Supply Chain Relationships and Refurbishing in the Healthcare Supply Chain

DISSERTATION

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By

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Abstract

In recent years, healthcare organizations (HCOs) in the United States and across the globe have come under increasing pressure to reduce cost while maintaining high quality of care. Supplies and equipment contribute significantly to the total healthcare cost as these categories account for approximately 40% of HCO spending. The healthcare supply chain is distinctly different from traditional supply chains, and findings from extant supply chain research may therefore not apply to the healthcare supply chain. The relationship between the supply chain members is a key determinant of supply chain excellence. In this dissertation the role of dependence and inter-organizational power and the effect of supply chain relationships in the healthcare supply chain are investigated. Survey data from 276 procurement professionals from US HCOs are analyzed using factor analysis and structural equation modeling. The relationship between an Original Equipment Manufacturer (OEM) and an HCO is interceded by a middleman, the Group Purchasing Organization (GPO). The analysis offers strong empirical evidence that this interceded relationship is positively affected by an OEM’s non-mediated power and that this relationship positively affects the performance of both the OEM and the HCO. The relationship between the GPO and the HCO is positively affected by the GPO’s non-mediated power, but is surprisingly not affected by the GPO’s mediated power. This GPO-HCO relationship furthermore only affects the GPO’s performance. The results
suggest that the performance of an HCO is not affected by a relationship with a GPO. The analysis also indicates that when a buyer uses a procurement service provider, such as a GPO, the buying organization can end up in a dependence trap; An HCO’s dependence on the GPO positively affects the HCO’s dependence on the OEM. Furthermore, an HCO’s dependence on a GPO and on an OEM affects the HCO’s assessment of the GPO’s power and the OEM’s power. Specifically, an increase in the HCO’s dependence on the GPO was found to increase the HCO’s assessment of the GPO’s non-mediated power and decrease the HCO’s assessment of the GPO’s use of mediated power. Lastly, an increase in the HCO’s dependence on the OEM yielded an increase in the HCO’s assessment of the OEM’s non-mediated power. Since inter-organizational power affects the supply chain relationships, executives of buying organizations considering or reconsidering procurement outsourcing decisions are cautioned that satisfaction with the relationship with procurement service providers and suppliers may in part and indirectly be caused by the organization’s dependence on the provider and the supplier.

Prior to the survey data collection, an extensive field study was conducted, involving HCO executives and the four major OEMs of medical digital imaging equipment. It became apparent that in recent years HCOs have become increasingly interested in refurbished equipment, as a means to reduce capital spending. The OEMs sell new and refurbished equipment to their customers, the HCOs, and a fraction of this equipment is sold with multi-year service contracts. An important problem facing the OEMs involves jointly managing new and refurbished products along with service contracts for new and
refurbished products. The OEM needs to make critical decisions with respect to the number of new products sold, the disposition of returned/collected cores, the number of cores bought from third-party brokers and the amount of inventory of finished refurbished products. An analytical model is developed in the dissertation to investigate this managerial problem faced by each of the four major OEMs of medical digital imaging equipment.
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Chapter 1 Introduction

1.1 Overview

In recent years, healthcare organizations (HCOs) in the United States and across the globe have come under increasing pressure to reduce cost while maintaining high quality of care. Supplies and equipment contribute significantly to the total healthcare cost as these categories account for approximately 40% of HCO spending. The healthcare supply chain is distinctly different from traditional supply chains, and findings from extant supply chain research may therefore not apply to the healthcare supply chain. The relationship between the supply chain members is a key determinant of supply chain excellence. In this dissertation the role of inter-firm power and the effect of supply chain partner relationships in the healthcare supply chain are investigated. Furthermore, HCOs have over the last few decades increasingly turned to Group Purchasing Organizations (GPOs) in response to pressure from third party payers to reduce cost. Outsourcing of any business function has been shown to affect the buying organization’s dependence on the provider. When the outsourced function involves procurement activities, the consequences for the relationships among the supply chain partners may be more complex and the buying organization’s dependence on not only the procurement service
provider, the GPO, but also on the supplier may be affected. In this dissertation the role of the buying organization’s dependence and its effect on inter-organizational power in the triadic healthcare supply chain relationships are therefore also investigated.

Survey data from 276 procurement professionals from US HCOs are analyzed using factor analysis and structural equation modeling, to investigate the influence of Original Equipment Manufacturer (OEM) power and GPO power on the GPO-HCO relationship and the OEM-HCO relationship. The effect of relationships between the supply chain partners on the performance of the respective partners is also investigated. In addition, the influence of an HCO’s dependence on a GPO onto the HCO’s dependence on the OEM is analyzed. It is also investigated how an HCO’s dependence on the GPO and on the OEM affects how the HCO perceives the GPO’s use of power and the OEM’s use of power.

A typical dichotomy of inter-organizational power is mediated versus non-mediated power. Mediated power involves the explicit use of extrinsic motivation to bring about some direct action (Benton and Maloni, 2005, Brown et al., 1995, Frazier and Summers, 1984) and is generally associated with competitive and negative uses of power. The non-mediated power types on the other hand are not forms of explicit actions but instead involve a cognitive state that develops over time (Maloni and Benton, 2000, Frazier and Summers, 1984). Non-mediated power bases are typically more positive and relational in orientation (Brown et al., 1995). The results of the analysis in this dissertation offer strong empirical evidence that non-mediated OEM power and non-mediated GPO power positively affect the OEM-HCO relationship and the GPO-HCO relationship.
respectively. Surprisingly however, a GPO’s mediated power does not affect the relationship between the GPO and the HCO. Furthermore, the performance of the OEM and the HCO are both positively affected by the OEM-HCO relationship, but the GPO-HCO relationship only affects the GPO’s performance. The results show that the performance of an HCO is not affected by a relationship with a GPO. The analysis also indicates that when a buyer uses a procurement service provider, such as a GPO, the buying organization can end up in a dependence trap. An HCO’s dependence on the GPO was found to positively affect the HCO’s dependence on the OEM. Furthermore, an increase in the HCO’s dependence on the GPO was found to increase the HCO’s assessment of the GPO’s non-mediated power and decrease the HCO’s assessment of the GPO’s use of mediated power. Lastly, an increase in the HCO’s dependence on the OEM yielded an increase in the HCO’s assessment of the OEM’s non-mediated power. One of the primary managerial implications of the study is that, when faced with a procurement outsourcing decision, buying organizations such as HCOs should consider the dependence trap, in other words, the resulting dependence on both the procurement service provider and the supplier, and the effects it may have on the perceived power use of both the service provider and the supplier.

