quality level.

ASSUMPTION 3A. *All reprocessed units of given output quality level m are sold for the same price p_m. The reselling prices are known before the disposition decision is made.*

These assumptions concerning the selling price can be deduced from our business case. Currently, long-term (up to one year) contracts exist between ARC and certain brokers, regarding the reselling of reprocessed products. These contracts define the quality levels and corresponding prices.

ASSUMPTION 3B. *The achievable prices increase the better the output quality level m.*

Intuitively, the better the technical standard of a reprocessed product and the better its appearance, the higher the predetermined price: $p_1 > p_2 > \ldots > p_M$.

ASSUMPTION 3C. *Service payments s_m are output-quality-dependent and increase the better the output quality level m.*

In the current business case, besides the selling price, a further payment needs to be considered. SP is paid by L for the services that he provides. These payments are so-called service payments (s_m) and necessarily are output-quality-dependent as L cannot verify the correctness of the grading outcome claimed by SP. If L offered service payments according to the conducted activities, SP would have an incentive to claim that the returned products are of poor input quality and require high reprocessing efforts and thus costs. Similar to Assumptions 3A and 3B, the service payments increase with the achieved output quality level m: $s_1 > s_2 > \ldots > s_M$. Furthermore, the service payments are known before SP makes the disposition decision.

ASSUMPTION 4A. *The reprocessing costs are input-quality-dependent and increase with q.*

ASSUMPTION 4B: *The reprocessing costs depend on the chosen output quality level and decrease with m.*

We denote the costs to reprocess a returned unit of input quality q to an output quality level m by $c_m(q)$.

The worse the input quality level q of a returned product, the higher the reprocessing cost necessary to achieve a given output quality level m. This is because the worse the input quality level is, the more reprocessing efforts and/or replacement of parts are required to achieve this given output quality level.

The better the achieved output quality level, the higher the reprocessing cost for a return of a given input quality level $\bar{q}$. Good output quality levels are related, for example, to technological updates and/or cosmetic improvements. Given a certain input quality level $\bar{q}$, to achieve such higher standards (i.e. a smaller m), it is required to update more components and to conduct more reprocessing activities, thus incurring higher reprocessing costs: $c_1(\bar{q}) \geq c_2(\bar{q}) \geq \ldots \geq c_M(\bar{q})$.

Assumption 4c. *The cost functions $c_m(q)$ are continuously differentiable in q and satisfy $\left|\frac{\partial c_m(q)}{\partial q}\right| \geq \left|\frac{\partial c_n(q)}{\partial q}\right| \forall\ m < n$ and $q \geq 0$. $c_M(q)$ is a constant function.*

This assumption states that the better the output quality level, the more sensitive the reprocessing costs are to the input qualities . The assumption originates from our business case context: the better an output quality level, the newer the technological standard of the included components needs to be and the fewer cosmetic issues and/or defective parts are accepted.

We illustrate this assumption with a short example. We differentiate between three input quality levels and two output quality levels. Returns of input quality $q = 1$ require minor rework to achieve a resellable condition, whereas returns graded $q = 2$ additionally have some cosmetic issues. Returns that are of input quality level $q = 3$ include some defects that do not necessarily hamper reselling but would not be accepted in very good output quality levels. With respect to the technological standard of the components, all returns are identical. Two output quality levels are distinguished here: $m = 1$ stands for reprocessed returns that are optically "as new" and that include a technological upgrade of the hard disk. Units resold as $m = 2$ do not include any component upgrades and cosmetic as well as minor defects are of lesser importance. Table 3.2 shows the required reprocessing activities, depending on the input and output quality levels.

	$m = 1$	$m = 2$
$q = 1$	component upgrade minor rework	minor rework
$q = 2$	component upgrade minor rework resolve all cosmetic issues	minor rework resolve major cosmetic issues
$q = 3$	component upgrade rework repair all defects	rework repair major defects

Table 3.2: Example Assumption 4C

The cost difference between reprocessing a return of $q = 1$ or $q = 2$ to $m = 1$ is the cost of resolving all the cosmetic issues. These costs are smaller in the case that inputs of these input qualities are reprocessed to $m = 2$ - in that case, only major cosmetic problems have to be resolved, but not all. The same is true for the cost difference between $q = 2$ and $q = 3$. The reprocessing costs differ in terms of repairing all vs. repairing only major defects.

In the case of recycling ($m = M$), standard activities like data wiping and sorting of materials are only required. These costs occur independently of the input quality, thus $c_M(q)$ is a constant function.

ASSUMPTION 4D. *Both actors have knowledge of SP's reprocessing cost structure* $c_m(q)$.

This is a standard assumption in the SCM literature that enables us to focus on the inefficiencies that result from quality uncertainty, one of the most frequently mentioned challenging characteristics of reverse flows. However, the effects of relaxing this assumption will be discussed in Chapter 3.5.

ASSUMPTION 5. *Both actors maximize their expected profits.*

In a reverse SC context, three general objectives are distinguished: economic, environmental, and social performance. Companies that participate in a reverse SC are aware of their environmental as well as their social performance already.[1] Now, they focus on carrying out these processes in an economically beneficial manner. Therefore, profit maximization is a reasonable goal in our analysis.

Following the standard SCM literature, we use a central decision maker, owning all the relevant information, as our benchmark and compare different strategies by means of the resulting reverse supply chain profits. π_i^j denotes the profit function of actor i in strategy j. Subscript i identifies the different actors L, SP, and the reverse supply chain (RSC), and superscript j identifies the different strategies central (C), business case strategy (BC), and acquisition (AC).

Relevant to the choice of the optimal, thus most profitable, disposition option are the received payments and incurred cost. The disposition decision $D(q)$ assigns each input quality level $q \in [0; Q]$ to an output quality level $m = 1, \ldots, M$: $D(q) : [0; Q] \rightarrow \{1, \ldots, M\}$.

ASSUMPTION 6A. *L knows the probability density function* $f(q)$ *and cumulative probability distribution function* $F(q)$ *of the input quality of product returns only and is not able to verify the actual input qualities of a given batch of returned products.*

According to the material flow shown, L does not come in contact with the returned units of his customers. Furthermore, it would be costly for him to verify the testing outcomes. This results in the fact that L has no knowledge of the actual quality of the returned units. However, we consider a leasing context in which products are

[1] Alternatively, one can assume that economic and social aspects are already included as opportunity costs in our cost functions. However, this is not explicitly included in our analysis.

<u>Indices</u>	
i = L, SP, RSC	Actor
j = C, BC, AC	Strategy
$m = 1 \dots M$	Output quality level
<u>Decision variable</u>	
s_m	Service payment that is paid for reprocessing a return to output quality level m
$D(q)$	Disposition decision
<u>Random variable</u>	
$q \in [0; Q]$	Input quality level Continuously distributed with cumulative distribution function $F(q)$ and density function $f(q)$
<u>Data</u>	
p_m	Achievable market price for output quality level m
$c_m(q)$	Cost to reprocess a return of input quality level q to output quality level m
X	Number of returned products within a batch

Table 3.3: Notation

returned after a predetermined period of time. Hence, it is reasonable to assume that L has information on the probabilities of input quality levels of the returned products.

Assumption 6b. *After grading, SP knows the actual quality of the returned products.*

Due to the current material flow, SP conducts the grading and hence gains knowledge of the input quality of the product returns.

Assumption 7. *L has enough market power over SP to act as a Stackelberg leader.*

The Stackelberg structure is a common methodology in the SC literature to model similar games (Tayur et al., 1998) and has been used in the reverse supply chain context as well (Savaskan et al., 2004).

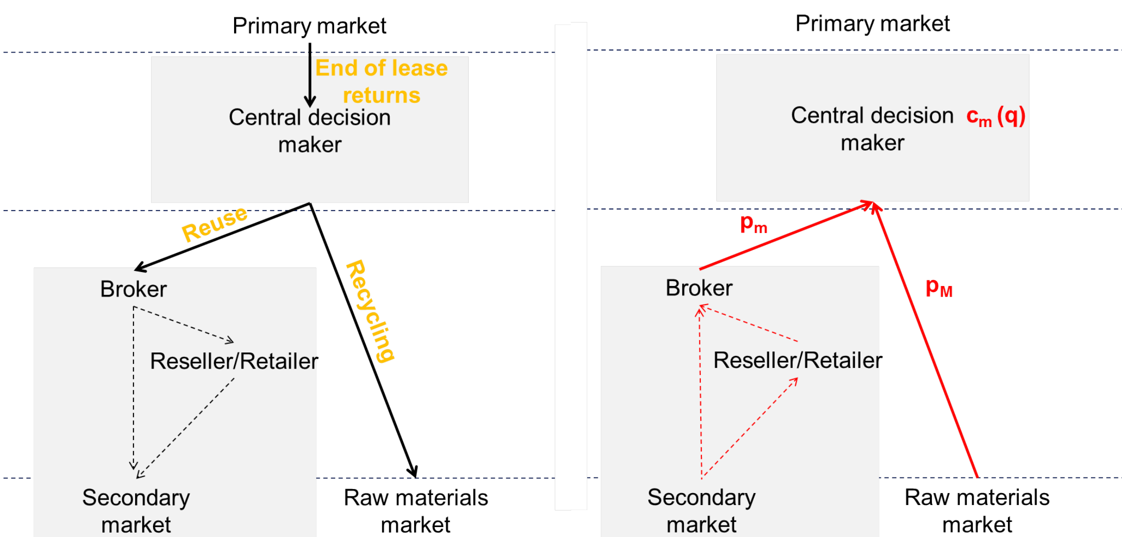
Table 3.3 summarizes the above notation.

3.3 The Disposition Decision

Our analysis of the disposition decision in a decentralized reverse SC consists of three parts. Following the standard SCM literature, we use a central decision maker, who owns all relevant information, as a benchmark (Section 3.3.1). The decisions and resulting profit functions of our business case are compared with this benchmark in Section 3.3.2. As the decisions are currently not reverse SC optimal, we suggest and analyze the case in which SP acquires returned products and show that this strategy coordinates the decisions of L and SP (Section 3.3.3).

3.3.1 Central Decision Maker - Benchmark

We start with the introduction of the benchmark: a central decision maker decides on the disposition and sells recovered products via brokers to the secondary market and recycled products on the raw materials market. The corresponding financial and material flows are depicted in Figure 3.4.



(a) Material Flow (b) Financial Flow

Figure 3.4: Material and Financial Flow of the Integrated Channel

According to Assumption 5, the goal of the central decision maker is to maximize his expected profit π^C_{RSC}. His profit function is:

$$\pi^C_{RSC} = \int_0^Q [p_{D(q)} - c_{D(q)}(q)] * f(q)\,\mathrm{d}q * X \tag{3.1}$$

To maximize Equation (3.1), for all $q \in [0; Q]$ the optimal disposition option

$D^*(q)$ needs to be determined by solving Equation 3.2 separately for each q.

$$D^*(q) = \underset{m=1...M}{\arg\max}(p_m - c_m(q)). \tag{3.2}$$

According to $D^*(q)$, the central decision maker receives p_m for each unit reprocessed to output quality level m and incurs costs of $c_m(q)$ to reprocess a returned product of input quality level q to output quality level m.

To determine $D(q)$, different disposition options, that is, output quality levels, m and n with $m < n$ need to be compared with respect to the achievable margins, given a certain input quality level q. m is more profitable than n if and only if

$$\underbrace{p_m - c_m(q)}_{b_m(q)} \geq \underbrace{p_n - c_n(q)}_{b_n(q)}. \tag{3.3}$$

Due to Assumption 4C, functions $b_m(q)$ and $b_n(q)$ intersect at most once. We denote this intersection by $q_{m|n}$ and refer to it as the *Clip Level*.

$$\text{Let} \quad q_{m|n} = \begin{cases} 0 & \text{if} \quad p_m - c_m(0) < p_n - c_n(0) \\ Q & \text{if} \quad p_m - c_m(Q) > p_n - c_n(Q) \\ \Delta c^{-1}_{m|n}(\Delta p_{m|n}) & \text{else} \end{cases} \tag{3.4}$$

with

$$\begin{aligned} \Delta p_{m|n} &= p_m - p_n \\ \Delta c_{m|n} &= c_m(q) - c_n(q) \end{aligned}$$

From Assumption 4C we furthermore know that for all $q > q_{m|n}$ at least one other output quality level $n > m$ is more profitable than output quality level m.

As a central decision maker chooses the reverse SC optimal output quality levels, we can exclude a priori all the disposition options that are not optimal for any input quality level q. Taking into account the remaining disposition options only, $D(q)$ is an increasing step function. This facilitates our further analysis without loss of generalizability: when determining the worst input quality level for which m is the optimal disposition option, the switch from m to $m+1$ needs to be considered only. The notation in the following is shortened accordingly:

$$\text{Let} \quad q_{m+1} = \begin{cases} 0 & \text{if} \quad p_m - c_m(0) < p_{m+1} - c_{m+1}(0) \\ Q & \text{if} \quad p_m - c_m(Q) > p_{m+1} - c_{m+1}(Q) \\ \Delta c^{-1}_{m+1}(\Delta p_{m+1}) & \text{else} \end{cases} \tag{3.5}$$

with

$$\Delta p_{m+1} = p_m - p_{m+1}$$
$$\Delta c_{m+1} = c_m(q) - c_{m+1}(q)$$

For the optimal disposition option $D^*(q)$ we receive the intervals within which a certain output quality level m is the most beneficial. The borders of these intervals are expressed in terms of Clip Levels q_m:

$$m \quad \text{is optimal on} \quad [q_m; q_{m+1}) \tag{3.6}$$

with

$$\begin{aligned} q_1 &= 0 \\ q_{M+1} &= Q \\ q_{m+1} &= \Delta c_{m+1}^{-1}(\Delta p_{m+1}) \quad \forall m = 1 \dots (M-1) \end{aligned} \tag{3.7}$$

Accordingly, a central decision maker's disposition decision $D(q)$ (Equation (3.8)) and the profit function (Equation (3.9)) can be expressed in terms of Clip Levels obtained.

$$D(q) = m \;\; \text{for} \;\; q \in [q_m; q_{m+1}) \tag{3.8}$$

$$\pi_{RSC}^{C} = \sum_{m=1}^{M} \int_{q_m}^{q_{m+1}} [p_m - c_m(q)] * f(q)\,\mathrm{d}q * X \tag{3.9}$$

We illustrate the aforementioned steps to determine $D(q)$ by an example which fulfills all the assumptions made in Section 3.2. In Figure 3.5, the profit margin functions b_m of four possible disposition options are depicted. The optimal disposition option for any given input quality level q is given by that option $m \in \{1, \dots, 4\}$ which maximizes $b_m(q)$. As can easily be seen, the blue line is dominated by at least one of the other profit margins for any $q \in [0; Q]$. Thus this disposition option can be excluded. This results in three different relevant output quality levels to be considered in this example. Intersections of the profit margin functions b_m and b_{m+1} are the Clip Levels representing the borders of the intervals within which each of these disposition options is the optimal choice.

We start by the determination of the interval for which the output quality level $m = 1$ is the most beneficial disposition option. This means we look for the interval

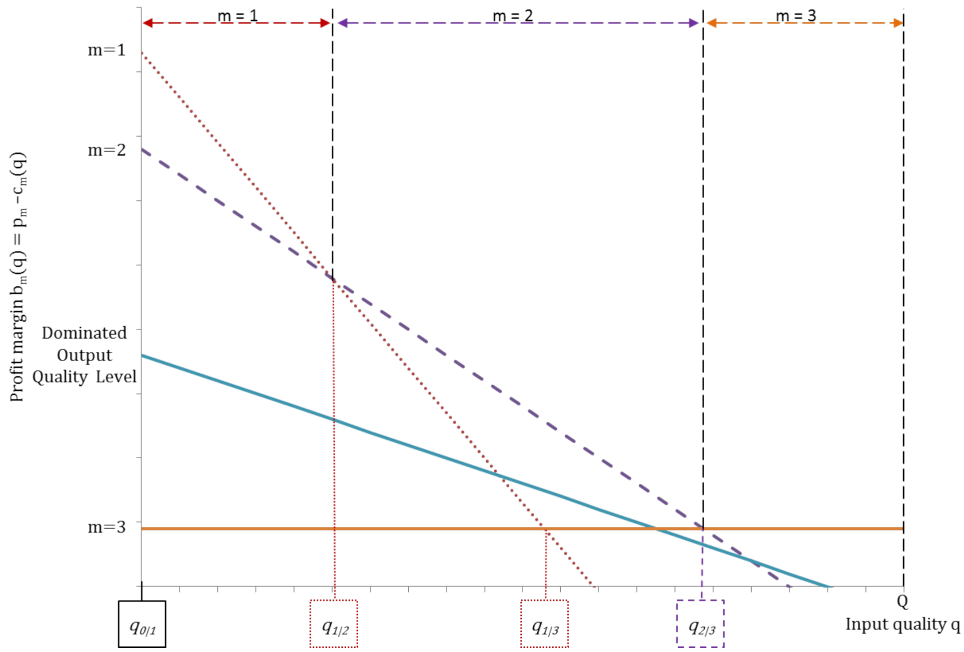


Figure 3.5: Illustration of Clip Levels

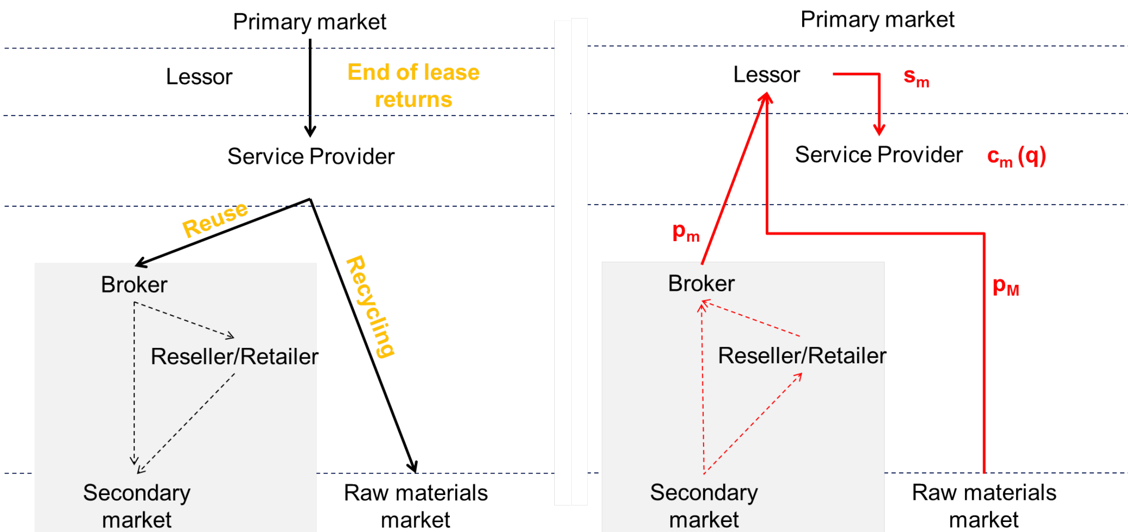
within which the profit function $b_1(q)$ (indicated by a red, dotted line) dominates all other profit functions in Figure 3.5. The lower bound of this interval is given by $q_1 = q_{0|1} = 0$ (Equation (3.7)). For the determination of the upper bound, potentially all intersections of $b_1(q)$ and $b_n(q)$ with $n > 1$ are relevant. We marked these intersections and potential Clip Levels by $q_{1|2}$ and $q_{1|3}$. $b_1(q)$ becomes less beneficial than at least one other profit margin function as soon as it intersects $b_2(q)$ or $b_3(q)$. As stated before, due to the made assumptions and the fact that disposition options that are not beneficial for any q are excluded a priori, it is sufficient to consider the comparison of two successive disposition options, only. Here, we need to look for the intersection of b_1 and b_2 and receive that $m = 1$ is the most beneficial disposition option for all returns of the input quality $q \in \left[q_1 = 0; q_2 = q_{1|2}\right)$. For all $q > q_{1|2}$ the disposition option is less profitable than at least the purple, dashed one $(b_2(q))$.

Next, the interval for which $m = 2$ is most profitable has to be determined in the same way. The lower bound is given by $q_m = q_{1|2}$. The Clip Level representing the upper bound of this interval is indicated by $q_{2|3}$. This results in $m = 2$ being the most beneficial disposition option for $q \in \left[q_2 = q_{1|2}; q_3 = q_{2|3}\right)$.