In addition to the empirical investigation of the healthcare supply chain, an analytical model has been developed in the dissertation with respect to a managerial problem faced by each of the four major OEMs of medical digital imaging equipment. Prior to the survey data collection, an extensive field study was conducted. During the field study,
managers and executives from the four major OEMs of digital imaging equipment were interviewed as part of site visits or via conference calls, plant tours were conducted and HCO managers and executives from various functional areas were interviewed. It became apparent that in recent years HCOs have become increasingly interested in refurbished equipment, as a means to reduce capital spending. The market for refurbished medical digital imaging equipment is at a high growth stage (Frost and Sullivan, 2010). With growth rates in the 7-8% ranges, the 4 main OEMs (Philips, Siemens, GE and Toshiba) as well as third-party brokers have developed their refurbishing capabilities. After-sales service contracts for refurbished equipment are important to attract customers. The OEMs, each providing these service contracts, therefore have a competitive edge over the third-party brokers. The digital imaging equipment OEMs sell new equipment to their customers, the HCOs, and a fraction of this equipment is sold with a multi-year service contract. At the end of its useful life, equipment is either returned to / collected by the OEM, often times as part of the purchase of new equipment, or will be sold to a competing OEM or a third-party broker. This return process presents the challenge for the OEM in the sense that the timing and quantity are uncertain. Of the equipment sold in a given year, it is uncertain what fraction will be returned, and over which periods it will be returned to the OEM. The OEM can affect this number of returned products by selling more or fewer new items to HCOs, through adjusting the price of new products. To meet the demand for refurbished products, the OEM has to decide which fraction of the returned products to discard or sell off to third-party brokers and which fraction to refurbish. The OEM can supplement the returned products with cores acquired from the
third-party brokers, who may have bought the OEM’s equipment directly from HCOs or from competing OEMs. The OEM will furthermore have to decide what fraction of the demand for refurbished product will be fulfilled and how much inventory of this high-value refurbished product will be carried.

Comparing remanufacturing and refurbishing settings investigated in the extant literature, the challenges around new manufacturing and refurbishing in the medical equipment supply chain are unique, for a number of reasons: (1) volumes are relatively lower, (2) prices are higher (> $1MM for new MRI equipment), (3) four OEMs control the market, (4) residence time, or useful life with the customer is long (typically 4-7 years), (5) service contracts for both new and refurbished products contribute significantly to the overall profit of the OEM, (6) products are only refurbished once. An important problem facing an OEM in the medical equipment supply chain can be described as follows: How should an OEM jointly manage new and refurbished products along with service contracts for new and refurbished products? Stated differently, how can an OEM in an environment with low volume, expensive products and multi-year service contracts, maximize the profit from new and refurbished products and service contracts for both new and refurbished products? The OEM needs to make critical decisions with respect to the pricing of new items and thereby the number of new items sold, the disposition of returned/collected cores, the number of items bought from third-party brokers and the amount of inventory of finished refurbished products. This problem is analytically investigated in chapter 7 of the dissertation.
1.2 The healthcare supply chain

The healthcare supply chain has received considerable attention from both the popular press and researchers over the last 15 to 20 years. Particularly in recent years the pressure on HCOs to reduce the cost of healthcare has been increasing and the configuration of the healthcare supply chain has come under more and more scrutiny (e.g., GAO report 323R, 2010; GAO report 10-738, 2010; GAO report 12-399R, 2012).

More than 40% of all HCO spending is accounted for by supplies and equipment (Burns, 2002). Practitioners and researchers alike increasingly recognize that supply chain management in the healthcare industry is one of the principal areas for improvement in performance (Schneller and Smeltzer, 2006). The healthcare supply chain is different from and more complex than supply chains in other more stable industries, such as the automotive industry, in at least five ways.

First, in contrast to the healthcare supply chain, supply chains in many industries have gone through significant transitions over the last few decades. The developments in the automobile industry form a fitting example to illustrate these transitions. Indeed, according to industry observers, the overall healthcare supply chain characteristics and practices resemble those of the automobile industry in the 1960s and 1970s (Burns, 2002). Prior to the 1980s, US automakers had strong market positions and profits and dominated the automobile industry. Then in the 1980s, with the onset of lean production, Japanese firms emphasized reliability, speed and flexibility rather than volume and cost (Hayes et al., 2004). These manufacturers were able to develop and manufacture high-
quality, fuel efficient cars and export them to the US at lower prices than the US automobile manufacturers. The US automobile industry, both the manufacturers as well as their suppliers, had been exposed to global competition. Over a period of fifteen years, foreign producers had taken over almost a third of the US passenger car market (Hayes et al., 2004). The healthcare supply chain, in contrast, has experienced only partial globalization. While medical OEMs, such as GE, Philips, Siemens and Toshiba, operate global businesses, the HCOs do not (Burns, 2002). Specifically, HCOs have not been exposed to global competition and sourcing of products. Consequently, a healthcare supply chain relationship between a supplier (OEM), exposed to global competition, and a buyer (HCO) without this kind of exposure may be expected to be different than a relationship between a supplier and buyer in a more traditional supply chain such as the automotive supply chain. It is important to note the significant effect of the presence or absence of global competition on the development of firms, institutions or entire industries.

A second critical difference between the healthcare supply chain and industrial supply chains such as the automotive supply chain is the manner in which revenue is generated. In contrast to many traditional industrial supply chains, HCOs have traditionally been compensated through cost-based reimbursement systems, leading to little incentive to focus on cost or efficiency (Burns, 2002). The prolonged cost-based reimbursement systems have had lasting effects on internal operations at HCOs, compared to operations at traditional cost-conscientious industrial firms.
The third difference between the healthcare supply chain and traditional industrial supply chains is the number of suppliers relative to the number of buyers. Automotive OEMs have oligopolistic control over their suppliers. The Big Three automakers, along with the two Japanese transplant manufacturers (Honda and Toyota) sell more than 85% of new automobiles in the US market (Benton and Maloni, 2005). Buyers at these firms have access to a multitude of suppliers and these suppliers are dependent on the volumes requested by the OEMs. A traditional supply chain such as the automotive supply chain can thus be characterized as a buyer-focused oligopoly. HCOs on the other hand have access to only a limited number of suppliers, in the case of most product groups, and these suppliers are much less dependent on the volume requested by an individual HCO. Simply put, while most well-defined traditional industries often times have few buyers and more possible suppliers, the healthcare industry is one of the unique industries with many buyers (HCOs) and few suppliers. The healthcare supply chain can thus be characterized as a reverse oligopoly or a supplier-focused oligopoly. The number of suppliers in an industry represents the number of alternative sources for buyers, which in turn affects a buyer’s switching cost and dependence on a supplier (Boyle and Dwyer, 1995, Frazier and Rody, 1991). Switching cost and dependence have been shown to affect supply chain partners’ commitment to and satisfaction with the relationship between the partners (Handley and Benton, 2012a, Cannon et al., 2010, Cannon and Perreault Jr., 1999, Dwyer et al., 1987). The relationships between HCOs and OEMs in the healthcare industry are thus likely to be different than buyer-supplier relationships in industries such as the automobile industry.
A fourth key difference between traditional industrial supply chains and the healthcare supply chain is the difference in the performance criteria. According to Porter and Teisberg (2006), the way to transform healthcare is to focus on value for patients, where value is the health outcome per dollar of cost expended. Members of the healthcare supply chain should put forth a coordinated effort to deliver the greatest patient value at the lowest cost (Burns, 2002). Stated more strongly, each practice of a participant in the system should contribute to value for patients (Porter and Teisberg, 2006).

A fifth important difference between traditional industrial supply chains and the healthcare supply chain concerns the fact that many hospital supply chain managers have relationships with a variety of organizations that bridge the gap between suppliers and the HCO, including distributors, wholesalers and GPOs (Schneller and Smeltzer, 2006). In a traditional industrial supply chain, firms typically develop close relationships with their suppliers (i.e., strategic suppliers and some of their preferred suppliers) based on the value they provide to the organization. More traditional relationships are maintained with transactional suppliers (Benton, 2009). The presence of purchasing partners or middlemen such as GPOs in the healthcare supply chain is a distinctive characteristic of this environment. Over the last decade, the role of these purchasing partners in the healthcare supply chain has received attention from researchers (Litan et al., 2011, Burns and Lee, 2008, Singer, 2006, Schneller and Smeltzer, 2006, Burns, 2002), the popular press (Neil, 2005, Bogdanich, 2002) and the federal government (GAO 323R, 2010; GAO-10-738, 2010; GAO-12-399R, 2012). A recent GAO report (GAO-323R, 2010) pointed out that just one peer reviewed article empirically analyzed the impact of GPOs.
on pricing for HCOs (Burns and Lee, 2008). According to Burns and Lee (2008), participation in GPOs may reduce product prices through pooled purchasing leverage of HCOs buying products on nationwide contracts and through the establishment of price ceilings in those contracts. 90-98% of HCOs belong to a GPO and they route 66-72% of their supply purchases through them (Burns and Lee, 2008). While over 600 GPOs are active in the United States, a relatively small number of GPOs dominate the market. In 2007, the six largest GPOs accounted for nearly 90 percent of the GPO market (GAO-12-399R, 2012). Since Premier Inc., Novation LLC and MedAssets, the three largest GPOs, account for approximately 75% of the purchasing volume, the healthcare supply chain is an oligopolistic environment. GPOs develop long term purchasing contracts with suppliers such as OEMs that its membership, the HCOs, can access (Schneller and Smeltzer, 2006). These exclusive contracts may last as long as three to five years and GPOs typically limit the supplier competition by narrowing the number of suppliers to two or three per product or product category (Burns, 2002). GPOs attempt to increase their HCO members’ adherence to these negotiated contracts by having the members agree to use a specific contracted supplier for a contracted product, services and equipment. The primary source of GPO revenues is the contract administration fee (CAF), paid by the product supplier, which is typically 2-3% of the contracted purchase price. GPOs may then distribute a portion of these fees to their customers, the HCOs (GAO-10-738, 2010).

The role of GPOs in the healthcare supply chains has been controversial (e.g., GAO, 2010a, 2010b, 2012). While some claim that GPOs are reducing healthcare spending,
others suggest HCOs would be better off without GPOs. Schneller and Smeltzer (2006) for example state that an HCO on average saves $1,367 in fixed contracting cost per contract. Burns and Lee (2008) find that GPOs succeed in reducing healthcare costs by lowering product prices and through rebates and dividends. Hu and Schwarz (2011) suggest that the presence of a GPO lowers prices for healthcare providers. In contrast, Singer (2006) indicates that elimination of the safe harbor provisions would be revenue neutral under the most conservative assumptions and would generate large savings for the federal government under more realistic assumptions. The safe harbor provisions form an amendment to the Social Security Act, intended to protect healthcare GPOs from prosecution under the anti-kickback statute. Simply put, after this 1987 amendment, GPOs were permitted to charge manufacturers contract administration fees (CAFs), without being prosecuted. Sethi (2006) states that the groups that should be the principal beneficiaries from GPOs, i.e. patients and HCOs, have in fact benefitted the least. Putting together the fourth and fifth difference between a stable, industrial supply chain such as the automotive supply chain and the medical equipment supply chain, a fitting characterization of the medical equipment supply chain is ‘GPO-driven reverse oligopoly’.

1.3 Research questions

The role of power has received significant research attention in the marketing channel literature (Brown et al., 1995, Brown et al., 1983) and in the Operations Management
literature (Handley and Benton, 2012a, Handley and Benton, 2012b, Zhao et al., 2008, Maloni and Benton, 2000). However, the role of power in a GPO-driven reverse oligopoly such as the medical equipment supply chain has not been analyzed to the best of our knowledge. In the extant literature concerning the role of power, it is typically the buyer who has the power advantage over the supplier. In the healthcare supply chain however, the HCO does not have the power advantage, given the dependence on both the GPO and the OEM as mentioned earlier.

In general, an organization’s procurement process consists of six basic steps: First, product specifications are determined. Next a suitable supplier is selected and contracted. Then, during the contract period, goods or services can be ordered from the supplier and the orders should be monitored and controlled. The final step in the process is evaluation of the supplier (Van-Weele, 2005). Outsourcing is defined as the complete transfer of a business process that has been traditionally operated and managed internally to an independently-owned external service provider (Handley and Benton, 2009). HCOs that use a GPO’s services rely on the GPO for procurement skills and expertise. Specifically, these HCOs outsource the first two steps, “specify” and “select”, to the GPO. Determining detailed product specifications and finding qualified suppliers are two specific steps of the procurement process that these HCOs have transferred to a GPO. Outsourcing a business process typically increases the buyer’s dependence on the provider. However, when the process outsourced by a buying organization, such as the HCO in the healthcare supply chain, involves the procurement function, the consequences for the relationships among the supply chain partners may be more
complex. Recent studies have shown that when a buyer outsources a customer service process, the service provider will gain direct contact with the buyer’s customer which may, if left unmanaged, have serious consequences for the performance of the buyer (Li and Choi, 2009; Van der Valk et al.; 2009, Balakrishnan et al.; 2008). In a similar manner, when a buyer outsources specific steps of the procurement function to a procurement service provider, this provider will now directly interact with the buyer’s supplier on the buyer’s behalf. Consequently, an HCO’s decision to outsource part of the procurement function to a GPO may affect not just the HCO’s dependence on the GPO but indirectly also the HCO’s dependence on the supplier, the OEM. Dependence and inter-organizational power are closely related. Inter-organizational power can be defined as “the ability of one individual or group to control or influence the behavior of another” (Hunt and Nevin, 1974; Emerson, 1962) and “The power of A over B is equal to and based upon the dependence of B upon A” (Emerson, 1962). The role of power has received significant research attention in the marketing channel literature (e.g., Brown et al., 1995; Brown et al., 1983) and in the operations management literature (Handley and Benton, 2012a, 2012b; Zhao et al., 2008; Maloni and Benton, 2000). Powerful parties can exert influence in different ways, through mediated power and non-mediated power. Mediated power refers to the power source’s explicit use of extrinsic motivation to bring about some direct action on the part of the power target (Brown et al., 1995). On the other hand, non-mediated power is not a form of explicit action but instead a cognitive state that develops over time (Maloni and Benton, 2000; Frazier and Summers, 1984). The use of mediated power by the power source typically has a negative consequence for the
quality of the relationship, while the effect of non-mediated power is generally more positive in nature (Benton and Maloni, 2005; Boyle et al., 1992). The influence of dependence on power usage has been studied extensively (e.g., Blau, 1964; Emerson, 1962, Geyskens et al., 1996, Caniels and Gelderman, 2007, Gulati and Sytch, 2007, Caniels and Roeleveld, 2009, Handley and Benton, 2012a). According to the “Logic of power”, if a party has the dependence advantage, then this party is in a position of relative power, leading to a situation where adversarial action, such as the use of mediated power, is more likely (Blau, 1964; Emerson, 1962). However, in subsequent studies, researchers have found that powerful parties do not always appear to exploit their dependence-advantage position in the form of use of mediated power (e.g., Geyskens et al., 1996; Caniels and Gelderman, 2007; Gulati and Sytch, 2007). In the healthcare supply chain, GPOs per definition use various forms of mediated power to increase their members’ compliance with negotiated contracts. GPOs reward HCOs with end-of-year rebates or will withhold these rebates in case HCOs opt to buy outside of the (Burns, 2002). In addition, GPOs will hold HCOs to their contracts to increase commitment and compliance (Burns, 2002). These are examples of reward power, coercive power and legal legitimate power, respectively, together classified as mediated power (Maloni and Benton, 2000; Brown et al., 1995).