Finally, the interval for which $m = 3$ is the optimal disposition option needs to be determined. The lower bound is given by $q_3 = q_{2|3}$ and the upper bound is given by Q (cf. Equation (3.7) with $m = 3 = M$).

3.3.2 Decentralized Decision Makers - The Situation of the Business Case

Next, we analyze the current business case setting. L commissions SP with all reprocessing activities. However, the ownership of the products that will be returned by customers remains with L. SP receives end-of-lease returns from primary customers, grades them and makes the disposition decision. After the required reprocessing activities have been conducted by SP, the recovered units are sold via brokers to the secondary market and recycled returns are sold on the raw materials market. For these services, SP receives a service payment from L, whereas L as the product owner receives the market prices achieved. The corresponding financial and material flows are depicted in Figure 3.6.



(a) Material Flow (b) Financial Flow

Figure 3.6: Material and Financial Flow of the Business Case

According to Assumption 7, L acts as the Stackelberg leader. SP, the Stackelberg follower, has to decide on the disposition decision. As the Stackelberg leader, L uses his knowledge of SP's reaction to determine his service payment offering. Thus, we first model SP's decision on the disposition of returns and use the outcome to analyze L's choice of the amount of service payments.

SP's Disposition Decision

According to Assumption 5, SP's goal is to maximize his profit π_{SP}^{BC}. His profit function is given by the following equation:

$$\pi_{SP}^{BC} = \int_0^Q \left[s_{D(q)} - c_{D(q)}(q)\right] * f(q)\,\mathrm{d}q * X \tag{3.10}$$

By comparing SP's profit function with the central decision maker's profit function (Equation (3.1)), we see that they differ only in terms of the payments that the responsible decision maker receives: $p_{D(q)}$ for the central decision maker and $s_{D(q)}$ here in our business case setting. This results in the same problem structure, and we can therefore use the Clip Level formulation of Section 3.3.1, but we need to change p_m into s_m.

Using these new Clip Levels, the intervals within which a certain output quality level m is the most beneficial are now given by

$$m \quad \text{is optimal on} \quad \left[q_m^{BC}; q_{m+1}^{BC}\right) \tag{3.11}$$

with

$$\begin{aligned} &q_1^{BC} = 0 \\ &q_{M+1}^{BC} = Q \\ &q_{m+1}^{BC} = \Delta c_{m+1}^{-1}(\Delta s_{m+1}) \quad \forall m = 1 \ldots (M-1) \end{aligned} \tag{3.12}$$

with

$$\Delta s_{m+1} = s_m - s_{m+1}$$

and SP's optimized profit function can be formulated accordingly:

$$\pi_{SP}^{BC} = \sum_{m=1}^{M} \int_{q_m^{BC}}^{q_{m+1}^{BC}} \left[s_m - c_m(q)\right] * f(q)\,\mathrm{d}q * X \tag{3.13}$$

Note that this expression assumes that $q_m^{BC} \leq q_{m+1}^{BC}\ \forall\ m$ and thus that no disposition option is strictly dominated and thereby redundant. Whether this assumption holds depends on the service payments s_m. We address this issue when analyzing the lessor's decision problem below.

L's Decision on Service Payments

L has to decide on the service payments that he offers to SP. These service payments are output-quality-dependent (Assumption 3C). As a profit-maximizing actor, L's aim is to maximize his profit function shown in Equation (3.14).

$$\pi_L^{BC} = \int_0^Q [p_{D(q)} - s_{D(q)}] * f(q)\,\mathrm{d}q * X \tag{3.14}$$

Per unit reprocessed to output quality level m, L pays the service payment s_m and receives p_m from the secondary or raw materials market. L's profit depends on SP's disposition decision, which again depends on L's choice of service payments. Therefore, to maximize his profits, L needs to take into account SP's reaction (i.e. $D(q)$) when deciding on the service payments. L's profit function can be expressed in terms of the Clip Levels derived in Equation 3.12:

$$\pi_L^{BC} = \sum_{m=1}^{M} [p_m - s_m] \int\limits_{\Delta c_m^{-1}(\Delta s_m)}^{\Delta c_{m+1}^{-1}(\Delta s_{m+1})} f(q)\,\mathrm{d}q * X \tag{3.15}$$

Recall from above that the expression for SP's optimal decision is only valid for

$$\Delta c_m^{-1}(\Delta s_m) \leq \Delta c_{m+1}^{-1}(\Delta s_{m+1}) \quad \forall \quad m = 1 \ldots (M-1). \tag{3.16}$$

We therefore impose this condition as a constraint for L's choice of the service payments. Note that we can do so without loss of generality since

$$\Delta c_m^{-1}(\Delta s_m) > \Delta c_{m+1}^{-1}(\Delta s_{m+1}) \quad \forall \quad m = 1 \ldots (M-1)$$

implies that this option m is redundant. In this case we can increase s_m such that

$$\Delta c_m^{-1}(\Delta s_m) = \Delta c_{m+1}^{-1}(\Delta s_{m+1}) \quad \forall \quad m = 1 \ldots (M-1),$$

without affecting π_L^{BC}.

We observe from Equation (3.12) that SP's disposition decision does not depend on the absolute values of s_m, but only on the difference between two successive payments s_m and s_{m+1}. We therefore rewrite s_m as

$$s_m = s_M + \sum_{m}^{M-1} \Delta s_{m+1} \quad \forall m.$$

To ensure that SP has an incentive to become part of the reverse SC and conduct the reprocessing services, it is required that at least the recycling costs[2] c_M are offset by the service payments received:

$$c_M \leq s_M \tag{3.17}$$

Using the aforementioned and cumulative distributions $F(q)$ instead of integrals, L's profit function (Equation 3.15) can be rewritten:

$$\begin{aligned}
\pi_L^{BC} &= \sum_{m=1}^{M} [p_m - s_m] \int\limits_{\Delta c_m^{-1}(\Delta s_m)}^{\Delta c_{m+1}^{-1}(\Delta s_{m+1})} f(q)\,\mathrm{d}q * X \\
&= \Bigg[-[p_1 - s_1] * F(0) \\
&\quad + \sum_{m=1}^{M-1} [[p_m - s_m] - [p_{m+1} - s_{m+1}]] * F(\Delta c_{m+1}^{-1}(\Delta s_{m+1})) \\
&\quad + [p_M - s_M] * F(Q) \Bigg] * X \\
&= \Bigg[-[p_1 - s_1] * F(0) \\
&\quad + \sum_{m=1}^{M-1} [\Delta p_{m+1} - \Delta s_{m+1}] * F(\Delta c_{m+1}^{-1}(\Delta s_{m+1})) \\
&\quad + [p_M - s_M] * F(Q) \Bigg] * X \\
&= \Bigg[\sum_{m=1}^{M-1} [\Delta p_{m+1} - \Delta s_{m+1}] * F(\Delta c_{m+1}^{-1}(\Delta s_{m+1})) \\
&\quad + [p_M - s_M] * F(Q) \Bigg] * X
\end{aligned} \tag{3.18}$$

Note that the last transformation of Equation (3.18) is due to the continuous distribution of input qualities which results in $-[p_1 - s_1] * F(0) = 0$.

[2]Or any other lower bound that guarantees SP a sufficiently large margin to participate

To summarize, we face a maximization problem subject to M inequality constraints:

$$\pi_L^{BC} = \left[\sum_{m=1}^{M-1} [\Delta p_{m+1} - \Delta s_{m+1}] * F(\Delta c_{m+1}^{-1}(\Delta s_{m+1})) \right. \\ \left. + [p_M - s_M] * F(Q) \right] * X \tag{3.19}$$

subject to

$$\Delta c_m^{-1}(\Delta s_m) \leq \Delta c_{m+1}^{-1}(\Delta s_{m+1}) \quad \forall \quad m = 1 \ldots (M-1) \tag{3.20}$$

$$c_M \leq s_M \tag{3.21}$$

We analyze this problem by considering the Karush-Kuhn-Tucker (KKT) conditions. The necessary KKT condition for a (local) maximum is given in Table 3.4.

$\frac{\partial L}{\partial s_M} \leq 0$	$s_M \geq 0$	$s_M * \frac{\partial L}{\partial s_M} = 0$
$\frac{\partial L}{\partial \Delta s_{m+1}} \leq 0$	$\Delta s_{m+1} \geq 0$	$\Delta s_{m+1} * \frac{\partial L}{\partial \Delta s_{m+1}} = 0$
$\frac{\partial L}{\partial \lambda_M} \geq 0$	$\lambda_M \geq 0$	$\lambda_M * \frac{\partial L}{\partial \lambda_M} = 0$
$\frac{\partial L}{\partial \lambda_m} \geq 0$	$\lambda_m \geq 0$	$\lambda_m * \frac{\partial L}{\partial \lambda_m} = 0$

Table 3.4: Karush-Kuhn-Tucker Condition for Local Maximum

We receive the following Lagrange equation (3.22) and KKT conditions (Equations (3.23) - (3.31)).

$$
\begin{aligned}
L(s_M, \Delta s_1 \ldots \Delta s_{M-1}, \lambda_1 \ldots \lambda_M) = \\
&\left[\sum_{m=1}^{M-1} [\Delta p_{m+1} - \Delta s_{m+1}] * F(\Delta c_{m+1}^{-1}(\Delta s_{m+1}))\right] * X \\
&+ [p_M - s_M] * F(Q) * X \\
&- \sum_{m=1}^{M-1} \lambda_m * [\Delta c_m^{-1}(\Delta s_m) - \Delta c_{m+1}^{-1}(\Delta s_{m+1})] \\
&- \lambda_M * [c_M - s_M]
\end{aligned}
\tag{3.22}
$$

$$
\frac{\partial L}{\partial s_M} = -F(Q) * X + \lambda_M \leq 0 \tag{3.23}
$$

$$
\begin{aligned}
\frac{\partial L}{\partial \Delta s_{m+1}} = \Bigg[& - F(\Delta c_{m+1}^{-1}(\Delta s_{m+1})) \\
& + [\Delta p_{m+1} - \Delta s_{m+1}] * f(\Delta c_m^{-1}(\Delta s_m)) * \frac{\mathrm{d}\Delta c_m^{-1}(\Delta s_m)}{\mathrm{d}\Delta s_m}\Bigg] * X \\
& + [\lambda_m - \lambda_{m+1}] * \frac{\mathrm{d}\Delta c_{m+1}^{-1}(\Delta s_{m+1})}{\mathrm{d}\Delta s_{m+1}} \leq 0
\end{aligned}
\tag{3.24}
$$

$$
\frac{\partial L}{\partial \lambda_M} = - [c_M - s_M] \geq 0 \tag{3.25}
$$

$$
\frac{\partial L}{\partial \lambda_m} = - [\Delta c_m^{-1}(\Delta s_m) - \Delta c_{m+1}(\Delta s_{m+1})] \geq 0 \tag{3.26}
$$

$$
s_M * \frac{\partial L}{\partial s_M} = 0 \tag{3.27}
$$

$$
\Delta s_{m+1} * \frac{\partial L}{\partial \Delta s_{m+1}} = 0 \tag{3.28}
$$

$$\lambda_M * \frac{\partial L}{\partial \lambda_M} = 0 \tag{3.29}$$

$$\lambda_m * \frac{\partial L}{\partial \lambda_m} = 0 \tag{3.30}$$

$$s_M, \Delta s_1 \dots \Delta s_{M-1}, \lambda_1 \dots \lambda_M \geq 0 \tag{3.31}$$

The goal of our further analysis is to check whether the decisions made in the current business case setting are reverse SC optimal. Therefore, we compare the profit function of a decentralized reverse SC (Equation (3.32)) and the reverse SC profit function of a central decision maker (Equation (3.9)).

$$\begin{aligned} \pi_{RSC}^{BC} &= \pi_L^{BC} + \pi_{SP}^{BC} \\ &= \sum_{m=1}^{M} [p_m - s_m] \int_{q_m^{BC}}^{q_{m+1}^{BC}} f(q)\,\mathrm{d}q * X + \sum_{m=1}^{M} \int_{q_m^{BC}}^{q_{m+1}^{BC}} [s_m - c_m(q)] * f(q)\,\mathrm{d}q * X \\ &= \sum_{m=1}^{M} \int_{q_m^{BC}}^{q_{m+1}^{BC}} [p_m - c_m(q)] * f(q)\,\mathrm{d}q * X \end{aligned} \tag{3.32}$$

We see that profit functions π_{RSC} and π_{RSC}^{BC} differ only in the borders of the intervals, thus in the Clip Levels. In an integrated channel, all the input qualities are reprocessed to the optimal output quality level m, meaning that each input quality level is brought to that output quality level that achieves the highest margin $p_m - c_m(q)$. Considering the decentralized reverse SC's profit, the margins are still $p_m - c_m(q)$, but the profit function differs with respect to the Clip Levels. In the case of changed Clip Levels, not all input qualities are reprocessed to the reverse SC optimal disposition option anymore. Hence, to gain a reverse SC optimal profit, it is necessary to achieve the Clip Levels of our benchmark. q_{m+1}^{BC} depends on the chosen service payments s_m (Equation 3.12), which makes a further analysis of these service payments necessary.

Due to the structure of the service payments (and resulting from that profit function), it is possible to analyze the service payments sequentially. We first consider L's choice of s_M.

As L is a profit-maximizing actor, from Equation (3.23) it follows that $\lambda_M > 0$. Hence, from Equation (3.29) we know that

$$\frac{\partial L}{\partial \lambda_M} \stackrel{!}{=} 0,$$

and we receive from Equation (3.25) that $c_M = s_M$. All subsequent payments s_m consist of this payment for recycling activities s_M and the sum from m to $(M-1)$ of Δs_{m+1}. The analysis of L's choice of Δs_{m+1} is separated into two parts. First, we consider the case in which the lower bound = upper bound of an interval (i); second, we turn to the case in which the lower bound < upper bound (ii).

In case (i), $\Delta c_m^{-1}(\Delta s_m) = \Delta c_{m+1}^{-1}(\Delta s_{m+1})$. Thus, the interval is empty and a certain disposition option m is optimal for none of the input quality levels. Compared with the integrated reverse SC, a previously optimal disposition option is no longer achieved. Hence, without any further analysis, we know that the chosen service payment cannot be reverse SC optimal.

In case (ii), $\Delta c_m^{-1}(\Delta s_m) < \Delta c_{m+1}^{-1}(\Delta s_{m+1}) \ \forall \ m$. Thus, all disposition options $m = 1 \ldots M$ are optimal for some input quality levels q. In this case, $\frac{\partial L}{\partial \lambda_m} > 0$ (Equation (3.26)) this results in $\lambda_m \stackrel{!}{=} 0$ (Equation (3.30)). Hence, Equation (3.24) becomes

$$\frac{\partial L}{\partial \Delta s_{m+1}} = \Bigg[- F(\Delta c_{m+1}^{-1}(\Delta s_{m+1})) + [\Delta p_{m+1} - \Delta s_{m+1}] * f(\Delta c_m^{-1}(\Delta s_m)) * \frac{\mathrm{d}\Delta c_m^{-1}(\Delta s_m)}{\mathrm{d}\Delta s_m} \Bigg] * X \leq 0 \tag{3.33}$$

Without further knowledge of the properties of the density function, we are not able to determine L's optimal service payments explicitly. Nevertheless, it is possible to show that L's profit-optimizing choice of Δs_{m+1} is not reverse SC optimal.

Comparing the two Clip Levels (Equation (3.7) and Equation (3.12)) one obtains

$$\Delta c_{m+1}^{-1} \underbrace{(p_m - p_{m+1})}_{:=\Delta p_{m+1}} \stackrel{!}{=} \Delta c_{m+1}^{-1} \underbrace{(s_m - s_{m+1})}_{:=\Delta s_{m+1}} \tag{3.34}$$

which means that to achieve the central decision maker's Clip Levels,

$$\Delta p_{m+1} \stackrel{!}{=} \Delta s_{m+1}. \tag{3.35}$$

If Equation (3.35) is fulfilled, Equation (3.33) < 0, thus from Equation (3.28) it follows that $\Delta s_{m+1} \overset{!}{=} 0$. No difference between two successive service payments means that the lower and upper bounds of some intervals are equal to each other, which - as argued before - is not reverse supply chain optimal.

To summarize, without knowledge of the probability distribution, it is not possible to specify the exact values of the service payments that L would choose to optimize his profits. The specific solution depends on the shape of the probability distribution function $f(\cdot)$ and needs to fulfill Equations (3.24), (3.28), and (3.31) to maximize L's profit function. However, a very interesting finding on the choice of service payments needs to be emphasized. Even without any concrete information on the probability distribution, we know that L's choice is not reverse SC optimal.

Before we come to the discussion of this result, we make this analysis a little more concrete. We analyze the decentralized SC for the specific case of linear cost functions and uniformly distributed input qualities. These characteristics will be used again in our numerical example in Section 3.4.

Consider the disposition options and corresponding profit margins b_m with $m = 1 \ldots 3$ introduced in the central setting. In Figure 3.7, we depict these disposition options, the corresponding profit margins, and the resulting Clip Levels q_{m+1}. Furthermore, we include the shift of profit margin functions and the resulting new Clip Levels q_{m+1}^{BC} in the case of decentralized decision making. While the reprocessing costs are independent of the actor responsible for reprocessing activities, the received payments vary from the centralized to the decentralized setting. Hence, while the slope values c_m of the profit margin functions remain, the intercept values change from p_m in the case of the central decision maker to s_m in the case of decentral decision making. This results in a parallel shift down of $b_m(q)$ by $p_m - s_m$. In the example, L's optimal choice of service payments s_m is depicted. The profit margin functions $b_m^{BC}(q)$ relevant to SP's choice of the Clip Levels q_{m+1}^{BC} are given by $b_m^{BC}(q) = s_m - c_m * q$.