Furthermore, the healthcare supply chain can be characterized as a reverse oligopoly; the healthcare supply chain consists of many buying organizations (HCOs) and relatively few powerful procurement service providers (GPOs) and few powerful suppliers (OEMs), which places the HCO in a dependent position in the relationship with the GPO and the
relationship with the OEM. Recent studies have investigated how a buyer’s dependence on a supplier affects the buyer’s use of power (e.g., Handley and Benton, 2012a; Caniels and Gelderman, 2007). The power-dependence literature has however yet to describe how a buyer’s dependence on a supplier affects the supplier’s power, as assessed by the buying organization.

The research questions addressed in the empirical part of the dissertation are:

1. How do supply chain relationships in the medical equipment supply chain affect the performance of the respective partners?
   a. How does a buyer-supplier relationship that is interceded, or mediated, by a procurement service provider or middleman like a Group Purchasing Organization, affect the performance of the buying organization and the supplier?
   b. How does a supply chain relationship between a buying organization and a procurement service provider or middleman affect the performance of the two partners?

2. How are relationships between partners in a GPO-controlled reverse oligopoly such as the medical equipment supply chain affected by inter-organizational power?
   a. How does a powerful supplier’s non-mediated power affect the relationship between the supplier (OEM) and the buying organization (HCO)?
b. How does a powerful middleman’s mediated and non-mediated power affect the relationship between the procurement service provider or middleman (GPO) and the buying organization (HCO)?

3. How does a buying organization’s dependence on a procurement service provider affect the buying organization’s dependence on the supplier?

4. How does a buying organization’s dependence on a procurement service provider affect the procurement service provider’s use of inter-organizational power?

5. How does a buying organization’s dependence on a supplier affect the supplier’s use of inter-organizational power?

The dissertation is organized as follows. Chapter 2 presents the literature review and the development of the hypotheses. In Chapter 3 the methodology of the empirical and analytical studies will be discussed. In Chapters 4 and 5 the testing of the measurement model and the results of the structural model for the two respective parts of the empirical component of the study will be presented. In Chapter 6 the development of the analytical model will be discussed. Chapter 7 provides a summary of the dissertation results.
Chapter 2 Literature and hypotheses

The dissertation consists of an empirical component and an analytical component. The empirical component of the dissertation is further divided in two parts and investigates the healthcare supply chain. In the analytical component of the dissertation, the OEM’s managerial problem with respect to offering new and refurbished equipment and service contracts for both new and refurbished equipment is investigated. This chapter covers the literature review and hypotheses related to the empirical part of the dissertation, followed by a review of relevant literature related to the analytical component of the dissertation.

2.1 Empirical literature

The empirical study lies on the nexus of the healthcare supply chain literature, the inter-organizational power and dependence literature, the outsourcing literature, buyer-supplier relationships, and strategic purchasing literature.

Part 1 of the empirical study contributes to the inter-organizational power literature by investigating the role of power in a supply chain that is characterized by the presence of a purchasing partner or a middleman, where the middleman and the supplier are the power sources in the relationships. Next, a contribution to the buyer-supplier relationships
literature is the analysis of the effect of relationships on the performance of supply chain partners in a supply chain that is characterized by the presence of a middleman. Finally, contributions are made to the healthcare supply chain literature by concurrently investigating the impact of an HCO’s relationships with a GPO and an OEM on the HCO’s performance. Table 1 details a synthesis of these streams, highlighting the positioning and contributions of Part 1 of the empirical component of the dissertation. Part 2 of the empirical study further investigates the healthcare supply chain and specifically analyzes the effect of dependence, first in a relationship where the powerful actor is a middleman (GPO), rather than a buyer or a supplier and second where the relationship between a buyer (HCO) and a supplier (OEM) is interceded by a middleman (GPO). In other words, it is analyzed how the HCO’s dependence on a middleman, the GPO, affects the GPO’s use of mediated and non-mediated power, as perceived by the HCO. Next, we investigate how an HCO’s dependence on a GPO affects the HCO’s dependence on the supplier (OEM). Lastly, the effect of an HCO’s dependence on the supplier (OEM) onto the OEM’s use of power, as perceived by the HCO is analyzed.
Table 1 Representative literature empirical Part 1

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Table 2 synthesizes the literature streams for Part 2 of the empirical component of the dissertation, highlighting the contributions and existing gaps in the literature along with the positioning of the study. The complete conceptual model for the empirical component of the dissertation is presented in Figure 1.
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Figure 1 Conceptual model
2.1.1 Inter-organizational Power

Power is defined as “the ability of one individual or group to control or influence the behavior of another” (Hunt and Nevin, 1974, Emerson, 1962). In other words, the power source is able to influence the behavior or decisions made by the power target. French and Raven (1959) developed a framework that is commonly used to explore power research. The framework includes five bases of power: reward, coercive, legitimate, referent and expert. It has been shown that reward, coercive and legitimate power sources are employed collectively (Frazier and Summers, 1984). Similarly, referent and expert power often times occur congruently (Kasulis and Spekman, 1980). Legitimate power includes an inherent, traditional form and a legal form (Brown et al., 1983). Legal legitimate power is based on the use of formal contracts such as sales contracts. This type of power is typically associated with reward and coercive power and these three power types are classified under the category of mediated power (Maloni and Benton, 2000, Brown et al., 1995). Mediated power involves the explicit use of extrinsic motivation to bring about some direct action (Benton and Maloni, 2005, Brown et al., 1995, Frazier and Summers, 1984) and is generally associated with competitive and negative uses of power. Coercive and reward power are often times difficult to distinguish conceptually and can be considered opposite sides of the same coin (Handley and Benton, 2012a, Handley and Benton, 2012b). A reward may be given to a supplier for going along with wishes or requirements. However if a buyer threatens to withhold a reward from an in compliant supplier, it may be interpreted as punishment or coercion. In a number of empirical
studies the use of reward and coercive power were grouped together (Boyle and Dwyer, 1995, Boyle and Dwyer, 1995, Frazier and Rody, 1991, Frazier and Summers, 1984). The other two power types, expert power and referent power are classified as non-mediated power. These power types are not forms of explicit actions but instead a cognitive state that develops over time (Maloni and Benton, 2000, Frazier and Summers, 1984). Non-mediated power bases are typically more positive and relational in orientation (Brown et al., 1995). This type of power is thus not explicitly exercised by the power source, but rather originates from the power target’s willingness to comply with the power source’s requests (Handley and Benton, 2012a, Zhao et al., 2008, Maloni and Benton, 2000, Brown et al., 1995, Frazier and Summers, 1984). Expert power refers to the perception that one firm holds information or expertise that is valued by another firm, while referent power implies that one firm desires identification with another firm for recognition by association (Maloni and Benton, 2000, Frazier and Summers, 1984). Non-mediated power has been found to enhance attitudes towards relationships between buyers and suppliers, fostering congruence in values and norms between members (Frazier and Summers, 1986). Jonsson and Zineldin (2003) found that non-mediated power increased the value of a relationship by enhancing the cooperation between supply chain partners. Maloni and Benton (2000) and Brown et al. (1995), respectively, provide a more detailed discussion on mediated and non-mediated power.
2.1.2 Strategic purchasing and supply chain management

The key concept in strategic supply chain management is developing superior relationships between supply chain members to create a win-win situation for both the buyer and supplier firms (Paulraj and Chen, 2005). Strategic relationships may however not always be required in all situations. High profitability can occur if the product being sourced requires high collaboration and high collaboration is used, but can also occur if the product being sourced requires no collaboration and no collaboration is used (Ittner, 1999).

Over the last two decades, purchasing has assumed an increasingly strategic role in organizations (Ellram and Carr, 1994, Cooper and Ellram, 1993). It has been shown that purchasing and supply management can have a profound impact on a firm’s financial performance (Ellram and Liu, 2002, Singhal and Hendricks, 2002). Carr and Smeltzer, (1999) have documented how firms with strategic purchasing are able to foster long-term, cooperative relationships and communication, and achieve greater responsiveness to the needs of their suppliers. Furthermore, it has been suggested that strategic purchasing can play a synergistic role in fostering value-enhancing relationships and knowledge exchange between a firm and its suppliers (Takeishi, 2001, Dyer and Nobeoka, 2000). Strategic purchasing fosters communication, which is critical to achieving effective integration throughout the supply chain (Cox, 1996). Effective communication contributes to the development and maintenance of inter-organizational routines that have
been documented to enhance a firm’s capability for effectively managing strategic alliance (Zollo et al., 2002).

2.1.3 Relationship management

Effective relationship management is a central concept of strategic purchasing, as indicated in Section 2.1.1.2. In empirical research, multiple dimensions of the characteristics of a relationship or partnership tend to be assessed (Maloni and Benton, 2000, Cannon and Perreault Jr., 1999, Lambert et al., 1996, Boyle et al., 1992, Heide and John, 1990; Handley and Benton, 2009; Prahinski and Benton, 2004). Morgan and Hunt (1994) empirically tested the relationship between commitment and cooperation between partners. They found that relationship commitment positively influences acquiescence and cooperation, but inversely influences propensity to leave.

Investments in relationship specific resources generally only occur when there is a high level of trust and mutual commitment between a supplier and a buyer (Zhao et al., 2008, Madhok and Tallman, 1998). Conversely, when firms make relationship specific investments they show trust and goodwill which leads to commitment from the other party (Das and Teng, 1998, Anderson and Weitz, 1992). Commitment and cooperation in relationships between buyers and suppliers are thus closely related to each other.

A buying firm’s commitment can be defined as the degree to which the firm feels pledged or obligated to continue business with a specific supplier (Prahinski and Benton, 2004) or the willingness of a party to invest financial, physical or relationship-based
resources in a relationship (Morgan and Hunt, 1994). This commitment can be reflected by loyalty, willingness to make investments in the supplier’s business, and confidence in the stability of a long-term relationship (Moore, 1998, Anderson and Weitz, 1992).

With relationship commitment, supply chain partners will become more intrinsically tied to established goals, and more willing to share information and integrate their business processes (Chen and Paulraj, 2004).

According to transaction cost theory, relationship commitment is an investment in transaction-specific assets which are difficult or impossible to re-deploy when the relationship is terminated (Heide, 1994). Williamson (1985) suggested that reciprocal or joint commitment can lead to stable long-term relationships in which opportunistic behaviors are reduced.

Cooperation, the second main dimension of a relationship between a buyer and a supplier, can be defined as the degree to which the two trading partners work together to solve problems, establish strategic directions and achieve their mutual goals (Prahinski and Benton, 2004, Maloni and Benton, 2000, Cannon and Perreault Jr., 1999). Stated differently, a cooperative relationship refers to the process of working together, over an extended period of time, for the benefit of both firms (Ring and van de Ven, 1992).
2.1.4 Purchasing relationships and performance

Research on the effect of relationships between buyers and suppliers onto the performance of both parties has been abundant. Dwyer et al. (1987) describe a continuum of different types of buyer–supplier relationships. They suggest that firms engage in cooperative buyer–supplier relationships because the firms anticipate benefiting from the relationship. In other words, only if firms perceive a benefit from a relationship do they continue in a cooperative buyer–supplier relationship.

Carr and Pearson (1999) suggest that those firms that pursue cooperative type relationships with key suppliers can anticipate some improvement in their firm’s financial performance. A close relationship means that partners share the risks and rewards and have willingness to maintain the relationship over the long term (Cooper and Ellram, 1993, Stuart, 1993, Landeros and Monczka, 1989). Choi and Hartley (1996) state that through a well-developed long-term relationship, a supplier becomes part of a well-managed supply chain and “it will have a lasting effect on the competitiveness of the entire supply chain”.

Eisenhardt and Schoonhoven (1996) suggest that firms enter into strategic partnerships either to acquire unique and valuable resources that they lack, or to leverage “social” resources, such as reputation, status, and legitimacy. In other words, firms with a strategic orientation that emphasizes cooperation among supply-chain partners are more likely to achieve greater economic benefits compared to firms that subscribe to the traditional, zero-sum-based notion of competition.
Maloni and Benton (2000) found that a strong buyer–supplier relationship was perceived to have a beneficial influence on supply chain performance. Finally, the results of a study by Handley and Benton (2009) offer strong empirical evidence that outsourcing performance is significantly influenced by proactive relationship management practices.