To determine L's choice of service payments, his profits need to be taken into consideration. L's profit resulting from SP's disposition decision is shown as the shaded areas in Figure 3.8. The shaded areas result from the following consideration: per unit of a returned product of input quality q reprocessed to m, L receives p_m and has to pay s_m. Thus, in the case of $m = 1$, L's profit results from

$$(p_1 - s_1) * \underbrace{(q_2^{BC} - q_1^{BC})}_{\text{Interval of input qualities that is reprocessed to } m=1} .$$

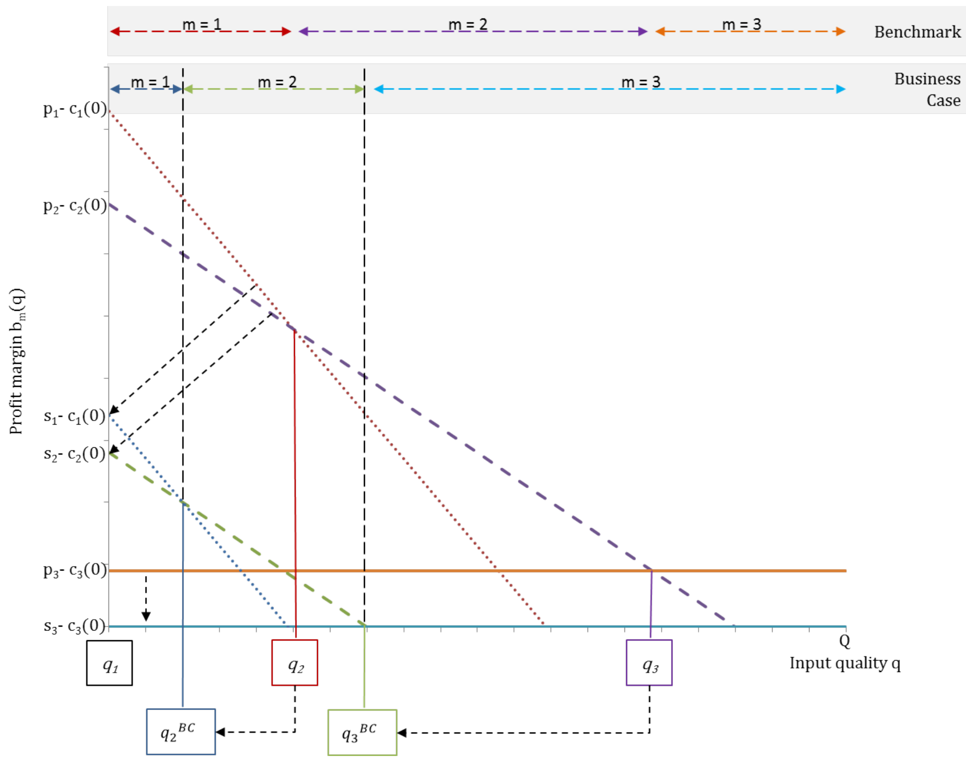


Figure 3.7: Change of Profit Margins and Clip Levels Compared to the Integrated Setting, Given Linear Costs and Uniformly Distributed Input Qualities

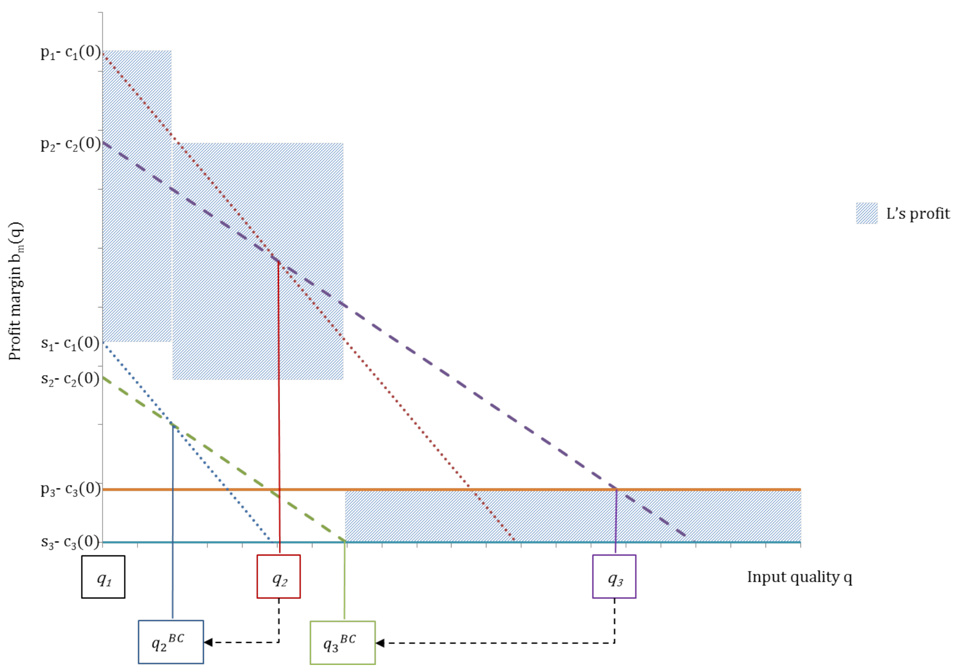


Figure 3.8: Resulting Profit of L, Given Linear Costs and Uniformly Distributed Input Qualities

As a profit-maximizing actor, his objective is to maximize these areas by optimizing his profit function:

$$\pi_L^{BC} = \left[\sum_{m=1}^{M-1} [p_m - s_m] * F\left(\left[\underbrace{\frac{s_m - s_{m+1}}{c_m - c_{m+1}}}_{:=q_{m+1}^{BC}} - \underbrace{\frac{s_{m-1} - s_m}{c_{m-1} - c_m}}_{:=q_m^{BC}} \right] \right) \right.$$

$$\left. + [p_M - s_M] * F\left(\left[Q - \underbrace{\frac{s_{M-1} - s_M}{c_{M-1} - c_M}}_{:=q_M^{BC}} \right] \right) \right] * X \tag{3.36}$$

$$= \left[\sum_{m=1}^{M-1} [\Delta p_{m+1} - \Delta s_{m+1}] * F\left(\frac{\Delta s_{m+1}}{\Delta c_{m+1}} \right) \right.$$
$$\left. + [p_M - s_M] * F(Q) \right] * X$$

subject to

$$\frac{\Delta s_m}{\Delta c_m} \leq \frac{\Delta s_{m+1}}{\Delta c_{m+1}} \quad \forall \ \ m = 1 \ldots (M-1) \tag{3.37}$$

$$c_M \leq s_M \tag{3.38}$$

Clip Levels are determined by comparing two successive profit margins b_m^{BC} and b_{m+1}^{BC}:

$$s_m - c_m * q \stackrel{!}{=} s_{m+1} - c_{m+1} * q$$
$$q_{m+1}^{BC} = \frac{\Delta s_{m+1}}{\Delta c_{m+1}}$$

Under the assumption of a concave objective function and linear constraints, KKT is sufficient to determine L's optimal choice of service payments.

$$
\begin{aligned}
L(s_M, \Delta s_1 \dots \Delta s_{M-1}, \lambda_1 \dots \lambda_M) = {} & \left[\sum_{m=1}^{M-1} [\Delta p_{m+1} - \Delta s_{m+1}] * F\left(\frac{\Delta s_{m+1}}{\Delta c_{m+1}} \right) \right] * X \\
& + [p_M - s_M] * F(Q) * X \\
& - \sum_{m=1}^{M-1} \lambda_m \left[\frac{\Delta s_m}{\Delta c_m} - \frac{\Delta s_{m+1}}{\Delta c_{m+1}} \right] \\
& - \lambda_M * [c_M - s_M]
\end{aligned}
\tag{3.39}
$$

$$
\frac{\partial L}{\partial s_M} = -F(Q) * X + \lambda_M \leq 0 \tag{3.40}
$$

$$
\begin{aligned}
\frac{\partial L}{\partial \Delta s_{m+1}} = {} & [\Delta p_{m+1} - 2 * \Delta s_{m+1}] * \frac{1}{\Delta c_{m+1}} * \frac{1}{Q} * X \\
& + [\lambda_m - \lambda_{m+1}] * \frac{1}{\Delta c_{m+1}} \leq 0
\end{aligned}
\tag{3.41}
$$

$$
\frac{\partial L}{\partial \lambda_M} = -[c_M - s_M] \geq 0 \tag{3.42}
$$

$$
\frac{\partial L}{\partial \lambda_m} = -\left[\frac{\Delta s_m}{\Delta c_m} - \frac{\Delta s_{m+1}}{\Delta c_{m+1}} \right] \geq 0 \tag{3.43}
$$

$$
s_M * \frac{\partial L}{\partial s_M} = 0 \tag{3.44}
$$

$$
\Delta s_{m+1} * \frac{\partial L}{\partial \Delta s_{m+1}} = 0 \tag{3.45}
$$

$$
\lambda_M * \frac{\partial L}{\partial \lambda_M} = 0 \tag{3.46}
$$

$$\lambda_m * \frac{\partial L}{\partial \lambda_m} = 0 \tag{3.47}$$

$$s_M, \Delta s_1 \ldots \Delta s_{M-1}, \lambda_1 \ldots \lambda_M \geq 0 \tag{3.48}$$

Analogous to the general analysis we derive from Equations (3.40), (3.42), and (3.46) that $s_M \stackrel{!}{=} c_M$. Analogous to case (ii) above, only if

$$\frac{\Delta s_m}{\Delta c_m} < \frac{\Delta s_{m+1}}{\Delta c_{m+1}} \tag{3.49}$$

it is assured that all not redundant output quality levels of a centralized case are achieved. Thus Equation (3.43) > 0, which requires $\lambda_m \stackrel{!}{=} 0$ to fulfill Equation (3.47). Hence Equation (3.41) becomes

$$\frac{\partial L}{\partial \Delta s_{m+1}} = [\Delta p_{m+1} - 2 * \Delta s_{m+1}] * \frac{1}{\Delta c_{m+1}} * \frac{1}{Q} * X \leq 0. \tag{3.50}$$

Furthermore, as upper and lower bounds are not identical, it is given that $\Delta s_{m+1} > 0$. Hence to fulfill Equation (3.45), Equation (3.50) $\stackrel{!}{=} 0$. Finally, we receive from Equation (3.50) the following result for L's choice of service payments:

$$\Delta s_{m+1} = \frac{\Delta p_{m+1}}{2} \tag{3.51}$$

Since in Equation (3.51) $\Delta s_{m+1} \neq \Delta p_{m+1}$ the service payments received under the assumption of linear costs and uniformly distributed input qualities q, are not equal to the reverse SC optimal choice of service payments.

Because L will not transfer Δp_{m+1} completely, but $\Delta s_{m+1} = \frac{\Delta p_{m+1}}{2}$, Clip Levels of a decentralized decision maker $(\frac{\Delta s_{m+1}}{\Delta c_{m+1}})$ will be smaller than those of a central decision maker $(\frac{\Delta p_{m+1}}{\Delta c_{m+1}})$. Compared with the integrated case, this results in smaller intervals within which an output quality level m is most beneficial. This holds for all intervals except for the "last" one, that is, the interval within which the input qualities are brought to the worst achieved output quality level. For this interval, two possibilities need to be distinguished: either it becomes larger or it becomes smaller as well and - compared with the integrated SC - higher, that is, worse output quality levels are achieved. Hence, compared with the integrated reverse SC, fewer input quality levels are reprocessed to the output option achieving higher market prices and more input quality levels are reprocessed to a worse output quality level, achieving lower market prices. Hence, depending on the actual batch structure (with respect to quality), the reverse SC profit is affected.

Besides this negative impact on the reverse SC profit, there is a further important aspect to mention. Smaller Clip Levels will result in the fact that returned products of a certain input quality possibly are reprocessed to suboptimal output quality levels. Accordingly, some input quality levels that are in fact reusable may be recycled - thus, the inherent value is wasted. This factor is optimal neither with respect to profit considerations nor with regard to environmental objectives. For all the disposition options in between, the change in the interval size depends on the characteristics of the situation considered.

In the following, we return to the general case. Without knowledge of the probability distribution of the input qualities, we cannot state L's actual choice of service payments. However, due to L's preference to choose $\Delta s_{m+1} \neq \Delta p_{m+1}$, we know that Clip Levels will not be optimal. We know that $\Delta s_{m+1} < \Delta p_{m+1}$, resulting in Clip Levels that are smaller than those of a central decision maker. In contrast to the above special case, we cannot tell exactly how much smaller the Clip Levels are compared with the integrated SC. However, it is still possible to make statements on the effects on two of the intervals within which a certain disposition option m is optimal:

1. The interval within which $m = 1$ is the most beneficial option becomes smaller than in the integrated reverse SC, that is, compared with the central decision maker, fewer input quality levels are reprocessed to $m = 1$.

2. Either the interval of the worst achieved output quality level becomes larger than in the integrated reverse SC or worse disposition option becomes optimal for some input quality levels.

The rationale behind this SC deficiency is that the achievable margin of $p_m - c_m(q)$ is shared between the two actors involved:

$$\underbrace{p_m - s_m}_{L} + \underbrace{s_m - c_m(q)}_{SP} . \tag{3.52}$$

While a central decision maker receives market prices p_m, in a decentralized reverse SC, SP as the reprocessing actor receives s_m from L. L's optimal choice of service payments $s_m < p_m$ results in a lower incentive of the reprocessing actor, SP, to incur higher reprocessing costs $c_m(q)$. Hence, compared with the integrated reverse SC, only better input qualities q (which incur lower costs) are reprocessed to m.

3.3.3 Decentralized Decision Makers - The Service Provider Acquires Product Returns

To overcome the reverse SC deficiency identified in the analysis of our business case, we consider an alternative contract structure and show that it coordinates the setting. The aim is to gain reverse SC optimal profits by achieving reverse SC optimal Clip Levels. In Chapter 2, we provided an overview of the mechanisms coordinating diverse forward SC settings. Some of these mechanisms have been transferred successfully to a reverse SC setting. Based on our discussions with ARC, we investigate the idea that the reprocessing company not only executes the reprocessing activities but also assumes ownership of the returned products.

In this section, L sells all of his end-of-lease products to SP[3] and receives a certain acquisition price per unit. It is assumed that the same acquisition price is paid for each return regardless of the future disposition decision. SP becomes the new owner of the returned products, makes the disposition decision, and conducts the required reprocessing activities. As the owner of the reprocessed products, SP receives the achievable market prices and has to pay for the reprocessing costs as well as the acquisition price. The corresponding financial flows are depicted in Figure 3.9. The material flow remains as in the current business case setting (Figure 3.6).

In this setting, again two independent actors have to make a decision that influences the reverse SC's profit. First, L decides on the acquisition price and second, SP makes the disposition decision. This disposition decision is influenced by several factors. As in the previous settings, the actual input quality of the returned products and the resulting reprocessing costs are of relevance. Now, though, the SP receives the market prices on the one hand and additionally has to take into account acquisition price on the other hand. As SP's profit is affected by the acquisition price, L needs to consider the effects of his choice of the acquisition price in his decision making.

SP's Disposition Decision

In this setting, SP receives the market prices p_m. Besides the reprocessing cost $c_m(q)$, he has to pay the acquisition price p_{ac} per unit. p_{ac} is determined by L. As L cannot control for the input qualities, p_{ac} is not determined for each input quality individually but is based on an expected distribution of input qualities and further considerations that we address below. Thus, unsorted batches are sold for a

[3]Although SP no longer acts as the service provider, we retain the naming of the actors of the previous sections.

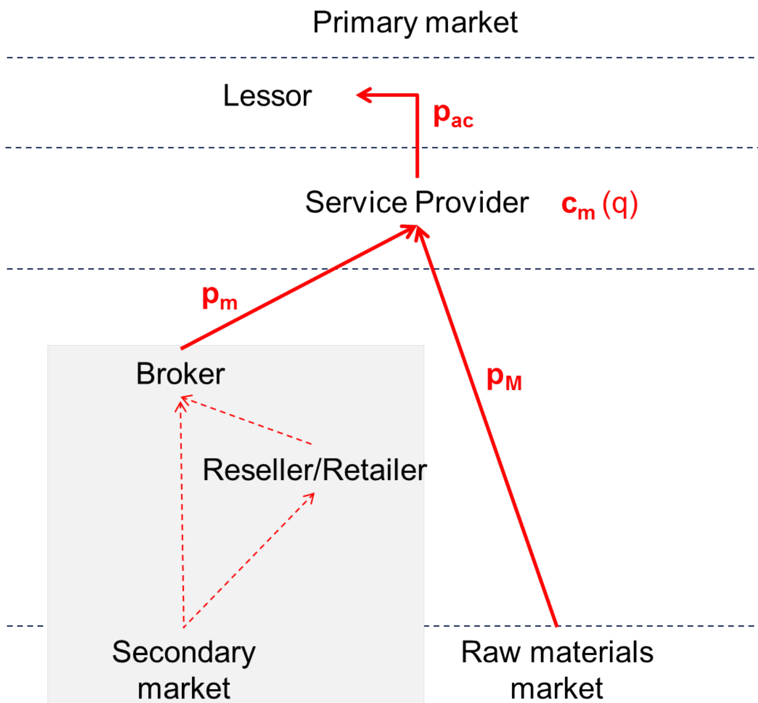


Figure 3.9: Financial Flow Coordinated Actors

predetermined p_{ac} per returned unit.

SP's profit function is shown in Equation (3.53). It is still SP's goal to maximize his profits (cf. Assumption 5) by choosing the optimal disposition decision $D(q)$ for all q.

$$\pi_{SP}^{AC} = \int_0^Q [p_{D(q)} - c_{D(q)}(q)] * f(q)\, \mathrm{d}q * X - p_{ac} * X \tag{3.53}$$

Equation (3.53) is identical to Equation (3.1) except for $-p_{ac} * X$. The acquisition price is independent of the disposition decision and does not influence SP's disposition. This means that SP faces the same decision as a central decision maker, which results in identical Clip Levels as in our benchmark (Equation (3.7)):

$$q_{m+1}^{AC} = \Delta c_{m+1}^{-1}(\Delta p_{m+1}) = q_{m+1} \quad \forall m = 1 \ldots (M-1).$$

with

$$q_1^{AC} = q_1 = 0$$
$$q_{M+1}^{AC} = q_{M+1} = Q$$

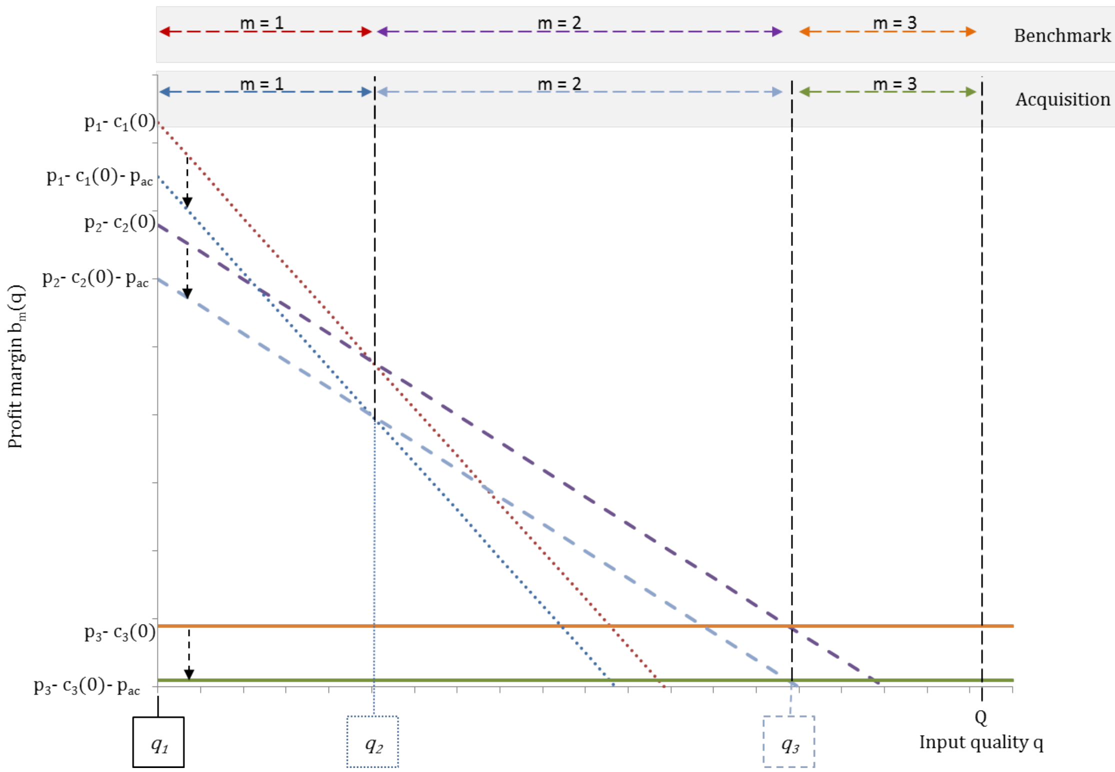


Figure 3.10: Comparison of Clip Levels in the Benchmark and in Case of Acquisition of Returned Products

Achieving the same Clip Levels means that under this contract type the same disposition decision as in the centralized case is made. Hence, all the returned products are reprocessed to the reverse SC optimal output quality level.

Using the simplified example of linear cost functions and uniformly distributed input qualities, Figure 3.10 shows the Clip Levels in the case that the SP acquires the returned products compared with our benchmark.

Having SP acquire the returns coordinates the disposition decision and results in reverse SC optimal profits. Compared with the current business case setting, in the coordinated case additional profits are gained in the CLSC. The question than arises of how to share these additional benefits between L and SP, that is, how to determine p_{ac}.

L's Decision on the Acquisition Price

L offers returned end-of-lease units and decides on p_{ac}. This predetermined acquisition price p_{ac} per unit sold to SP is the only payment that L has to consider. Hence, his profit function is given by

$$\pi_L^{AC} = p_{ac} * X \tag{3.54}$$

L's profit no longer depends on the disposition decision but only on the choice of p_{ac}. To achieve his goal of profit maximization, L wants to maximize p_{ac}. However, L has to consider SP's reaction. As p_{ac} has a negative impact on SP's profit, L has to take into account whether SP has an incentive - by means of profit - to participate in the contract or not. Based on the participation constraints of both actors, upper and lower bounds for p_{ac} can be stated.

From L's profit function, we can derive a lower bound of the acquisition price. If L's profit is lower than his current (business case) profit, L has no incentive to change the setting. Hence, a lower bound can be stated (Equation (3.55)).

$$\begin{aligned} \pi_L^{AC} &\geq \pi_L^{BC} \\ p_{ac} * X &\overset{!}{\geq} \pi_L^{BC} \\ p_{ac} &\geq \frac{\pi_L^{BC}}{X} \end{aligned} \tag{3.55}$$

An upper bound of p_{ac} can be stated from the argument that SP's profit needs to be positive (Equation (3.57)).

$$\pi_{SP}^{AC} = \underbrace{\sum_{m=1}^{M} \int_{q_m}^{q_{m+1}} [p_m - c_m(q)] * f(q)\,\mathrm{d}q * X}_{:=\pi_{RSC}^{C}} - p_{ac} * X \tag{3.56}$$

$$\begin{aligned} \pi_{SP}^{AC} &\overset{!}{>} 0 \\ p_{ac} &< \frac{\pi_{RSC}^{C}}{X} \end{aligned} \tag{3.57}$$

Alternatively, one can argue that SP, as well, takes part only if $\pi_{SP}^{AC} \geq \pi_{SP}^{BC}$. This results in a tighter upper bound:

$$\pi_{RSC}^{C} - p_{ac} * X \geq \pi_{SP}^{BC}$$

$$p_{ac} \leq \frac{\pi_{RSC}^{C} - \pi_{SP}^{BC}}{X}. \tag{3.58}$$

We show that this rather simple strategy results in the same disposition decisions as in the case of a central decision maker: all the returns are reprocessed to the optimal output quality level from a reverse SC perspective. Consequently, the reverse SC profit equals the optimal reverse SC profit achieved by a central decision maker. The resulting reverse SC profit is split between L and SP depending on the acquisition price. Thereby, the negotiations between SP and L on p_{ac} take place within the upper and lower bounds introduced above.[4]

Summarizing, this contract does not only coordinate the decentralized reverse SC, but furthermore it is a very flexible solution. While the aforementioned bounds are based on pure profit considerations, the negotiation process itself may be influenced by market power and certain risks. One major risk that needs to be considered is the risk of uncertainty with regard to the actual input quality of the returned products. Above, we assume quality-independent acquisition prices. This assumption is realistic in our case, as we observed long-term contracts between L and SP. In such settings, this assumption is justified as the actual realization of the distribution of input qualities within one batch may differ from the expected one, nevertheless, in the long run, the deviations should be balanced.

However, a disposition independent p_{ac} bears some risk that needs to be considered in the case of interactions that take place only once. In such settings, it can be expected that SP would renegotiate p_{ac} if the grading shows that the input qualities within a batch are worse than announced. The possibility to renegotiate shifts the risk to L, as the risk of the actual quality means for L that the determined p_{ac} might be too low for certain batch structures, but on the other hand L needs to lower p_{ac} in the case of lower qualities than announced. In such a setting, it may be assumed that L has the incentive to choose an unreasonably high price at the beginning as L knows that SP will claim a lower price for returns of low quality.

Taking one step further, such a renegotiation mechanism could also be introduced by L to renegotiate with his primary customers in the case that the input quality does not match the agreed return quality level. As we regard the interplay between SP and L, this consideration is beyond our recent focus. However, it is certainly an interesting idea for further research (cf. Chapter 3.5).

Besides SP's profit-driven considerations regarding whether to take part or not, for the implementation of the suggested contract it is also of interest whether L

[4] The range of the acquisition price negotiation is illustrated in the numerical example (Section 3.4, Figure 3.13).

is interested in selling its end-of-lease returns to a reprocessing company at all. Until now, we have considered lessors in general. When it comes to selling the returned IT hardware, the kind of company that is acting as lessor probably becomes relevant. Potentially, two kinds of companies need to be distinguished here: OEMs and financial service providers. In the case of an OEM, protection of the brand image is a relevant aspect (Ferguson, 2010). Many OEMs are afraid of losing control of the reprocessing activities of products that are labeled with their brand. Thus, the consideration of potential damage to the brand image needs to be taken into account here as well. This aspect is not relevant in the case that a financial service provider acts as the lessor.

3.4 Numerical Example

In the following, we illustrate our analysis on the basis of a short example. First, the data used in this example are presented; then the decisions made in the aforementioned settings are shown.

A batch consisting of $X = 100$ end-of lease units of an IBM notebook (Intel Core 2 Duo, 1.6 Ghz, and 14" screen) is considered in the following. These notebooks can be of different, continuous input qualities $q \in [0; Q]$. Input quality $q = 0$ represents product returns in an "as new" condition. The other end of the input quality spectrum is given by Q. Returns of input quality Q require severe repair and have cosmetic issues. To allow for a variety of input qualities, we chose to scale $Q = 5$.

In this example, $m = 5$ different output quality levels can be achieved. The worst output quality level $M = 5$ is the recycling option. All the other options represent recovery of the returned product. The possibility to upgrade a returned unit to achieve higher market values is included in our example. We consider two different components that can be upgraded: the random-access memory (RAM) and the hard disk drive (HDD). The current version of returned notebooks includes a HDD of 100 GB and a 2 GB RAM. Without any upgrading, output quality level $m = 4$ can be achieved. Thus, depending on the input quality level, repair, cosmetic rework, and exchange of defective parts need to be conducted. Better output quality levels $m < 4$ are achieved by updating one of the two mentioned components or both of them. An upgrade to a 200 GB hard disk ($m = 3$) is possible as well as additional RAM of 2 GB ($m = 2$). The best standard ($m = 1$) is achieved in the case that both components are updated.

The achievable market prices attached to certain product configurations are

m	RAM	Hard disk	Price
1	4 GB	200 GB HDD	188 €
2	4 GB	100 GB HDD	177 €
3	2 GB	200 GB HDD	163 €
4	2 GB	100 GB HDD	152 €
5	Recycling		5 €

Table 3.5: Prices on Raw Materials Market and Secondary Market

taken from the so-called BFL IT Index.[5] The index is provided by BFL Leasing, which is part of Volksbanken Raiffeisenbanken Leasing Group. BFL Leasing refers to itself as an IT specialist that can look back on more than thirty years of experience in IT financing. This index is also used by ARC to forecast prices on secondary markets. The achievable market prices depend on the technological standard of the components included. These output-quality-dependent prices are shown in Table 3.5. The price achievable on the raw materials market is assumed to be € 5 per notebook.[6]

An underlying aspect of the disposition decision is the cost $c_m(q)$ of reprocessing a unit of input quality q to output quality m. Neither the BFL IT Index nor ARC provides any information concerning reprocessing costs. Therefore, we need to refer to literature evidence at this point. In a study on trade-in rebates for IT equipment, Agrawal et al. (2008) provide information on remanufacturing costs as a fraction of manufacturing costs. As we are studying the same industry, we assume this ratio to be appropriate for the following example.

To achieve an output quality level m, input-quality-dependent and linear reprocessing costs $c_m(q)$ occur, with $c_m(q) = cost\ ratio_m(q) *$ manufacturing cost. In our example, manufacturing costs of € 375 are assumed. According to Agrawal et al. (2008), for IT hardware, the cost ratio is between 0.04 and 0.20. There is no clear statement in the paper, but as no upgrading is mentioned, it may be assumed that this ratio is valid for reprocessing to a standard technological level, which corresponds to $m = 4$ in our example. Besides the output quality level m, the input quality q of returned products is a driver of the reprocessing costs. To have the possibility to be within the suggested ratio range, we determine the cost ratio to reprocess one return of input quality level q to $m = 4$ to be 0.04. Hence, depending on the input quality $q \in [0; 5]$, we receive cost ratios $\in [0.04; 0.2]$.

[5] http://www.bfl-it-index.de

[6] According to WDR / SWR / BR-alpha (2013), one ton of notebooks contains precious metals that are worth about € 1700. Assuming a weight of 2.5 kilos per laptop, $\frac{1700\frac{Euro}{t}}{1000\frac{kg}{t}} * 2.5\frac{kg}{notebook} \approx 5\frac{Euro}{notebook}$ are considered here as achievable price on the raw materials market.

m	*cost ratio*$_m(q)$
1	$0.15 * q$
2	$0.07 * q$
3	$0.05 * q$
4	$0.04 * q$
5	quality independent recycling costs $c_5(q) = 1$ €

Table 3.6: Reprocessing Cost Ratios

Our model allows for product upgrades; thus, the idea of ratios needs to be extended accordingly. To end up with reasonable ratios for all input-output quality level combinations, we decide that for all output quality levels the ratio needs to be within the given range for at least the best input quality $q = 1$. The chosen cost ratios to reprocess returns of input quality q to output quality m are given in Table 3.6. Due to the assumption of quality-independent and constant recycling costs (Assumption 4C), there is no ratio needed for $m = 5$. However, even in the case that a product is recycled, reprocessing costs occur due to handling costs such as grading, data erasure, and recycling activities themselves. The costs of these quality-independent activities are assumed to be € 1.

Finally, we need information on the input quality probabilities of the returned products. In the literature, there is no generally established probability distribution that represents input qualities. To keep the example simple, we choose a uniform distribution. This is in line with Galbreth and Blackburn (2010), for example. The authors justify their assumption by the fact that it captures a high degree of uncertainty, which is common in the remanufacturing industry.

Central Decision Maker - Benchmark

We start by calculating the SC optimal disposition decision. In Figure 3.11, the profit margin function $b_m(q) = p_m - c_m(q)$ of each output quality level is depicted and the chosen disposition options are highlighted. We assume a profit-maximizing decision maker; thus, for each input quality level, the disposition option that results in the highest profit margin is chosen. The intersections of $b_m(q)$ and $b_{m+1}(q)$ represent the Clip Levels. Here, Clip Levels can be calculated explicitly by

$$q_{m+1} = \frac{p_m - p_{m+1}}{c_m - c_{m+1}}.$$

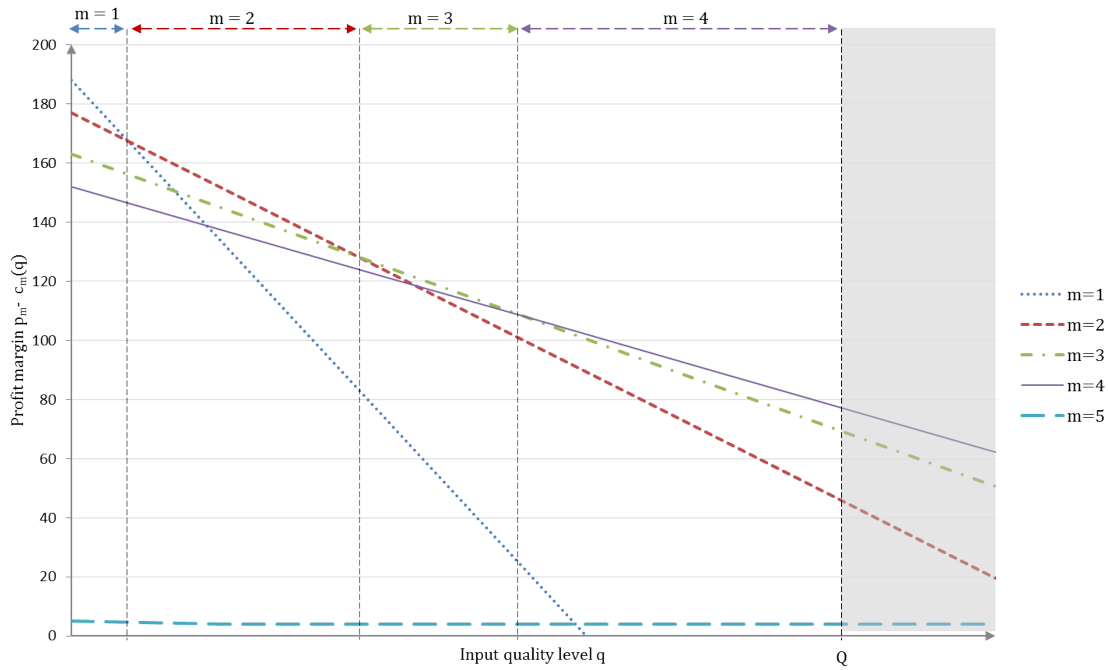


Figure 3.11: Profit Margins and Disposition Decision of a Central Decision Maker

Given the data introduced, the following disposition decisions are made in the case of a central decision maker:

q	$D(q)$
$q \in [0.00; 0.37)$	$m = 1$
$q \in [0.37; 1.87)$	$m = 2$
$q \in [1.87; 2.93)$	$m = 3$
$q \in [2.93; 5.00)$	$m = 4$

Table 3.7: Disposition Decision of a Central Decision Maker

This results in a profit of € 14,928 for a centralized reverse SC in our example.[7]

Decentralized Decision Makers - The Situation of the Business Case

We compare the outcome of the decentralized strategy observed in the business case with the above centralized decisions and resulting reverse SC profit. L's profit depends on SP's disposition decision, which depends on L's choice of service payments. Hence, anticipating SP's disposition decision, L determines the service payments. Due to an assumed uniform distribution function of input quality levels, we are able to determine the optimal values for the service payments according to Equa-

[7]Remark: In this example, the recycling option ($m = 5$) is chosen for none of the input quality classes. However, cases like breakdowns of particularly expensive components, like the motherboard, are not covered by the exemplary cost structure.

s_1	92.50
s_2	87.00
s_3	80.00
s_4	74.50
s_5	1.00

Table 3.8: L's Optimal Decision on Service Payments [in €]

tion (3.51). Analogous to the considerations in Chapter 3.3.2, the service payments for recycling are fixed as equal to the recycling cost. L's profit-optimizing choice of service payments is given in Table 3.8.

Based on these service payments and the grading outcome, SP makes the disposition decision. SP's profit margin functions $b_m^{BC}(q)$ are depicted in Figure 3.12. Again, the profit-optimizing actor SP chooses for each input quality level the disposition option that results in the highest profit margin. The chosen disposition options are highlighted in Figure 3.12. Again, the intersection of successive profit margin functions need to be determined and Clip Levels are given by

$$q_{m+1}^{BC} = \frac{s_m - s_{m+1}}{c_m - c_{m+1}}.$$

Given the data introduced, a decentralized decision maker makes the following disposition decision:

q	$D(q)$
$q \in [0.00; 0.18)$	$m = 1$
$q \in [0.18; 0.93)$	$m = 2$
$q \in [0.93; 1.47)$	$m = 3$
$q \in [1.47; 5.00)$	$m = 4$

Table 3.9: Disposition Decision of a Decentral Decision Maker

By comparing the chosen disposition options of the integrated and the decentralized reverse SC, it can easily be seen that they differ from each other. In both settings, the returned products are reprocessed to output quality levels $m = 1 \dots 4$ and none of the input quality levels $q \in [0; 5]$ is reprocessed to $m = M$. However, the disposition decisions differ with respect to the Clip Levels and thus which input quality levels are reprocessed to which disposition option. The profits that result from the decentralized decision maker's disposition decision are shown in Table 3.10. Taking the sum of both actors' profit, we receive a reverse SC profit of € 13,732. Thus, the reverse SC profit in the current decentralized setting is below the profit that is achieved in the centralized setting. The uncoordinated strategy results in a

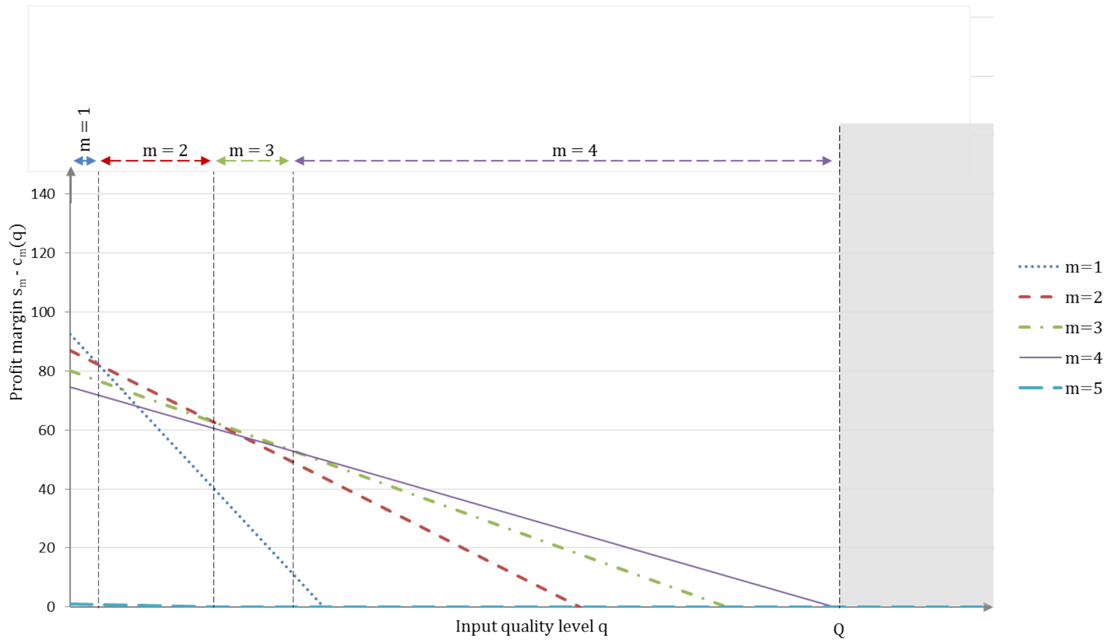


Figure 3.12: Profit Margins for SP and Disposition Decision of a Decentral Decision Maker

Lessor:	8062 €
Service Provider:	5670 €
Reverse Supply Chain:	13,732 €

Table 3.10: Profits Business Case

reverse SC profit decrease of 8% for the example data.

Decentralized Decision Makers - The Service Provider Acquires Product Returns
Making SP acquire all the returned products for a certain price p_{ac} was shown to coordinate the introduced problem setting. According to this strategy, the disposition decisions of a decentralized decision maker are made as they are made by a centralized decision maker. Therefore, the resulting reverse SC profit is equal to that of the integrated reverse SC. The remaining question is how this (additional) reverse SC profit is split between the two actors. As already explained in the analysis section, different factors influence the determination of this acquisition price. Regardless of the knowledge of the strength of different factors, we can state a lower and two potential upper bounds of p_{ac}. According to these boundaries (Equations (3.55) and (3.58), or (3.57)), in our example, the negotiation of the acquisition price takes place in the range of € 80.62 to € 92.58 (€ 149.28). In Figure 3.13, different actors' profits are depicted depending on the various possible acquisition prices.

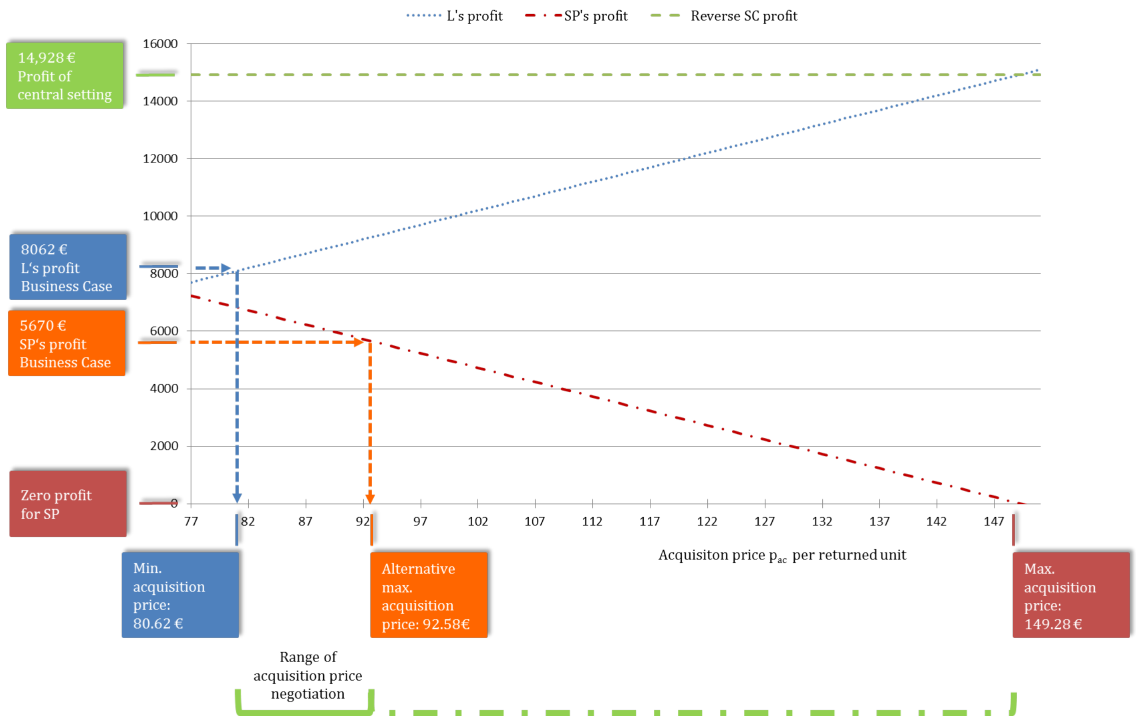


Figure 3.13: Split of (Additional) Reverse Supply Chain Profit Depending on the Acquisition Price

3.5 Discussion

We introduced the ARC business case (Section 1.3) and highlighted the need to coordinate the disposition decision (Section 1.4). The focus of our analysis is on two actors, L and SP. As argued before, this is a reasonable limitation due to the leasing context and long-term agreements with brokers. Furthermore, due to the ongoing trend in the IT hardware industry to outsource production and focus on research and development, the involvement of service providers as reprocessing actors can be expected to be of increasing interest.