2.1.5 Healthcare supply chain

The importance of effective supply chain management in the healthcare industry has been stressed by a number of researchers (Mustaffa and Potter, 2009, Kumar et al., 2008). Schneller and Schmelzer (2006) define the healthcare supply chain as “the information, supplies and finances involved with the acquisition and movement of goods and services from the supplier to the end-user in order to enhance clinical outcomes while controlling costs”. The main players in the supply chain or value chain in the healthcare industry include the manufacturers, the group purchasing organizations and healthcare providers (Burns, 2002). Sinha and Kohnke (2009) develop a framework based on affordability, access and awareness, to inform the design of supply chains for the health sector. The authors conceptualize care as a bundle of goods and services. Their macro-perspective of the healthcare supply chain includes the key industries to develop and deliver the elements of this care bundle and the interdependencies among these industries. From a supply chain management perspective, the body of knowledge regarding the healthcare sector is still rather fragmented (De Vries and Huijsman, 2011). The
challenges inherent in the healthcare industry are described in an excellent manner by Burns (2002) and by Schneller and Smeltzer (2006).

Some researchers have analyzed the effect of the presence of a GPO in a healthcare supply chain using game theoretic models. Marvel and Yang (2008) suggest the GPO intensifies the competition between rival manufacturers and therefore lowers prices. While according to Marvel and Yang (2008) the presence of a GPO has a positive effect on the manufacturer’s innovation, Hu and Schwarz (2011) suggest that manufacturers will decrease their innovation efforts under the presence of a GPO. In a more recent study they show how the presence of a GPO affects an HCO’s total purchasing cost (Hu et al., 2012). While making the assumption that an HCO’s fixed contracting costs are lower through the GPO, the authors propose that a GPO will set the product price equal to the break-even price of the largest provider that it chooses to contract for. Based on this stylized representation, the authors claim that HCOs with smaller purchasing requirements will experience lower total purchasing costs when purchasing through a GPO but may experience higher per unit prices.

Some of the other supply chain related research in the healthcare sector includes an analysis of the influence of packaging in purchasing decisions (Kumar et al., 2008), the role of JIT in cost reduction (Jarrett, 1998), pharmacy distribution management and inventory policies (Beier, 1995), implementation of e-business processes (Bhakoo and Chan, 2011) and barriers to supply chain management implementation (McKone-Sweet et al., 2005). Agwunobi and London (2009) show how practices in mass retail can be applied to remove costs from the healthcare supply chain, in particular with respect to
drugs and medical supplies. Furthermore, Germain et al. (2011) use the lens of contingency theory in the healthcare context and find that highly responsive hospitals benefit from relational supplier exchange, while hospitals with low levels of responsiveness may not improve their performance through relational exchanges with their suppliers. Lee et al. (2011) study large hospitals in South Korea and find that supply chain innovation and supplier cooperation improves organizational performance. In a case study, Bhakoo et al. (2012) investigate collaborative arrangements between wholesalers, distributors and hospitals in the Australian healthcare supply chain.

2.1.6 Dependence, inter-organizational power and buyer-supplier relationships

According to “Resource Dependence Theory” (RDT), organizations are entities whose survival depends on their exchange of resources with multiple environmental elements such as suppliers, competitors and regulators (Pfeffer and Salancik, 1978). Interdependence between actors is thus defined as a phenomenon that exists whenever one actor does not entirely control all of the conditions necessary for the achievement of an action or for obtaining the outcome desired from the action (Pfeffer and Salancik, 1978). Dependence can be operationalized using the concepts of essentiality and substitutability (Jacobs, 1974). Essentiality or the importance of the exchanged resource can be captured by the magnitude of the exchange (Pfeffer and Salancik, 1978; El-Ansary and Stern, 1972; Pugh et al., 1969) and by the concentration of the exchange, or the number of exchange partners (Kumar et al., 1998; Burt, 1982). The concept of
substitutability can be captured by the availability of alternative sources (Kumar et al., 1998; Brass, 1984; El-Ansary and Stern, 1972) and the relative ease of switching suppliers or the magnitude of switching costs or level of relationship specific investments (Buchanan, 1992).

The power of one party over another is considered to be a function of dependence (Frazier and Rody, 1991; Emerson, 1962). Early research on power and control focused primarily on this dependence asymmetry. Relationships with balanced dependence between the actors were considered rare. According to Emerson (1962), if an actor’s net dependence was negative, then the actor was believed to have a dependence advantage and thus be in a position of relative power. In such a situation of dependence asymmetry, and of resulting power disparity, adversarial action is more likely (Gulati and Sytch, 2007; Ireland and Webb, 2007; Geyskens et al., 1996; Frazier and Rody, 1991).

Similarly, Blau (1964) states that an actor possessing a dependence advantage – and hence the more powerful actor in a relationship – will increase its use of adversarial tactics because of a decreased fear of retaliation. While early research led to concern for the performance of the dependence-disadvantaged actor (Pfeffer and Salancik, 1978; Cook, 1977), more recent studies indicate that a positive effect of dependence advantage or negative effect of dependence disadvantage may not necessarily occur. Gulati and Sytch (2007) found in their study of automotive manufacturers and suppliers that a manufacturer’s dependence advantage diminished its performance in a procurement relationship and that a supplier’s dependence advantage had no significant effect on the manufacturer’s performance. The authors concluded that powerful manufacturers use
coercion (mediated power) to get a larger *share* of the pie (the value created through the relationship). However, the use of coercion at the same time reduces the *size* of the pie, or the total value created through the relationship, leaving manufacturers with a net loss. They furthermore found that suppliers, who find themselves in a possession of power, typically do not use it, unlike manufacturers, leaving the distribution of value intact and leading to a null effect of supplier’s dependence advantage on a manufacturer’s performance. Geyskens et al. (1996) found that relationship commitment of a dependent party increases as its dependence on the other party increases. The authors offer as possible explanation for their surprising finding that a more powerful partner may not need coercive strategies to obtain cooperation, but may instead rely on non-coercive strategies which are typically perceived as fairer by the weaker partner (Frazier and Summers, 1986; Blau, 1964). Furthermore, Provan and Gassenheimer (1994) found that unbalanced relationships, in which one partner depends to a great extent on the other partner, do not automatically lead to actual use of power, depending on the commitment from partners. It has been argued that buyer dependence on the provider has been associated with a longer-term orientation toward the relationship (Cannon et al., 2010) and with a greater concern for relationship quality and commitment (Dwyer et al., 1987). The dissertation research departs from the above literature focused on power and dependence in several ways. First, the influence of dependence on the use of power has to date not been investigated in a relationship where the dependence-advantaged party is a middleman (GPO) instead of a buyer or a supplier. Second, the relationship between the supplier (OEM) and the buying organization (HCO) is interceded in the healthcare supply
chain. The HCO has outsourced the supplier selection step of the procurement process to the GPO and the relationship between the HCO and the OEM is thus interceded, or mediated, by the GPO. The OEM is the dependence-advantaged party in this relationship. The literature is void of analysis of the influence of dependence on power in a relationship that is interceded, or mediated, by a middleman.