The decisions in the decentralized setting observed in the business case are shown to be not reverse SC optimal (Section 3.3.2). To overcome this SC deficiency, we introduced an alternative strategy in Section 3.3.3. The strategy suggests that the current material flows remain, but the financial flows are changed, due to the acquisition of product returns by SP. It was shown that reverse SC optimal profits are achievable by this strategy. We found upper and lower bounds of the range within which the negotiation on the acquisition price takes place. Furthermore, we highlighted the considerations that influence this negotiation process.

Our analysis provides helpful results for the reverse SC setting considered and provides an easy-to-implement strategy that coordinates the disposition decision in a

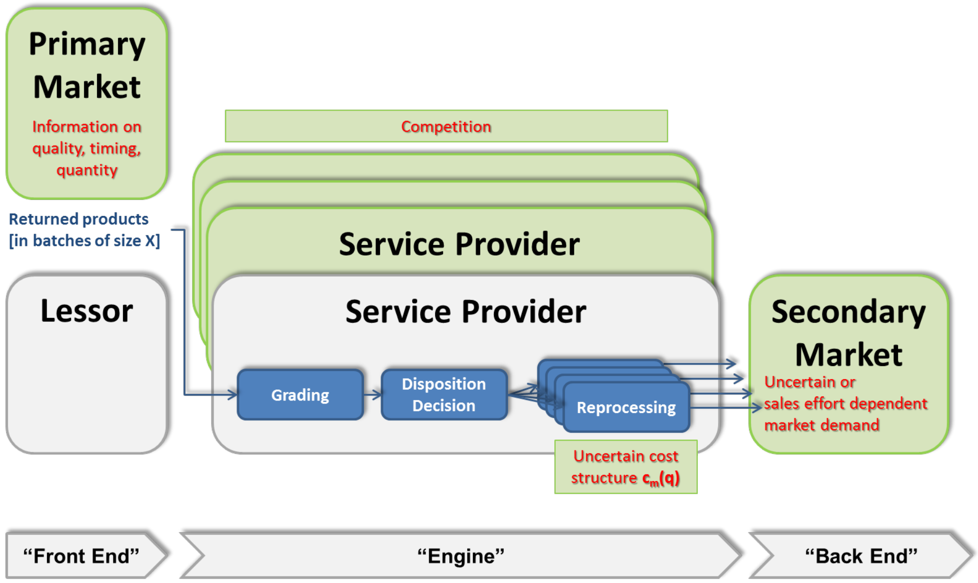


Figure 3.14: Relaxation of Assumptions and Suggested Extensions

SC with two decentralized decision makers. The idea originates from considerations in this direction observed during our discussions with ARC. However, there might be environments in which the OEM does not want third-party remanufacturers to buy, reprocess, and resell its products. Therefore, future research may address alternative mechanisms. The literature on the coordination of forward SCs may offer valuable insights to be used as a starting point.

We use the rest of this section to discuss the effects of relaxing some of the assumptions made in Section 3.2. An overview of the issues discussed below is provided in Figure 3.14.

In our analysis, we assume two monopolistic actors. This setting is reasonable as a historically grown relationship exists in the business case considered. However, this situation may change due to increasing numbers of third-party manufacturers (Ferguson, 2010) as well as due to IT brokers seeking to extend their business by including reprocessing activities (cf. Section 1.3.2).

In settings of one monopolistic lessor working with competing third-party reprocessing companies, there is still no need for the lessor to adapt his service payments to a reverse SC optimal level of $s_m = p_m$. Hence, as long as the cost functions $c_m(q)$ of the reprocessing actors are not affected, the identified reverse SC deficiency is expected to remain. How Clip Levels are actually affected by such an adapted setting requires further analysis.

The contract type to make SP acquire end-of-lease products suggested in Section 3.3.3 coordinates this changed setting as well. Although competing SPs are considered, each SP makes the reverse SC optimal disposition decision, as the financial flows between L and SP remain. However, in the case of our proposed coordinating strategy, the competition between SPs possibly strengthens L's position. Using his stronger position, L can take advantage of the negotiation range of acquisition prices, thus shifting the additional benefits, which result from a coordinated disposition decision, to L.

Analogous to the standard SCM literature, we made the assumption that both actors have knowledge of SP's reprocessing cost structure (Assumption 4D). In our analysis, we indicated that L's decision on service payments relies on the knowledge of SP's corresponding Clip Level, namely the disposition decision. Hence, without knowledge of SP's cost structure, an additional level of uncertainty with regard to SP's disposition decision occurs.

Lack of knowledge of SP's cost structure is not expected to make L transfer Δp_{m+1} to SP completely. Hence, the situation in which SP chooses reverse SC sub-optimal Clip Levels remains. This brings us to the question of whether the relaxation of Assumption 4D affects the coordinating strategy. L's profit does not depend on the disposition of returns. This means that the lack of knowledge of SP's disposition decision is not damaging and the strategy still coordinates the setting. However, to determine the acquisition price, among others, SP's resulting profit is of relevance to find the upper bounds of p_{ac}. Hence, the negotiation process concerning p_{ac} may be affected by the relaxation.

Currently, long-term agreements with brokers exist. Relaxing the resulting assumption of given, known, and unrestricted market demand incorporates the "back end" into our analysis. We propose several research ideas in this direction.

If the assumption of unlimited market demand is relaxed, market saturation of the total market or some brokers' networks is an aspect that needs to be taken into account in the analysis. As a consequence, the market prices are valid for certain amounts reprocessed to a given output quality level only. Then, the disposition decision depends not only on the input quality of returns but also on the market demand for certain output quality levels and previously sold amounts. Market saturation potentially affects the disposition decision in all the settings considered. Thus, to be able to make reliable conclusions, further analysis is required.

If the market demand is no longer given and known, the factors influencing the demand of reprocessed products represent a further potential research focus. In the traditional SCM literature, besides prices, sales effort represents one of these factors. How does sales-effort-dependent demand affect our reverse SC setting? The business case's decentralized decision maker, SP, receives service payments from L and incurs reprocessing costs. In the case of sales-effort-dependent demand, SP additionally incurs costs for sales effort. He does not directly benefit from this effort, as L receives the market prices per unit sold to the secondary market. Hence, besides the disposition decision, an additional coordination obstacle with regard to the level of sales effort arises.

According to Cachon (2003), coordination of the sales-effort problem can be achieved by simply sharing the costs of the sales effort if

1. the supplier can observe the retailer's exerted effort,
2. the retailer's effort is verifiable to the courts, and
3. the supplier directly benefits from the exerted effort.

Thus, it needs to be determined whether the above criteria are fulfilled. If they are not fulfilled, besides the sub-optimal Clip-Levels, an additional coordination requirement exists with respect to the choice of the sales effort: a setting that provides potential for further research projects. However, even though the above criteria are potentially fulfilled and reverse SC optimal sales effort is achieved, we still face the problem of SP's sub-optimal choice of Clip Levels as the service payments for reprocessing activities are unchanged.

Does the suggested strategy to make the SP acquire the returned products coordinate the extended setting as well? To be considered here is that it is no longer given that all the reprocessed units can be sold. This probably results in the case that SP no longer acquires all the returned units, which affects L's profits. Hence, L benefits from increased sales efforts resulting in higher demands. Given that the above criteria hold, the sales effort costs can be split between the actors involved and SP exerts the reverse SC optimal sales effort. What about SP's Clip Level decision under this strategy? Does the suggested strategy still result in the reverse SC optimal disposition decision or does the sales-effort-dependent demand affect SP's decision? This depends on the characteristics of the sales effort costs. In the case that these costs are independent from the output quality level, SP's disposition decision is still reverse SC optimal. Otherwise, further analysis is required.

The incorporation of the "front end" provides further alternatives to extend our analysis. Uncertainty with respect to timing, quantity, and quality is commonly mentioned as a complicating characteristic of reverse SC. Due the assumption of starting the analysis at the moment that the products arrive at the reprocessing facility, uncertainty with respect to timing and quantity can be excluded. The only remaining uncertainty is the quality of returns. When starting our analysis earlier, questions regarding how to include the supply side in our disposition decision are of interest for future projects, in our opinion. In the discussion concerning acquisition price determination, we already mentioned one idea related to this: the idea to include a renegotiation process step between L and his leasing customers. Further ideas in this research direction include the question of how to incentivize customers to provide information with regard to the timing, quantity, and quality of returns and the probability that this information is correct. Therefore, customers as suppliers of used products come into focus. Leasing offers control over the return process to some extend, but the problem remains that it is not certain whether leased products are returned at all, whether they are returned in time, and in which condition they are returned.

Chapter 4

Coordination in Closed-Loop Supply Chains - The Customer Interface

4.1 Introduction

In this chapter, we address the supply side of CLSCs and focus on the customer as valuable source of information. One intended contribution of this chapter is to provide a description of how CLSC processes are affected by the use phase at the customers. This may increase the awareness of the actors involved of the special role that customers play in a CLSC context. Furthermore, we derive coordination needs at the customer interface and suggest first ideas how to achieve coordination.

Matching supply with demand is the underlying objective of SCs, and it is a challenging one. Compared with traditional SCs, supplies in a CLSC setting are more uncertain, and the objective of matching supply with demand becomes even more challenging. The increase in supply uncertainty originates from the customer's usage and return behavior. Thus, to achieve an efficient management of CLSC it is necessary to include the customer into the considerations. However, customers have not been addressed explicitly in previous literature; in many cases customers are a kind of "black box" for the other actors of CLSCs.

Value of information

The value of information (VOI) on supply uncertainties is shown by several authors. Given deterministic demand and return rates, Ferrer (2003) considers the disassembly and new product procurement decisions of a remanufacturer. The underlying trade-off is between investing in early yield information and establishing a responsive supplier of new components. His analysis indicates that yield information outweighs responsive suppliers of new components with respect to operating costs as long as the yield variance is low. Ferrer and Ketzenberg (2004) consider the same trade-off. Based on an assessment of 135 test instances, the authors conclude that earlier yield information performs better than the establishment of a responsive supplier. Investing in both capabilities results in only minor improvements compared with the investing in earlier yield information. However, the value of a responsive supplier increases with product complexity. Ketzenberg et al. (2006) evaluate the VOI in reducing different types of uncertainties or combinations of uncertainties. According to their analysis, return information and yield information are more valuable than demand information, and it is beneficial to invest in multiple types of information simultaneously. A further perspective on the VOI is provided by De Brito and Van der Laan (2009), who analyze the impact of imperfect information on inventory-related costs. They state that in the case of imperfect information on the return process, "(. . .) the method that uses the most information does not necessarily have the best forecasting performance" (p.86). That result is even true for minor errors in parameter estimates.

According to research on the VOI, it is beneficial for the reprocessing actor to gather information in order to decrease the uncertainties. However, the focus of the previous research, as well as the focus of the industry practice, is on the operational aspects of CLSCs, which take the aforementioned uncertainties as exogenous. The focus of these is to establish an efficient reverse SC with exogenously given return flows.

Since 2001, a shift towards an actively managed return process has been observed. In general, the literature covers three different concepts, which we introduce in the following. While product acquisition management is assigned to tactical issues in CLSC research, leasing and trade-in programs are assigned to the strategic level (Souza, 2013).

Product Acquisition Management

Guide and Van Wassenhove (2001) represent the starting point of the research stream on active product acquisition management. Returns are no longer passively accepted; companies actively acquire products from the market. To do so, the reprocessing actor buys returned products from a consolidating facility such as a broker. The literature is separated into two directions. In the first, the quality of products is uncertain a priori. Then, the decision is on the optimal acquisition quantity of the used products (e.g. Galbreth and Blackburn, 2006, 2010). The more used products are acquired, the more selective the reprocessing actor can be to lower his reprocessing costs. The other direction assumes that the used products have been graded already and that it is possible to influence the received quality by offering quality-dependent prices (e.g. Guide et al., 2003).

Two recent publications in this second direction include direct customer interaction. In their paper on the value of acquisition price differentiation, Hahler and Fleischmann (2013) focus on the interplay between return behavior, pricing strategies, and reverse network design. Gönsch (2014) introduces bargaining as an alternative to the posted prices to obtain product returns from primary customers.

Leasing

Leasing is the strategy in place in our business case. As indicated, this mechanism is beneficial for both parties involved. According to Souza (2013), leasing as a take-back mechanism is considered by only two CLSC papers. Agrawal et al. (2012) address the question of whether leasing or selling is the greener alternative. The authors show that depending on a product's inherent use impact and its durability, leasing can be both greener and more profitable for the producer than selling. Robotis et al. (2012) determine the optimal duration of leasing contracts and the optimal pricing of such contracts. The analysis considers a monopolistic OEM that leases its products and additionally offers a repair and maintenance service. Both the production and the service capacity are limited. The aim of the OEM is to optimize its leasing profits jointly with service revenues and remanufacturing savings. The results show that the optimal leasing duration and pricing decision depend on two major factors: the remanufacturing savings and the product's life cycle length.

Trade-In Programs

Trade-in rebates are offered to customers of durable products to induce product owners to replace their current product with a new one. These so-called "replacement customers" base their purchasing decision not only on the price but also on the perceived value of the product that they currently use. Ray et al. (2005) analyze the optimal pricing and trade-in rebate strategy for a profit-maximizing actor. Three different pricing schemes are offered: a uniform price for all customers, meaning that no trade-in rebates are offered, an age-independent trade-in rebate, that is, one price for new customers and one price for replacement customers, and age-dependent trade-in rebates. Furthermore, the authors discuss the effects of operational factors (such as the durability, remanufacturability, and quality of products), the effect of the efficiency of the returns handling process, as well as the effect of the market condition (the age profile of products on the market and the size of the two customer segments) on the optimal pricing and trade-in rebate decision. Li et al. (2011) address the forecasting of trade-ins to enhance both the effectiveness and the efficiency of trade-in programs. Their methodology is based on two pillars: customer segmentation and customer signals.

Actively managing return flows is attracting increasing research interest. We review three concepts for the take-back of used products discussed in the previous literature. The realization of such concepts leads to a reduction of uncertainty, especially with respect to the timing of returned products. However, the customer remains a "black box" in these models. An efficient management of CLSCs requires the consideration of all the actors involved. Thus, when thinking of coordination in a CLSC, the customers as link between forward and reverse SC need to be considered, too. When talking about coordination, first, we need to identify coordination needs. This means, where do customers interact with the CLSC in a way that potentially is not CLSC optimal? To answer this question, we describe the customers' usage phase via customers' decisions during this phase. We use decisions for this description due to two reasons. On the one hand, customers' decisions have an effect on the usage of the product and thus, on the potential future supplies and on the other hand, and this is even more important, one can intervene at the instances at which other decisions are possible and can be incentivized.

To the best of our knowledge, there is no research on customers and the effects of their decisions on CLSC processes. Therefore, the first contribution of this chapter is to bring light to the "black box" customer and to describe how CLSC processes are affected by customer decisions. Based on these insights, we will answer our research question:

Taking a holistic CLSC perspective, what are the needs for coordination at the customer interface?

Furthermore, we will discuss whether the coordination mechanisms discussed in the previous literature can be used to coordinate the identified coordination needs at the customer interface as well.

The chapter is structured as follows. In Section 4.2, we introduce the customer decisions and the effects on CLSC processes. The identified coordination needs at the customer interface are derived in Section 4.3. The chapter is completed by the discussion of potential coordination mechanisms (Section 4.4) and a concluding discussion in Section 4.5.

4.2 Decisions of Customers and How They Affect Closed-Loop Supply Chain Processes

The CLSC processes that we consider in this chapter are depicted in Figure 4.1. The forward SC consists of three process steps, which represent the major phases of a forward SC: *development and design*, *production*, and *distribution* of products. For the reverse SC as well, we focus on the process steps commonly accepted in the literature (cf. Section 1.2). To obtain supplies, some form of *acquisition* of used products is necessary. *Collected* supplies have to go through the *grading* procedure and a *disposition* needs to be performed.[1] According to the outcome of these process steps, the reverse flow of products splits into three parts. Products can be *reintroduced* into the forward SC as spare parts or by reuse of their materials. Alternatively, products are *recovered* to be resold in the secondary market (*reselling*). In the case that a returned product is no longer of value, it is declared to be *waste*. *Customers*, as the third component, link these two SCs. Hence, from a CLSC perspective, customers take a dual role: besides representing the demand side of the forward SC, they act as the supplier of the reverse SC.

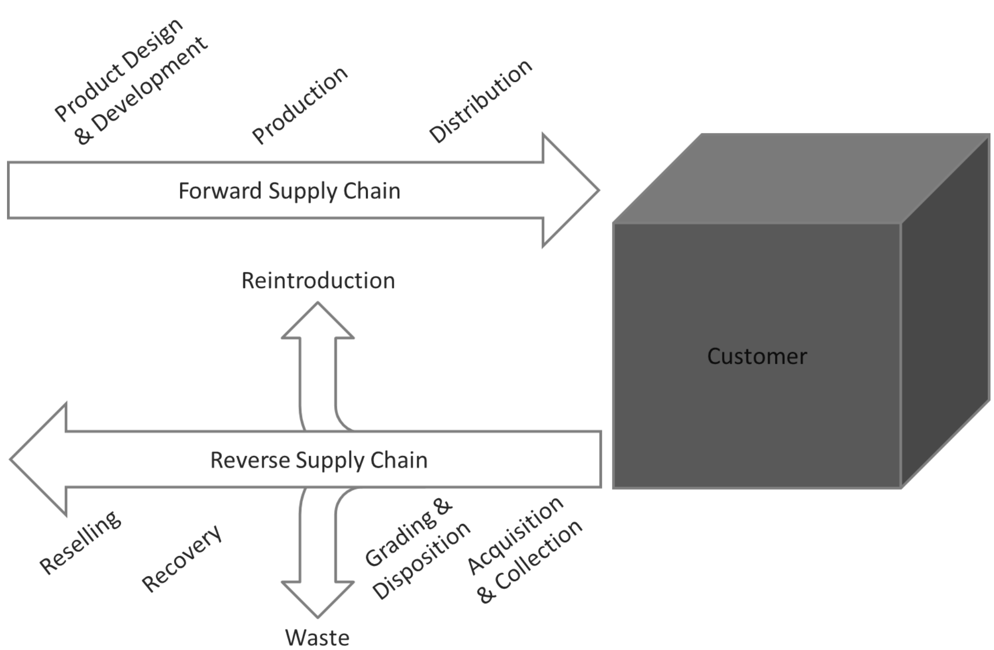


Figure 4.1: Considered Closed-Loop Supply Chain

[1]Depending on the structure of the reverse SC, these processes are conducted in the mentioned order or alternatively, *grading* takes place before *acquisition*.

Figure 4.2: Stages of The Customer Acquisition Decision (based on Homburg, 2012, p.104)

To achieve an efficient management of CLSCs, we need to know what happens during the use phase at the customer. To bring light to this “black box”, we describe a customer’s usage and return behavior via the decisions that a customer makes. In the following subsections, we discuss how these customer decisions affect the considered CLSC processes and identify coordination needs.

To be able to provide appropriate incentives to the customers, it is of relevance to know how a customer benefits from a product, its usage and a potential return. Based on literature evidence, we therefore also describe how a customer is expected to benefit from these decisions, when we introduce customer decisions. We will return to these customer benefits when addressing the mechanisms that can be used to the facilitate identified coordination issues at the customer interface (Section 4.4).

First of all, a customer needs to decide to acquire the offered, new product. In fact, the customer’s acquisition decision needs to be regarded as a process (Homburg, 2012). In Figure 4.2, we depict the four stages of which this process consists. After the decision to acquire any product (Stage 1) and the choice of a certain product category (Stage 2), the customer chooses an actual product from the offered alternatives on the market. Based on the assumption of customers as rational decision makers, in the marketing literature microeconomic utility based selection models are common to explain the customer’s product choice theoretically. Particularly important thereby is the model introduced by Lancaster (1966): based on its utility function, the decision maker assesses characteristics of a product instead of the product as a whole. Hence, in traditional forward SCs, the customer’s acquisition decision is influenced by the possibility (with respect to monetary limitation), the need to use the product, and the characteristics of the offered product. In a CLSC context, besides the characteristics influencing the value of using a product, customers extent their valuation of a product to the characteristics that come into play after the usage phase. This reselling value needs to be taken into account in a customer’s acquisition decision (Debo et al., 2005; Oraiopoulos et al., 2012). Upon the acquisition, the product is handed over to the customer and the usage phase starts.

The end of the usage phase is represented by the - as we call it - customer's disposition decision. A customer decides whether to return a product or not, and in the case of returning the product, to whom the product is given. Reverse SC literature distinguishes between returning the product to the OEM or a third-party reprocessor (e.g. Ferguson and Toktay, 2006). Trading activities between (private) customers e.g. via internet platforms and donation represent two further customer disposition options. Assuming the customer has no further interest in the product in terms of usage, the customer's different disposition options offer value to the customer according to his individual characteristics, which can be seen as his individual "mental book value" (Ray et al., 2005) or "willingness to sell" (Gönsch, 2014).

Related to the customer's disposition decision is his decision how long to use the acquired product. Following Fisher's (1997) distinction of functional and innovative products, depending on the product type, the benefits that a customer takes from a product during the usage phase are either rather stable or slowly decreasing in the case of functional products, decreasing quickly in the case of innovative products.

Furthermore, the usage of a product may vary from customer to customer in several aspects, which usually cannot be observed by other actors than the customer himself. First to mention, the intensity with which a product is used, which usually affects the condition of the product. Hence, the more a customer benefits from a product, the higher the usage intensity and the greater the wear and tear of the product. Some customers may decide to use (maintenance) services during the usage phase. This decision can affect the benefits in both ways. On the one hand, the customer usually cannot use the product during the service; on the other hand, he can benefit from an improved product with an increased reselling value (Oraiopoulos et al., 2012). Thus, negative and positive impacts depend on the service type and the way in which the product itself is affected. Another customer decision is related to complementary products, like toner cartridges for printers. The usage of such complementary products usually enables the further use of the original product and thereby increases a customer's benefits. However, the costs of such complementary products need to be taken into account as well.

Summarizing, to bring light to the "black box", we discuss the effects of the following six decisions on the above CLSC processes:

- Customer acquires the product
- Customer's disposition decision
- Duration of usage phase

- Intensity of usage
- Demand for (maintenance) services
- Demand for complementary products

This list is neither provided in a particular order nor presumed to be complete. However, the chosen decisions provide a profound basis on which to derive coordination needs at the customer interface. Hence, at the end of this section, we will be able to answer our research question.

4.2.1 Customer Acquires the Product

Customers' acquisition decision determines the quantity of products delivered to customers and therefore the generated profits of the forward SC. Extending the setting to a CLSC, the acquisition quantity has an additional impact. The quantity acquired in the first period represents the upper bound of the available supplies in the future, after-usage period (Debo et al., 2005).

The value-generating usage of these supplies is twofold in our example. Either returned products are recovered and generate profits on the secondary market or their components and materials are reintroduced into the forward SC as inputs, which usually results in production cost savings. Thus, taking for example a smartphone, the phone can either be dismantled and included materials such as rare earth metals recycled and used in the production of new phones or be repaired or refurbished and sold to customers with a lower willingness to pay. However, the question arises of whether these recovered smartphones cannibalize the new product demand (e.g. Ferguson, 2009; Guide and Li, 2010).

This results in a crucial trade-off (Figure 4.3): from a long-term CLSC perspective, on the one hand, the amount of available supplies should be sufficiently large to fulfill the demand for recovered products and the producing actors want to benefit from materials and components that are less expensive than new ones. On the other hand, there might be the necessity to limit sales to the primary market artificially and thereby limit the available supplies of the reverse SC to avoid the cannibalization effect. It is therefore of interest to balance the profits of the primary and the secondary market and thereby consider the customer's acquisition decision, which is affected by the product attributes.

The aim to balance the primary and the secondary market profits may be further complicated due to independent reprocessing companies that potentially enter the

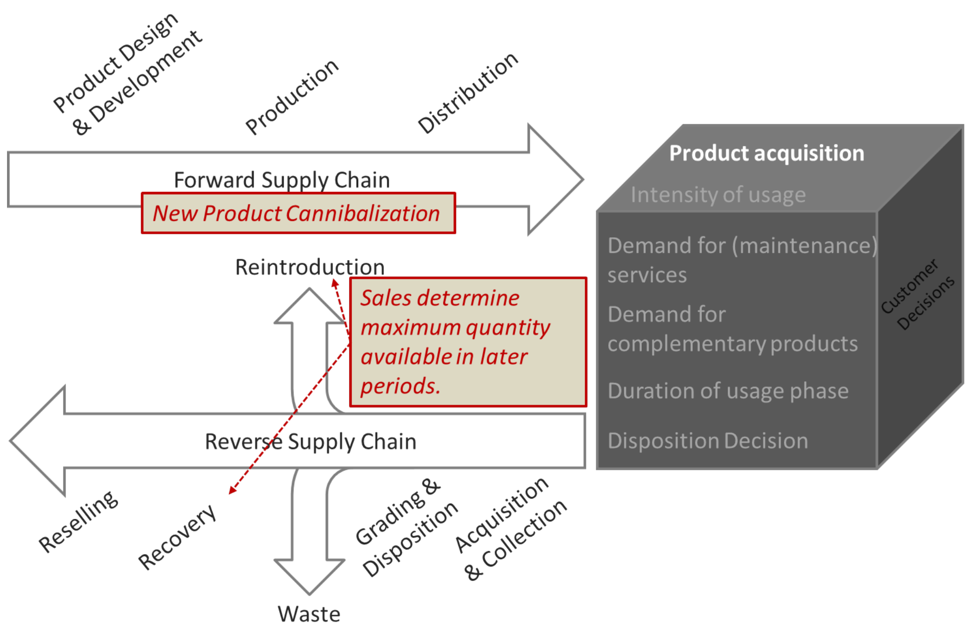


Figure 4.3: Effects of the Customers Product Acquisition Decision

market. This damages OEMs in two ways. First, reprocessed products sold by competitors cannibalize the OEM's new products sales, which additionally impacts on the OEM's profits. Second, the OEM cannot benefit from investments in reusability attributes (Ferguson and Toktay, 2006).

Hence, as a first coordination need at the customer interface, we derive: Incentivize the CLSC optimal acquisition quantities to balance the profits of the primary and the secondary market.

4.2.2 Customer's Disposition Decision

While the product acquisition decision represents the beginning of the usage, the customer's disposition decision represents its end. One disposition option is to keep the product, which means that there is no reverse flow originating from this customer. Given that a customer decides to return his product, we distinguish further disposition options:

- Direct disposal by the customer
- Donation without any value-adding activity
- An interaction between customers takes place without any value-adding activity

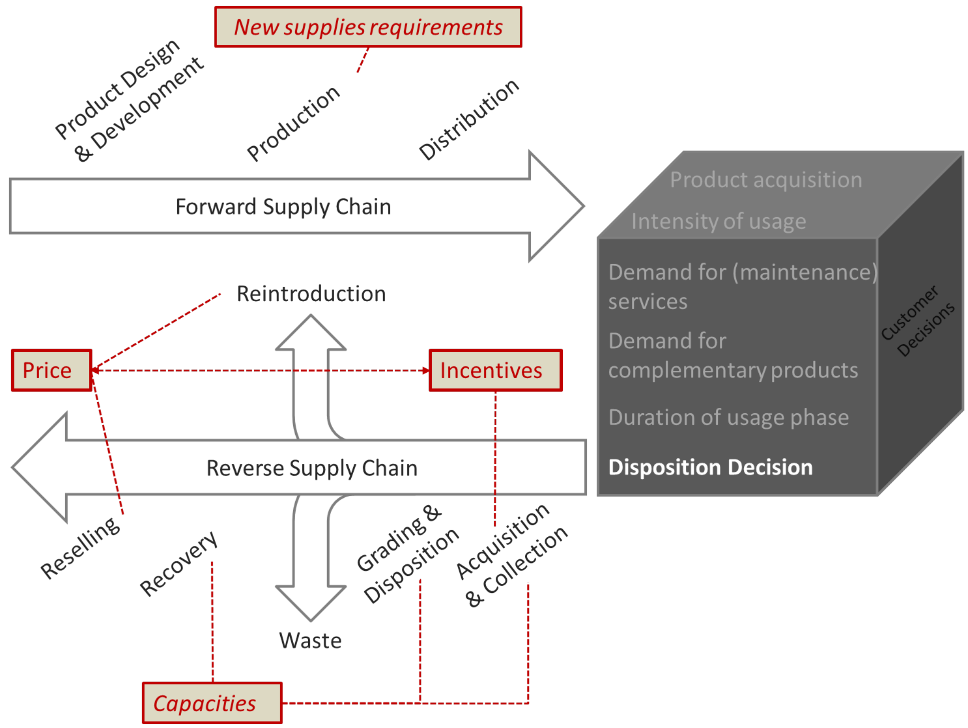


Figure 4.4: Effects of the Customer's Disposition Decision

- The product is provided as supply for the reverse SC. In this case, which actor it is submitted to is of interest:
  - OEM
  - Third-party remanufacturer

Due to these multiple disposition options, there is uncertainty with respect to the amounts of returned products that reach the reverse SC and to which actor they are actually sent. In Figure 4.4, we indicate which CLSC processes are affected by this customer decision.

One issue is that due to the quantity uncertainty, the capacity planning of reverse SC activities is complicated. Additionally, uncertain return volumes affect the disposition decision and thus, the available amounts for reselling and reintroduction into the forward SC are affected (Fleischmann et al., 2010). We take for example the CLSC of a notebook and assume that our reverse SC faces some market demand for recovered notebooks, which depends on the price as well as the offered quality. To receive supplies, current users (= customers) need to be incentivized to return their used notebook (Gönsch, 2014). By doing so, incentives + reprocessing cost $\leq$ market price. Otherwise, reprocessing activities are not beneficial for the reprocessing actor. However, current users need to be convinced to return their notebook to

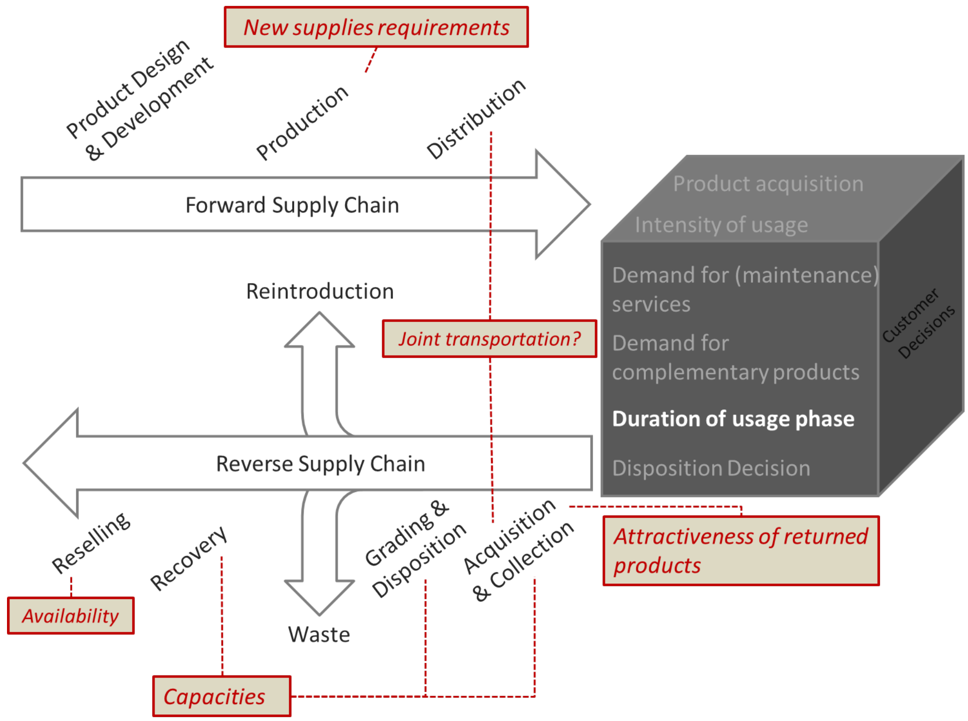


Figure 4.5: Effects of the Customer's Decision on the Duration of the Usage Phase

assure supplies to satisfy the demand. As long as the customer has multiple disposition options, he needs to be influenced to make the optimal disposition decision from a CLSC perspective. When designing the incentive for the customer, both sides therefore have to be considered, the customer (=supply) and the demand side, meaning what can be gained on the secondary market or saved in the production of new products. This means that a pricing decision is central.

The arising coordination need is to incentivize the customer to choose the CLSC optimal disposition decision to match the supply quantities with the demand.

4.2.3 Duration of Usage

Highly related to the customer's disposition decision is his decision on the duration of the usage phase. However, the effects of the two decisions differ from each other. Assuming that a customer returns his product to the SC under consideration, the decision on the duration of the usage phase determines the timing of a return, while the effects of the decision actually to return a product concern the quantity.

The effects of the customer's decision on the duration of the usage phase are summarized in Figure 4.5. Usually the customer's decision is unknown to all the other CLSC actors and therefore the timing of returns is uncertain a priori. This uncertainty especially affects the planning of resources, both in the forward and in the reverse SC. We identify four effects on the CLSC processes related to the uncertain timing of returned products. First, the capacities for the reverse SC activities are affected. As an example, we again consider the case of returned smartphones. Due to the high depreciation rate, it is necessary to conduct the reverse processes in a short period of time. However, as the timing is uncertain a priori, the reverse SC needs to build up high capacities to be able to handle all the returned units even in the case of return peaks. Second, reselling is affected due to uncertain availability of the recovered products. Third, the planning of the required new supplies in the forward SC is affected (Ketzenberg et al., 2006). Producers face a trade-off between relatively cheap but uncertain materials and components that can be obtained from used products and more expensive but rather reliable new supplies: an aspect that is of special importance in the case of used components are used as spare parts. A customer who wants, for example, his car repaired will not be willing to accept long waiting times due to unavailable supply, but instead will go to another repair shop. Fourth, the planning of transportation is affected. The joint delivery of products and the collection of used products in a CLSC setting provides the opportunity to save transportation costs (Fleischmann et al., 2009). However, the complexity of the planning tasks increases due to the uncertainty regarding whether the event of a product return coincidences with the necessity to deliver something.

Furthermore, the duration of the usage phase and thus the timing of the return of a product (may) affect the attractiveness of return flows. This can be seen from two perspectives. First, it depends on whether an actor has empty capacities for reverse flows - this is related to the aforementioned planning issues. Second, there needs to be a demand for recovered products and respectively used parts and materials.

On the one hand, there is the customer who requires and therefore benefits from the usage of a product for some time. On the other hand, there are the other CLSC parties involved in the reprocessing activities, who require supplies to fulfill their demands at a given point in time. The effects on the CLSC processes introduced above result in the coordination need to incentivize the CLSC optimal duration to manage the timing of returns according to the available capacities and the required supplies to satisfy the demand.

4.2.4 Intensity of Usage

Next, we consider the question of how CLSC processes are affected by the customer's decision on the intensity of usage (Figure 4.6). The intensity of usage impacts on the quality of a product. The more intense the usage and the less carefully a product is

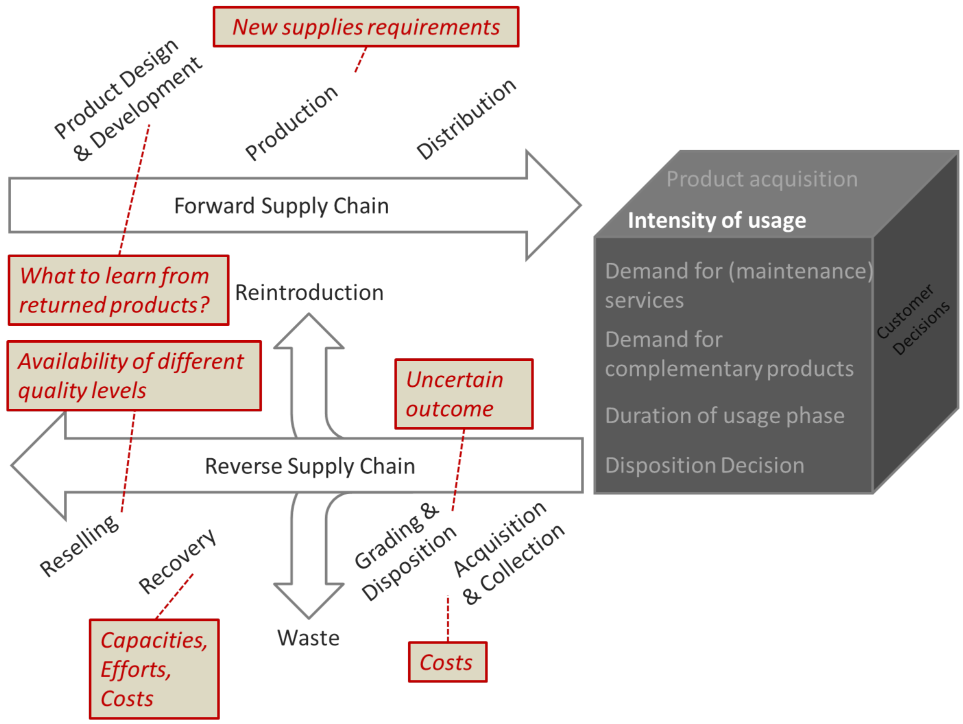


Figure 4.6: Effects of the Customer's Decision on the Intensity of Usage

handled, the worse the condition usually becomes. Depending on the condition of a returned product, the disposition decision is made. The reprocessing and reselling of returned products is beneficial only in the case that the acquisition and handling costs do not exceed the revenues gained on secondary markets.[2] Similarly, the reuse of components and materials is beneficial only in the case that the savings due to lower supply costs are not exceeded by the costs of the processes of the reverse SC. Hence, via the decision on the intensity of usage, a customer impacts on the required reprocessing effort, associated capacities, and costs. In the end, the achievable margins are influenced.

As the intensity of usage usually cannot be observed by other actors than the customer himself, there is uncertainty with respect to the quality of returns before a product is graded. This complicates the CLSC processes additionally. The complications start with the determination of acquisition prices for used products. Due to the uncertain condition of the supplied products, the disposition of returns is uncertain in advance. This affects both the forward and the reverse SC. Again, the planning of required new supplies is complicated as the producer a priori does not know the amounts of components and materials that can be obtained from the returned products (e.g. Ketzenberg et al., 2006). The heterogeneity of supplies re-

[2]Assuming further effects like the aforementioned cannibalization effect is not effective.

sults in highly uncertain reprocessing efforts, which in turn complicate the capacity planning (e.g. Fleischmann et al., 2010). Furthermore, due to the uncertain yield of supplies, the reprocessing costs are uncertain a priori. This makes it difficult to predict how many reprocessed products of which quality can be offered to secondary customers.

These effects on the CLSC processes result in the coordination need to incentivize the CLSC optimal intensity of usage to align the received and the required quality of returned products.

Another effect occurs less due to the uncertain condition of returned products but rather due to the unobservable handling causing this uncertainty. Once products are returned to the OEM, one advantage of reverse flows can be seen in the chance to gather additional information for new product development or the improvement of the current product versions. However, OEMs are only able to draw conclusions from the observed condition, in the case that they know how the product was used by the customer. Hence, it is of importance to establish a relationship between the reprocessing OEM and the customer to establish transparency with regard to the handling of the product.

4.2.5 Demand for (Maintenance) Services

While the aforementioned decisions affect the physical flow or the product itself, the following two decisions impact on the availability of information. This is less about causing uncertainty, but rather about gathering information on other customer decisions.