2.1.7 Outsourcing and dependence

Outsourcing is defined as the complete transfer of a business process that has been traditionally operated and managed internally to an independently owned external service provider (Handley and Benton, 2009). Outsourcing decisions have been investigated using transaction cost economics, among other theoretical lenses. According to the transaction cost perspective, organizations will consider costs and resources required to coordinate with an external party and to mitigate any risks associated with external sourcing. These strategic risks include capability erosion (Dierickx and Cool, 1989; Quinn and Hilmer, 1994), intellectual property breaches (Aron et al., 2005; Walker, 1988) and opportunistic renegotiation (Williamson, 1979). Williamson (1985) argues that buying organizations use farsighted contracting to avoid these risks. Another risk involves the degree of asset specificity (Williamson, 1985). When organizations outsource activities that use assets being specific to the transaction, they may become locked-in to their suppliers. If an organization wished to switch providers, it would have to write off the asset specific investments, creating a situation where the buyer is locked-
in to the provider. While transaction cost theory suggests that organizations consider the level and implication of these and other risks when facing outsourcing decisions, Lonsdale (2001) found that organizations do not always have a farsighted contracting perspective. Many organizations will find themselves in a post-contractual dependence position, where they are locked in to and dominated by the provider (Cox, 2003). Similarly, Caniels and Gelderman (2007) found that once buyers enter into a partnership, they perceive higher switching costs than suppliers and have fewer alternative trading partners than the supplier does, collectively increasing the buyer’s dependence on the supplier. In the current study HCOs outsource the first two steps of their procurement process to GPOs, which, based on the literature, will increase HCOs’ dependence on GPOs. However, the current study differs from the outsourcing–dependence literature in that the function being outsourced by the buyer (HCO) involves the procurement function. While the literature may suggest buyers become increasingly dependent on providers when entering into an outsourcing agreement, empirical evidence of the effect of dependence on a procurement service provider (or middleman) onto the dependence of the buyer onto the supplier has yet to be provided.

In recent years, service outsourcing has received significant research attention (e.g., Li and Choi, 2009; Van der Valk et al., 2009; Balakrishnan et al., 2008). One characterizing difference between the outsourcing of a manufacturing process and the outsourcing of a customer service process is that as a result of outsourcing of customer service processes, the service provider of the buying organization will have direct contact with the customer of the buying organization, as shown in Figure 2 (Li and Choi, 2009). Balakrishnan et al.
(2008) argue that the decision to outsource front-end tasks needs to take into account the nature of the customer contact. Lack of understanding of the shifting relationship structures among the services buyer, the services provider and the buyer’s customer, as a result of the service process outsourcing, has been suggested to be an important root cause of failed attempts of service process outsourcing (Li and Choi, 2009). In the healthcare supply chain, it is the procurement process rather than the customer service process that is being outsourced by the buying organization, the HCO, to the provider, the GPO. Therefore, the triad of interest in the current study is the buying organization (HCO), the procurement service provider (GPO) and the supplier (OEM), rather than the customer. In the healthcare supply chain, a portion of the typical contacts between the buyer (HCO) and the supplier (OEM) now occurs through the service provider (GPO), as shown in Figure 2. Specifically, once an HCO decides to purchase through GPO-negotiated contracts, procurement activities such as determining product specifications and supplier selection are now no longer completed by the HCO but transferred to the GPO.

![Figure 2 Procurement service triad versus customer service triad](image-url)
The importance of a strategic evaluation of an organization’s capabilities and resources and of the strategic risks associated with outsourcing a business activity has been highlighted in the outsourcing literature (e.g., Barney, 1991; Wernerfelt, 1984; Williamson, 1979). A strategic evaluation of an outsourcing decision was recently found to indirectly and positively affect an outsourcing organization’s performance through the positive effect it has on an organization’s capabilities to manage the relationship with the provider (Handley and Benton, 2009). When an organization outsources parts of the procurement function, as is the case in the healthcare supply chain, the organization’s relationship with not only the service provider but also the supplier may be affected. The literature is void of studies that investigate the effect of procurement service outsourcing on the relationship structures among the triad consisting of the buying organization, a procurement service provider and the buying organization’s supplier. The current study therefore begins to fill this gap by investigating how a buyer’s (HCO’s) dependence on a procurement service provider (GPO) affects the HCO’s dependence on the supplier (OEM).

2.2 Hypothesis development

The insights derived from the empirical literature review guided the development and theoretical justification for the hypothesized relationships, depicted in Figure 3.
HCO’s dependence on OEM

HCO’s dependence on GPO

HCO's dependence on OEM

HCO's dependence on GPO

H1a:+
H1b:+
H2a:+
H2b:+
H3a:−
H3b:−
H3c:−
H4a:+
H4b:+
H4c:0
H4d:0

Part 1

Part 2

Figure 3 Hypotheses
A detailed discussion of the literature, as it relates to each of the hypothesized relationships, is provided in the following sections. This review develops the theoretical underpinnings for each hypothesis.

2.2.1 Inter-organizational Power and Supply Chain Relationships

Previous research has shown that the relationship between a buyer and a supplier is influenced by the use of power. The current study will focus on the role of power in the healthcare supply chain. Specifically, the role of power in the relationships between the OEM and the HCO and between the GPO and the HCO, respectively, will be investigated.

2.2.1.1 Power and the OEM-HCO relationship

Based on the authors’ field visits and conversations with executives of the four major OEMs, it is postulated that the HCO is the power target in the relationship with the OEM of digital imaging equipment, where the OEM holds expert and referent power. The intuition of the executives can more formally be supported with the literature. Power is considered to be a function of dependence (Frazier and Rody, 1991, El-Ansary and Stern, 1972, Emerson, 1962). The number of OEMs in this industry is small and the number of alternative suppliers for HCOs is therefore limited. Switching between OEMs of digital imaging equipment involves additional user training of doctors and nurses, potentially
new or additional maintenance service providers and finally potential resistance of the users, the physicians (Burns, 2002).

A smaller number of alternative sources and switching difficulties have been shown to increase the buyer’s dependence on the supplier (Boyle and Dwyer, 1995, Frazier and Rody, 1991, El-Ansary, 1975, Emerson, 1962). Furthermore, as Emerson (1962) states, “the power of A over B is equal to and based upon the dependence of B upon A”. The OEM is therefore the power source in the OEM-HCO relationship. The OEM provides an HCO with product expertise, information and training, on which an HCO increasingly depends as it reduces purchasing staff and expertise (Schneller and Smeltzer, 2006).