We start with a customer's decision to demand (maintenance) services and show which kind of information can be gathered in Figure 4.7. Let us take a copying machine for example, which is currently used by a customer. During his usage phase, the customer may request maintenance due to a problem that has occurred or according to a predetermined inspection on a regular basis. This interaction with the customer offers the opportunity to access information on both the way in which the copying machine is used and the condition of the components, like hardware or included technology. Furthermore, it may be possible to obtain additional information, such as whether the customer intends to return the copying machine and if so, when this will probably be. This means that the forecasting of returned products with respect to timing and quality becomes more accurate. Thus, it is possible to decrease the aforementioned planning complexities and manage the CLSC more efficiently.

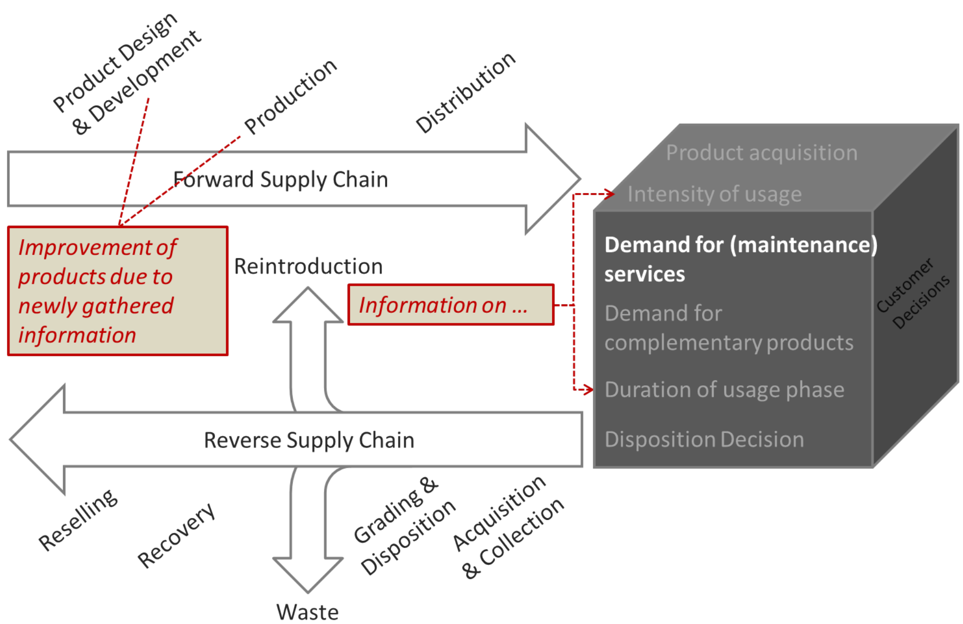


Figure 4.7: Effects of the Customer's Decision to Demand (Maintenance) Services

Moreover, customers can be asked whether the handling of the copying machine is in accordance with their expectations, whether they have observed any problems, and whether they have ideas for further improvements. Thus, due to the interaction with customers, it is possible to identify problems and potentially adapt the current product versions or to improve future versions of the product.

One aspect to add here is that information gathered during the service activities needs to be accessible by the actor responsible for the aforementioned CLSC processes, namely on the one hand, the OEM for improvement of future design and production processes and, on the other hand, the actor who is responsible for the reverse flow activities. Otherwise, the actor responsible for the service activities can take advantage of the information obtained either by selling the information or by avoiding other parties entering the market.

4.2.6 Demand for Complementary Products

Similar to the aforementioned decision, the demand for complementary products represents a decision that provides information on other decisions rather than causing uncertainty itself (Figure 4.8). As an illustrative example we choose a printer with toner cartridges as complementary products. In the case that a reprocessing actor can access the information on a specific customer buying toner cartridges, he can learn two things. First, due to the frequency of the orders of toner cartridges, it

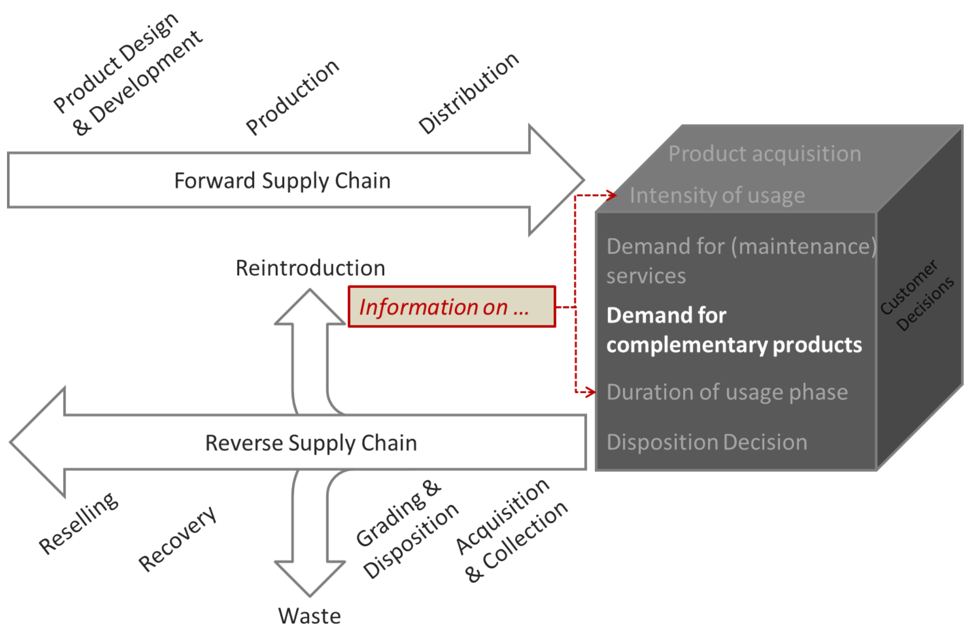


Figure 4.8: Effects of the Customer's Decision to Demand Complementary Products

becomes more transparent how many printouts are being made; thus, information on the intensity of the usage can be gathered. Second, buying a new toner cartridge implies that a customer will most likely use the printer for a further length of time. In combination with the information on the frequency of purchases, information on the further minimum duration of the usage, and thus the timing of the return, is provided.

Hence, similar to the service demand, the reprocessing actor is able to gather information that enables him to manage the CLSC activities and resources more efficiently. It is less the need for coordination, but rather the necessity to offer these complementary products and make the relevant conclusions that can be derived from the information that customers usually provide on a voluntary basis or that are enabled due to information systems becoming more and more sophisticated.

Both the demand for maintenance services and the demand for complementary products provide the opportunity to gather information; however, this information should not be taken for granted. Thus, the uncertainty decreases but still exists.

In Table 4.1, we provide an overview of the effects of the customer decisions discussed in previous sections.

	Design & Development	**Production**	**Distribution**	**Collection & Acquisition**	**Grading & Disposition**	**Recovery**	**Reintroduction**	**Reselling**
Product acquisition	product attributes	demand cannibalization					max. available amount	max. available amount
Customer's disposition decision		required new supplies		incentives, capacity	capacity	capacity	price	price
Duration of usage phase		required new supplies	transportation	transportation, capacity, attractiveness of return flows	capacity	capacity	availability	availability
Intensity of usage	product improvement	required new supplies		acquisition costs	uncertain outcome	efforts, capacity, cost		

Table 4.1: Summary of Effects of Customer Decisions

4.3 Identified Coordination Needs at the Customer Interface

In Figure 4.9, we cluster the customer decisions considered in the previous sections according to two insights. First, the customer decisions can be divided into decisions causing coordination needs at the customer interface and decisions that facilitate the customer interface as they provide the opportunity to gather information on future reverse product flows. Second, the effects of the decisions causing coordination needs at the customer interface can be clustered into quantity-, quality-, and timing-related. Each of the four decisions can be clearly assigned to one of these categories and accordingly can be seen as their drivers:

- While a customer's acquisition decision determines the total amount of potential future supplies, a customer's disposition decision determines the amount of supplies of a certain reverse channel. Therefore both decisions affect the CLSC processes via the *quantity*.
- The decision on the intensity of usage affects several CLSC processes via the *quality* of return flows.
- The decision on the duration of usage affects several CLSC processes via the *timing* of return flows.

Concerning our research question, we can state that quantity-, quality-, and timing-related coordination needs exist.

The decisions facilitating the customer interface are not assigned to further subcategories. Both the customer decision on maintenance services and the one on complementary products help to gather information on the quality and on the timing of the return flows. Furthermore, on an aggregated level, they provide information on the quantities of reverse flows.

In Table 4.2[3], we indicate which CLSC processes are affected by the customer decisions considered and state the identified coordination need for each decision. In total, we identified five coordination needs at the customer interface:

- Incentivize the CLSC optimal acquisition quantities to balance the profits of the primary and the secondary markets.

[3]This table represents an extension of Table 4.1. However, due to clarity reasons, we indicate which CLSC processes are affected by a customer decision with an "x" instead of stating the actual effect.

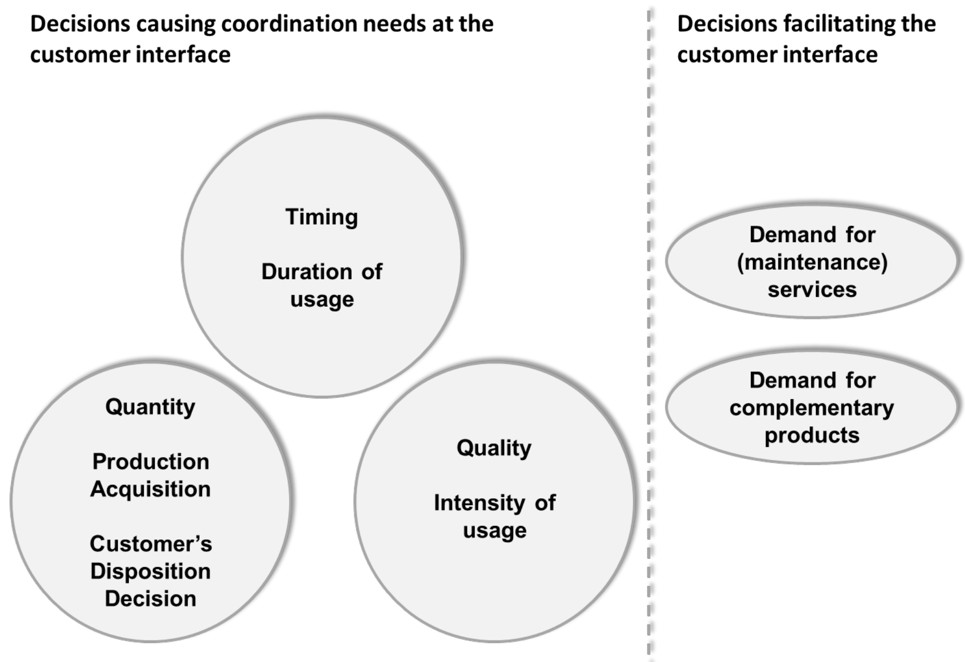


Figure 4.9: Clustered Summary of Customer Decisions

- Incentivize the customer to choose the CLSC optimal disposition decision to match the supply quantities with the demand.
- Incentivize the CLSC optimal duration of usage to align the end of usage phase with the timing of the demand for reprocessed products.
- Incentivize the CLSC optimal intensity of usage to align the received and the required quality of returned products.
- Incentivize transparency with regard to the intensity of usage to enable product improvements.

In their acquisition decision, customers take into account the attributes of a product. Hence, by the determination of these attributes, the first coordination need to incentivize the CLSC optimal acquisition quantities to balance the profits of the primary and the secondary markets can be addressed. Among others, a product's attributes determine whether a product is reusable at all. Thus, the determination of the attributes of a product is of a strategic nature. We cover this issue in Section 4.4.1.[4]

Turning to the remaining coordination needs, these are more about initiating reverse flows in sufficient quantities, with the perfect timing, or of the CLSC op-

[4]When addressing the other coordination needs, the product's attributes are assumed to be given and the forward SC process design and development is excluded from the further consideration.

timal quality to satisfy the demand for reprocessed products (=reintroduction and recovery). In the summary of effects of customer decisions (Table 4.1) we see that the only identified effect of customer decisions on the forward SC process distribution concerns the joint transportation of new and returned products. Due to the subordinated role of transportation in comparison to all other effects identified, we exclude this effect for a moment.

Revisiting Table 4.2, we make an important observation. Except for the reintroduction, all the processes considered are affected by quantity, timing, *and* quality. This implies that the underlying goal of matching supply and demand can therefore only be achieved by mechanisms that take into account the three customer decisions simultaneously. Otherwise, driver(s) of uncertainty are potentially neglected and a full picture of real-world problems cannot be provided. Hence, the identified coordination needs at the customer interface can be summarized as:

The initiation of reverse flows in sufficient quantity, of CLSC optimal quality, to satisfy the demand for reprocessed products at a given time.

We discuss mechanisms that could potentially satisfy this coordination need in Section 4.4.2.

	Design & Development	Production	Distribution	Collection & Acquisition	Grading & Disposition	Recovery	Reintroduction	Reselling	Category	Identified coordination need	
Product acquisition	X	X					X	X	Quantity	Incentivize CLSC optimal acquisition quantities	
Customer's disposition decision		X		X	X	X	X	X	Quantity	Incentivize CLSC optimal customer disposition decision	
Duration of usage phase		X	X	X	X	X	X	X	Timing	Incentivize CLSC optimal duration of usage	Initiate CLSC optimal reverse flows
Intensity of usage		X		X	X	X		X	Quality	Incentivize CLSC optimal intensity of usage	
	X									Transparency with regard to the intensity of usage	

Table 4.2: Identified Coordination Needs at the Customer Interface

4.4 Mechanisms to Coordinate the Coordination Issues at the Customer Interface

We were able to identify two coordination needs at the customer interface originating from the customer decisions considered. In this section, we discuss how these coordination needs can be addressed. In this regard, we provide an overview of the potential sources of useful coordination mechanisms and discuss the most promising ones. Due to coordination, the maximization of CLSC benefits will be achieved. In this regard, we need to take into account both the customer benefits and the profit-maximization objective of all the other actors involved.

4.4.1 Incentivize the Closed-Loop Supply Chain Optimal Acquisition Quantities

A customer's acquisition decision is influenced by the buying opportunity, the necessity to use the product, and the attributes of an offered product (Homburg, 2012). In a CLSC context, we need to consider the attributes that come into play after the usage phase (Debo et al., 2005; Oraiopoulos et al., 2012).

Consider a customer decides to acquire a smartphone. In terms of the customer acquisition decision process (Figure 4.2), the customer is on stage three "Product Choice" and needs to choose a particular product. Among the offered products, the customer chooses based on the his valuation of certain product attributes (Lancaster, 1966), such as features, performance, and price. In addition to these characteristics affecting the customer valuation during the usage phase, customers potentially think of what happens after their usage of the phone. Some customers may want to sell their used smartphone when they acquire a new one. Thus, the quality and durability of, for example, the battery become relevant to assure some reselling value. Furthermore, a major product characteristic in a CLSC context is its reusability. Reusability determines whether a product can be reprocessed in later periods at all. Different degrees of reusability affect the ease of reverse flow activities. Besides these considerations of an OEM, the environmental perspective of reusable products is relevant to the acquisition decision of "green customers".

Taking a CLSC perspective, diverse impacts need to be considered when determining a product's attributes:

1. The customer's acquisition decision itself; thus, the sales volumes of the new product are affected.

2. Cannibalization of the new product demand due to reprocessed products.

3. Increased production costs due to enhanced product attributes.

4. Reusability simplifies the reverse flow of products and cost savings can be achieved.

Thus, it comes down to the decision on the design of a product. The paper by Debo et al. (2005) described in the general literature review (Section 2.2) addresses the key managerial issue of whether it is profitable to produce a reusable product. Besides the influence of cost structures, the authors explicitly address the issue "How the optimal level of remanufacturability[5] changes as a function of the customer profile" (p.1199). In their model, customers are characterized in terms of willingness to pay for new as well as willingness to pay for reprocessed products. Their results show that the optimal choice of a product's reusability depends on the market structure. In case of a diverse market, a high reusability level is optimal, whereas in case of "markets with high concentration of customers on either the high end or the low end, the optimal remanufacturability level is low"(p.1200). These results offer an excellent basis for the optimal choice of product attributes to balance the profits of the primary and the secondary market depending on the customer structure.

In the following, we assume that the decision on the reusability of a product is given and address the second coordination need.

4.4.2 Initiating Closed-Loop Supply Chain Optimal Reverse Flows

From our analysis of the effects of customer decisions on CLSC processes, we derived that there are interdependencies of the effects of the customer decision on the disposition, duration, and intensity. These interdependencies require joint consideration and the resulting coordination need can be summarized as *the initiation of reverse flows in sufficient quantity, of CLSC optimal quality, to satisfy the demand for reprocessed products at a given time*. Against the background of this coordination need, we briefly revisit the concepts of active product acquisition management, leasing, and trade-in programs introduced in Section 4.1.

The aim of active *product acquisition management* is to receive products of the right quality, in the right quantity, at the appropriate time to satisfy the demand - which is equal to the identified coordination requirement. However, an underlying assumption of these models is that the supply of returned products is restricted by

[5]This corresponds to our term "reusability"

the amount of products sold in previous period(s) only. The effects of customer decisions on the availability of supplies are not included. This means that the customer interface is not covered.

To the best of our knowledge, the recent publication by Gönsch (2014) is the only work that includes direct customer interaction in a CLSC context. Assuming that customers do not "(...) simply want to get rid of their used products without expecting any compensation for them (...)" (p.715), he addresses the benefits of bargaining instead of posted prices. Product owners return their product if and only if the price received is higher than their willingness to sell. A product owner's valuation is uniformly distributed in the interval [$\alpha*$ price paid, price paid] with $\alpha \in [0,1]$. The profit-maximizing OEM chooses his maximum bargaining price and thereby manages the received quantities in the current period. The author covers the customer's disposition decision and, due to the formulation as a single-period model, to some extent the customer's decision on the duration of usage. However, as it is assumed that all the products received have the same input quality, the heterogeneity of customers' decisions on the intensity of usage is not included. Furthermore, the focus is on the maximization of an OEM's profit and not on CLSC optimization.

Leasing is a popular take-back mechanism, especially in a B2B context, because lessors as well as customers can take advantage of leasing. While customers benefit from increased flexibility to update their equipment frequently, from a CLSC perspective, the advantage of decreased timing and quantity uncertainty needs to be highlighted. Although a leasing duration is usually agreed, a customer is not forced to return his product at the end of the leasing period. This results in a certain level of uncertainty (Guide, 2000). This circumstance, in which a customer may not return a product after a leasing period, is incorporated into the work neither by Agrawal et al. (2012) nor Robotis et al. (2012). Agrawal et al. (2012) assume a fixed usage phase of one period. After this period, the product is - depending on whether the leasing or the selling strategy is followed - either returned to the leasing company or sold to other customers or respectively recycled by the primary customer. Robotis et al. (2012) determine the optimal duration of leasing contracts. They also do not consider the customer's decision, but assume that the same leasing duration is valid for all customers and that at the end of the leasing contract, the products are collected by the OEM. Leasing is seen as an attractive mechanism to initiate reverse flows (Souza, 2013). However, as the previous models do not incorporate the customer interface, the effects of customer decisions have been neglected.

Finally, we introduced *trade-in programs* as a take-back mechanism found in the previous literature. As mentioned, the idea is to offer a rebate to customers to induce product owners to replace their current product with a new one. In a CLSC context, two papers consider this mechanism. Ray et al. (2005) suggest optimal pricing and trade-in rebates based on the age profile of the products in use. While this age-structure-based rebate matches the customer's willingness to sell quite well, both return revenues and cost savings for reverse and forward SC actors usually rather depend on the quality of a product - which is influenced by the customer's decision on the usage intensity. This customer decision (and its resulting effects) is not included in their analysis. Li et al. (2011) suggest a customer segmentation method that may be used by the OEM (the authors consider a company in the high-tech sector) to offer segment-specific trade-in rebates. Customers are segmented according to their reliability, which is derived from a comparison of previous customer signals and actually returned products. The customer signals are observed via a so-called return merchandise authorization form, which usually includes information on the name of the product and the customer, as well as the quantity and condition of the trade-in product. Due to the customer segmentation method, reprocessing actors are able to forecast the quality of future returns. However, the timing as well as the quantity remain unknown. This is because of the time windows that are commonly offered to customers. Due to this period of up to 120 days, the timing of returns remains uncertain to some extent. Furthermore, it is not given that the announced products are returned at all. Hence, the amount actually received is uncertain as well.

As summarized in Table 4.3, the previous developments towards an actively managed return process cover some of the identified customer decisions but so far none of the concepts provides an integrated mechanism. In contrast to the coordination need at the customer interface covered in Section 4.4.1, the coordination of reverse flows has not been covered in the previous literature. To clear the way for such a mechanism jointly coordinating the quantity, quality, and timing of reverse flows, we discuss potential "candidates" in the following. By coordination, the customer's benefits as well as the other actors' profits will be optimized. We provide a summary of the effects of customer decisions on the CLSC processes as well as the benefits that a customer receives from his decisions in Figure 4.10.

Avoiding unnecessarily reinventing the wheel, we draw on the aforementioned take-back mechanisms as well as on the coordination concepts introduced in the forward SC literature. While we introduce ideas and focus on a conceptual level, future projects may focus on how actually to choose contract parameters/design mechanisms, depending on different context settings.

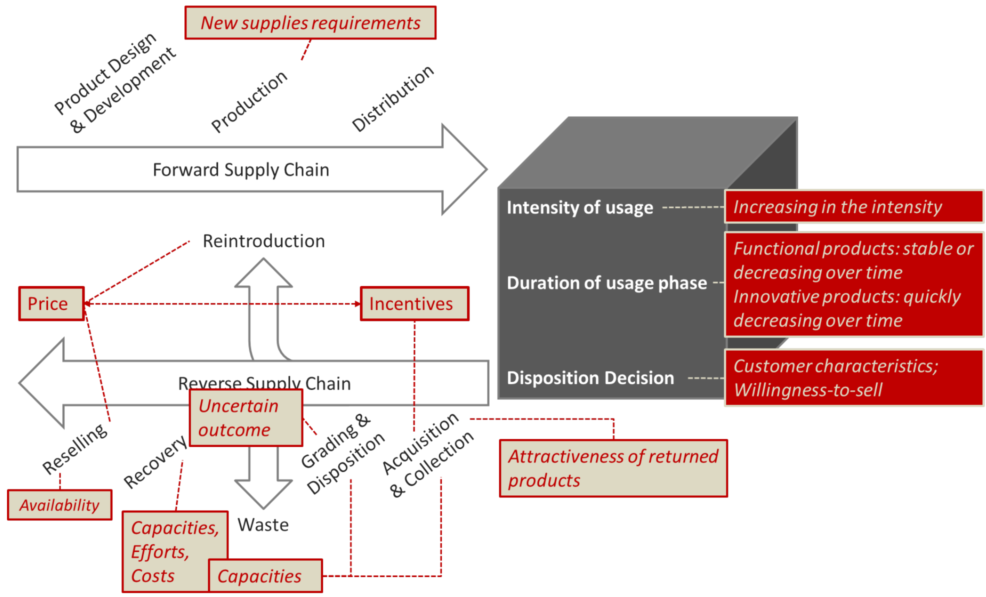


Figure 4.10: Customer Decisions - Summary of Effects on Closed-Loop Supply Chain Processes and How Customers Benefit

Strategies Based on Take-Back Mechanisms

We discuss potential extensions/modifications of the two strategic take-back concepts, leasing and trade-in, to take into account the customer interface, in the following.

The current *leasing* considerations do not incorporate the customer interface. This results in a certain extent of uncertainty with respect to the quantity and timing of return flows - both complicating the planning of CLSC activities and capacities. Furthermore, the heterogeneity of returned products with respect to the quality is not included, which increases the planning complexity further. To establish a CLSC optimal reverse flow, these disadvantages need to be overcome.

In fact, the timing and the quality of the returned products should be stipulated and in the case that a customer does not meet these agreed-on stipulations, penalties are incurred. Taking this as an assumption, the heterogeneity of supplies is avoided and the planning complexity is no longer greater than in a forward SC setting. However, to derive CLSC optimal stipulations with regard to the leasing duration and the condition of end-of-lease products as well as to derive the associated penalties, both the customer benefits and the profit maximization of all the other actors need to be taken into account. The introduction of penalties represents a crucial change of the current concept and its impact on customer's acquisition decision has to be taken into account.

In contrast to leasing, there are no contractual agreements between the actor

	Disposition decision (Quantity)	Duration of usage (Timing)	Intensity of usage (Quality)
Product acquisition management			
Gönsch (2014)	affected by price		
Leasing			
Agrawal et al. (2012)	decreased uncertainty	decreased uncertainty	
Robotis et al. (2012)	decreased uncertainty	decreased uncertainty	
Trade-in			
Ray et al. (2005)	affected by rebate		age-dependent
Li et al. (2011)	time window	time window	forecasts based on customer segmentation

Table 4.3: Coverage of the Customer Interface by Previous Literature

offering a *trade-in program* and the product user. Hence, penalties are an ineligible lever here. The customer segmentation method developed by Li et al. (2011) makes it possible to forecast the quality of returns. However, timing and quantity uncertainty is still an issue. Therefore, the customer's disposition decision and his decision on duration have to be considered.

Whether a product is handed in at all represents a customer's disposition decision. A customer can choose between different alternatives (Section 4.2.2). Usually a product owner will not keep, donate, or dispose of his current product if the price that is offered is higher than his willingness to sell. This results in three remaining disposition options, between which the customer can choose. He can return the product to the OEM, sell it to a third-party reprocessor, or sell it to other customers. Hence, competition for the used products needs to be taken into account when determining the offered trade-in rebate.

Usually, if a customer accepts a concrete trade-in offer, he does not really use the current product anymore and the timing decision is less affected by the benefits from the product itself than by the "burden" actually to hand in the product. Thus, to receive the product in a timely manner, bonus payments in addition to the agreed on trade-in conditions may be an idea to decrease the timing uncertainty.

However, the trade-off between bonus payments and costs savings due to decreased uncertainty needs to be taken into account.

Strategy Based on Forward Supply Chain Mechanisms
As an alternative to these take-back mechanisms, the coordination concepts introduced in the forward SC literature may offer mechanisms that can be adapted to the CLSC setting. While the mechanisms (introduced in Section 2.1) focus on demand uncertainty (Arshinder et al., 2011) our coordination need mainly originates from uncertainties with regard to the supply side. However, in line with the suggestion of Debo et al. (2004), to use existing forward SC theory to address coordination issues faced in reverse SCs, we use the existing coordination mechanisms as starting point.

We reviewed mechanisms that either coordinate settings of unaligned incentives of decision makers or both unaligned incentives and information asymmetries. As we have seen, customers acting as the demand as well as the supply side possess exclusive information that results in supply uncertainties. Hence, a mechanism is required that addresses both unaligned incentives and information asymmetries. In this regard, we reviewed the agency literature and technology-driven joint decision-making initiatives. While the first requires assumptions on and the analysis of cost structures and distributions of preferences and so on, the latter can be discussed on a higher, rather conceptual level - which is the matter considered in this section. Our choice is further driven by the rapidly growing diffusion of ICT. This arouses our interest in a concept using the opportunities that technological support provide.

Among the technology-enabled mechanisms, VMI is an accepted industry practice and one of the most discussed joint decision making initiative (Waller et al., 1999; Pfohl, 2002). This raised our interest in adapting the idea of VMI to a CLSC setting. In the following, we will suggest how to adapt the concept to coordinate the customer interface with regard to the initiation of CLSC optimal reverse flows.

In the original setting, the retailer's decision on timing and quantity is shifted to the supplier. While the supplier benefits from avoidance of the bullwhip effect, retailers benefit from reduced ordering and monitoring costs. Transferring the idea to our setting, the decision to initiate reverse product flows needs to be shifted from the customer to the reprocessor. Such a shift enables the reprocessing actor to receive (based on his demand forecasts of new and recovered products) the required amounts of returned products at the optimal quality at the perfect point in time. This raises two questions:

1. How does a customer benefit from shifting his decisions and transferring his private information to another actor?

2. Which information is required by the reprocessor?

We start with the latter question and discuss how to convince the customer to transfer this information as well as shifting (some of) his decisions subsequently. To begin with, the reprocessor requires demand information. Assuming that the reprocessor sells directly to the primary and secondary markets, this information is given by the reprocessor himself. Moreover, to fulfill the demands, supply and information on supply is required. While for the production of new products supplies are either in form of new parts and components or in the form of used products, the single source of supply to fulfill the demand for recovered products is used products. The planning of these supplies is complicated due to the heterogeneity of supplies with respect to their condition and the available amount at a given point in time.

Depending on the reprocessing choice (reintroduction vs. recovery), distinct planning issues arise. To achieve a profitable reintroduction of used products into the new product production processes, the sum of the acquisition costs and reprocessing costs needs to be lower than the costs of new supplies. Additionally, in order to plan the required amount of new supplies, information on the available amount of used materials and components is required.

Used products are the only supply for recovery. The condition of the products is the major driver of the reprocessing costs. Together with the acquisition costs, reprocessing costs determine the minimum reselling price to gain profits in the secondary market. The secondary demand is driven by these reselling prices and the quantity of recovered products that is offered.

Planning is further complicated by the consideration of multiple periods. The opportunity costs of initiating a reverse flow of a given quality now need to be taken into account as well as the potential future condition of the product. The capacities to conduct reprocessing activities now or in the future are a further driver of the reprocessing costs.

To summarize, the reprocessor requires information on the current quality of a product as well as information on the customer's intended future intensity of usage. In addition to this information, the reprocessor needs the power to initiate the reverse flow of products of the required amount of products of a known quality at a given point in time.

How does a customer benefit from shifting the decision to return his product and transferring his information on intensity of usage to the reprocessor? While the reprocessor facilitates his planning task due to the implementation of the idea of VMI, the customer needs convincing arguments on the one hand to shift the decision to return a product to the reprocessor and on the other hand to provide him with quality information and in the case of multi-period considerations with his future usage intensity intention.

Making a customer return his product at a given point in time obviously requires some form of compensation, usually in form of a transfer payment or product exchange. With regard to information on quality, there are several possibilities. First, the technological features of a product to track the usage come to mind. Thereby, either the reprocessor is able to track the condition of a product continuously or the stored data can be accessed during contact with the product during, for example, maintenance servicing. The advantage of the integration of a data logger is that no activity of the customer is required to transfer the information and the information is not biased by the customer. On the other hand, adding technology increases the production costs and customers potentially need to agree to their usage data being accessed. Servicing represents a second possibility to gather quality information. Either due to the possibly included data logger or via testing, the reprocessing actor can gather information on the current condition. To gather this valuable information, a reprocessing actor should encourage customers to request services on a regular basis. How can this interaction with the customer be achieved? In general, we distinguish two types of service requests: due to a problem or due to a service arrangement, the latter being either enforced by law or voluntary. The reprocessing actor does not need to incentivize the customers further to interact with him in the case of a problem or if the service is enforced by law. However, incentives are required if the service is voluntary. When designing the incentive scheme, the reprocessing actor has to take into account that his benefits of decreased uncertainty need to exceed the costs to incentivize the customers as well as the cost of providing the service. The incentives should therefore be based on the consideration that customers take advantage of regular arrangements usually due to extended product life, increased security, and a potentially increased reselling value due to documentation of the services conducted. Nevertheless, they have to pay for the services and hence need to be incentivized either due to the aforementioned aspect or due to the incentives offered by the reprocessing actor. Another possibility to gather quality information is the customer segmentation method suggested by Li et al. (2011). The method is based on customer signals observed via return merchandise authorization forms and allows for quality forecasts.

Taking a multi-period planning horizon, there is one remaining question concerning how to gather information on the customer's future decision on intensity of usage. Here as well, one of the previously considered customer decisions can provide insights. The customer's decision on complementary products provides information on the intensity of usage as well as on the intention to continue using the product. We provided the example of toner and the insights with respect to intensity and duration that one may obtain from the usage of complementary products such as toner cartridges.

In this section, we discuss mechanisms to initiate CLSC optimal reverse flows. We find that in previous modeling of take-back mechanisms, the customer's disposition decision and his decisions on duration and intensity of usage are not considered jointly. Furthermore, an OEM perspective is often taken. As a starting point to overcome this weakness, we discuss strategies for including the customer in the concept of leasing and trade-in programs. Additionally, we consider the coordination concepts developed in the forward SC literature and suggest how the idea of VMI can be transferred to our CLSC setting.

4.5 Discussion

The value of information on quality, quantity, and timing uncertainty is shown by several authors (among others Ferrer, 2003 and Ketzenberg et al., 2006). However, the customer as the origin of these supply uncertainties commonly remains disregarded, both in the literature and in the industry practice. The focus of this chapter therefore was to bring light to the "black box" that customers often are.

In Section 4.2, we discussed the effects of six customer decisions on the diverse CLSC processes shown in Figure 4.1. The first insight was that customer decisions either cause coordination needs at the customer interface or facilitate the customer interface. In Section 4.3, we answered our research question *Taking a holistic, CLSC perspective, what are the needs for coordination at the customer interface?* and formulated the following coordination needs at the customer interface:

- Incentivize the CLSC optimal acquisition quantities to balance the profits of the primary and the secondary markets
- Initiation of reverse flows in sufficient quantity, of CLSC optimal quality, to satisfy demand for reprocessed products at a given time

The first coordination need comes down to a product design decision, an issue that is addressed by Debo et al. (2005). However, previous developments towards an actively managed return process fail to take a CLSC perspective and customer decisions are not covered jointly. Hence, so far there is no coordinating mechanism for the second identified coordination need. As the first step in closing this gap, we discussed the adaptability of three coordination mechanisms, namely leasing, take-back programs, and VMI, to our setting (Section 4.4.2).

To summarize, the contributions of this chapter are:

- The description of the effects of customer decisions on the CLSC processes.
- The identification of two coordination needs at the customer interface.

Furthermore, we discussed the adaptability of existing coordination concepts to achieve CLSC optimal reverse flows. This discussion is seen as a starting point for future research.

This brings us to the question of future research directions, which we want to point out in the following:

- Using our discussion as a starting point, the first aspect to mention is the actual modeling of leasing, trade-in programs, and VMI.
- In our opinion, these three concepts are the most promising ones to coordinate the initiation of CLSC reverse flows. However, future research may analyze other alternatives as well. The choice of appropriate concepts may depend on context attributes, like the customer structure (e.g. business vs. private customers, "green" customers, etc.) as well as the product under consideration (functional vs. innovative) and the industry.
- We study the effects of six different customer decisions. However, we do not presume this list to be complete. Hence, further customer decisions may be considered to identify further coordination needs at the customer interface.
- Beyond the pure "operations/SC perspective", considerations at the intersection with other disciplines, such as marketing, seem to offer attractive research opportunities when taking into account the customer interface.

Chapter 5

Conclusion

We started this thesis by highlighting that reverse product flows are no longer seen as a threat but are perceived as an opportunity to gain additional benefits. This change of perception originates from multiple aspects. Against the background of scarce resources and increasing consumption worldwide, the materials and components included in products in use become valuable supplies for future new production. On the other hand, in the context of spreading popularity of e-commerce and shortened product life cycles, returned products have increasing inherent value. However, the known challenge of matching supply and demand is further complicated by the involvement of multiple, independent decision makers and to a great extent by the heterogeneity of supplies - the reverse product flows. Based on these developments, we formulated the following underlying research questions of this thesis:

1. **What are the potential coordination needs in a CLSC environment?**
2. **What are the appropriate coordination mechanisms?**

We approached these questions by introducing the ARC business case. The usage of a business case as a starting point on the one hand assured practical relevance and on the other hand delivered an illustrative example for sometimes abstract problems. Summarizing, this illustrative case contributed to the literature (i) by the description of a new business case and (ii) by the introduction of a new reverse SC setting. Furthermore, we were able to identify potential coordination requirements with regard to the *disposition decision* (iii) and the *customer interface* (iv). These two aspects are of special interest as they are CLSC-specific; thus, they open up the possibility to provide new insights to the research on coordination in SCs. Following our research objectives, we analyzed both aspects in more detail in Chapters 3 and 4.

In Chapter 3, we addressed the potential coordination requirement of the disposition decision. We compared the current business case setting with the benchmark of a central decision maker and observed that the disposition decision made in the business case is not CLSC optimal. Hence, with regard to our first research objective, we could state that under the given SC structure, there is a coordination need with respect to the disposition decision.

We suggested an alternative strategy to overcome the identified SC deficiency. The simple strategy to make the service provider acquire the end-of-lease returns coordinates the disposition decision and SC optimal profits are achieved. Furthermore, we identified the upper and lower bounds of the acquisition price. Depending on the negotiation on the acquisition price, the allocation of additional benefits takes place.

To summarize, Chapter 3 made the following contributions:

- We revealed the coordination need with respect to the disposition decision observed in industry practice.
- We developed an easy-to-implement strategy that results in the CLSC optimal disposition decision, thus leading to an increase in the total profits.
- We discussed the factors influencing the negotiation process on the acquisition price, which represents the basis of the allocation of additional benefits.

In Chapter 4, we focused on the coordination needs at the customer interface. Remarkably, we observed that although the customer's usage phase is the origin of the increased uncertainties in CLSC settings compared with traditional SCs, the customer is sill a "black box". Therefore, an important contribution of this chapter was to provide answers to the following questions:

1. What are relevant customer decisions?
2. How does a customer benefit from his decisions?
3. How are CLSC processes affected by customer decisions?

Based on the results of the last question, we identified two coordination needs at the customer interface:

- Incentivize the CLSC optimal acquisition quantities to balance the profits of the primary and the secondary markets.
- The initiation of reverse flows in sufficient quantity, of CLSC optimal quality, to satisfy the demand for reprocessed products at a given time.

Finally, with respect to the objective to find appropriate coordination mechanism(s), we reviewed the previous coordination mechanisms and discussed the adaptability of three concepts. Considering both the benefits of customers and the profit-maximization objective of the other CLSC actors involved, we discussed how to integrate the customer into leasing, trade-in programs, and the concept of VMI to achieve CLSC optimal reverse flows.

To summarize, Chapter 4 made the following contributions:

- As the origin of supply uncertainties in CLSCs, customers are of crucial importance. However, customers are hardly addressed by the previous literature. We describe customer actions by six customer decisions.
- We discuss the effects of these customer decisions on CLSC processes.
- We are able to identify two coordination needs at the customer interface.
- We discuss the adaptability of existing mechanisms to the coordination needs at the customer interface.

The practical relevance of considering coordination to ensure efficient CLSC management was shown in this thesis. Moreover, we observed the necessity to understand that the customer's role in CLSCs is of crucial relevance to enhance the theoretical understanding further. Due to the increasing importance of considering reverse product flows motivating this thesis, future research on CLSCs and their inherent coordination needs is necessary. Based on our observations, we subsequently discuss potential directions for future research.

With respect to the coordination of individual CLSC processes, such as the disposition, the analysis of different CLSC structures is of interest. As indicated in our discussion in Chapter 3, we observed increasing competition with regard to reprocessing activities. In consideration of the aforementioned shift in the perception of reverse product flows, this development is most likely not peculiar to the considered business case but shows a general development. Hence, the coordination of CLSC settings with one OEM and multiple reprocessors is the first research direction to mention.

Surprisingly, the customer as the origin of the uncertainties characterizing CLSCs has largely been ignored. In Chapter 4, we identified the coordination needs arising from several customer decisions. However, we see great research potential in this direction: on the one hand the identification of further coordination requirements potentially originating from other customer decisions and on the other hand the determination of parameters to model coordination mechanisms. In this regard, the incorporation of behavioral research seems promising.

In times of rapidly growing diffusion of ICT, the often-discussed obstacles with respect to asymmetries in supply information may be overcome more easily than in the past. We discussed the possibility of VMI as a technology enabled mechanism to coordinate the customer interface with respect to the initiation of CLSC optimal reverse flows. The usage of ICT and its impact on the efficiency of CLSC processes represent an interesting opportunity and should not be neglected in future research.

In our discussion of the coordination of the customer interface, we already came across the interdisciplinary aspect. The considerations of customers is usually associated with marketing. Hence, the intersection of research on operations and marketing represents one extension of research on coordinating the customer interface. Besides marketing, the intersection with finance needs to be mentioned when it comes to the coordination of profit generation of forward and reverse SC activities.

Considering these research opportunities indicates that more interesting work is to be expected in this area. Hopefully, the results, ideas, and thoughts developed in this thesis will contribute to future research in the area.

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