Inherently the OEM therefore has non-mediated power, given the definition of this power type (Frazier and Summers, 1984). Frequent exchange of information has been shown to build cooperation and trust, (Anderson and Weitz, 1992, Anderson and Narus, 1990). An OEM’s expert power, partly driven by its information sharing and product expertise, is therefore expected to enhance the perceived cooperation and thereby the strength of the relationship. Indeed, Jonsson and Zineldin (2003) found that non-mediated power increased the value of a relationship by enhancing the cooperation between supply chain partners.

The marketing literature has provided evidence that the use of non-mediated power enhances positive attitudes toward the relationship between channel members (Frazier and Summers, 1986) leading to a heightened degree of relationalism between channel partners (Boyle et al., 1992). Increased use of non-mediated power by a powerful supplier in a supplier-retailer relationship was found to enhance the relationship between the
supplier and the retailer (Brown et al., 1995). The operations management literature has furthermore offered empirical evidence that a powerful buyer’s non-mediated power enhances the buyer-supplier relationship. In the automobile industry for example, the OEM is the power source in the supply chain formed by the OEM and 1st tier suppliers (Benton and Maloni, 2005). In the current study the relationship between an OEM and an HCO is interceded or mediated by a GPO, while the relationships between buyers and suppliers in the extant literature have been formed without interceding by a middleman. It is hypothesized that the positive effect of an OEM’s non-mediated power onto the strength of the relationship between the OEM and the HCO holds, even if this OEM-HCO relationship is interceded by a middleman.

**H1: Increased non-mediated OEM (supplier) power (expert and referent) will have a positive effect on the strength of the relationship between the OEM and the HCO (buyer).**

2.2.1.2 Non-mediated power and the GPO-HCO relationship

HCOs seek alliances with GPOs to carry out exchange functions associated with product sourcing, supplier negotiations and contract development and management functions associated with procurement and materials management (Schneller and Smeltzer, 2006). In fact, as HCOs join GPOs, they increasingly reduce their staff that would be conducting procurement tasks such as testing, researching, negotiating and purchasing items on their own (Schneller and Smeltzer, 2006). GPOs furthermore offer their HCOs bench-marking information in the form of comparative data on supply chain expenditures, technology management programs and insurance services for example (Neil, 2005, Burns, 2002).
Many HCOs view the GPO price as a reference and see if they can get a better price in the market (O Connor, 2011). Expert power refers to the perception that one firm holds expertise or information that is valued by another firm (Maloni and Benton, 2000, French Raven, 1959). Based on this definition, a GPO intrinsically is in a position of expert power in its relationship with an HCO.

It has been suggested that GPOs succeed in lowering product prices for HCOs and in lowering transaction costs through commonly negotiated contracts (Burns and Lee, 2008). Burns et al. (2002) found that HCO procurement managers viewed pricing practices of suppliers as opportunistic and irrational and that the materials managers believed that GPOs historically delivered lower prices to them than they would have achieved on their own. Referent power implies that one firm desires identification with another for recognition by association (Maloni and Benton, 2000, French Raven, 1959). It is thus conceivable to expect that HCO procurement managers wish to be associated with GPOs in their quest for lower prices from the OEMs. Following this logic, a GPO will have referent power in its relationship with the HCO.

In summary, when an HCO joins a GPO, it is expected that the GPO will have the two types of non-mediated power, expert as well as referent power, respectively. Non-mediated power was earlier hypothesized to positively affect the relationship between the powerful supplier (OEM) and the buyer (HCO). We build on this argument by hypothesizing that this positive effect also occurs in a relationship between a powerful middleman (GPO) and a buying organization (HCO). We formally hypothesize:
H2: Increased non-mediated GPO (middleman) power (expert and referent) will have a positive effect on the strength of the relationship between the GPO and the HCO (buyer).

2.2.1.3 Mediated power and the GPO-HCO relationship

The healthcare supply chain is characterized partly by the prominent role played by the GPOs. Based on the authors’ interviews with OEM and HCO executives it is concluded that a GPO is the power source in the relationship between a GPO and an HCO. HCO executives have indicated that they depend on GPOs for access to lower product prices and that GPOs have delivered lower prices than they had achieved on their own (Burns, 2002). Recall that “the power of A over B is equal to and based upon the dependence of B upon A” (Emerson, 1962). The GPO is therefore the power source in the GPO-HCO relationship. Volume and compliance with the GPO are two key factors in the medical equipment supply chain (Burns, 2002). GPOs, (1) reward HCOs at the end of a calendar year through rebates that are based on the HCOs’ compliance with the GPOs’ programs, (2) withhold the rebates to punish non-compliance or offer upfront discounts for mandated compliance or (3) require the HCOs to comply 100% with GPO contracts (Burns, 2002). These actions are examples of reward power, coercive power and legal legitimate power, respectively, which are forms of mediated power (Maloni and Benton, 2000, Brown et al., 1995). HCOs that use a GPO are therefore expected to be the targets of mediated power in the relationship with GPOs. Use of mediated power has been shown to damage relational norms (Boyle et al., 1992) and cooperation between channel partners (Skinner et al., 1992). Mediated power has furthermore been shown to increase
channel conflict (Frazier and Rody, 1991) and to lower commitment to a relationship by the target (Brown et al., 1995). In the Brown et al. (1995) study, the target was the retailer and the source was the supplier. In their study of the automobile industry, Maloni and Benton (2000) found that a powerful buyer’s use of coercive and legal legitimate power had harmful effects on the relationship between the buyer and the supplier. In the extant literature the power source was either a powerful buyer of products in a buyer supplier relationship or a powerful supplier of products in a supplier-retailer relationship. In the current study however, the power source is a powerful middleman, the GPO, who provides the HCO with access to lower OEM prices and contract management services among others. Based on the above, it is hypothesized that the negative effect of mediated power onto a relationship also occurs when a middleman (GPO) is the power source and the buyer (HCO) is the power target. We formally hypothesize:

\[ H3: \text{Increased use of mediated GPO (middleman) power (reward, coercive and legal legitimate) will have a negative effect on the strength of the relationship between the GPO and the HCO (buyer).} \]

2.2.2 Relationship Management and Healthcare Supply Chain Performance

2.2.2.1 OEM-HCO relationship and OEM and HCO performance

The relational view of the firm provides the theoretical foundation for the notion that strong buyer-supplier relationships are a means to achieving superior performance (Dyer and Singh, 1998). The relational view is one perspective to explain how firms together
achieve above-normal returns. Dyer and Singh (1998) describe how idiosyncratic inter-firm linkages may be a source of relational rents, which are supernormal profits jointly generated in an exchange relationship that cannot be generated by either firm in isolation and can only be created through the joint idiosyncratic contributions of the specific alliance partners. Development and maintenance of a network of cooperative and committed relationships with suppliers can be a source of cooperative advantage. Commitment to a relationship frequently is believed to result in a higher performance level (Stern and Ansary, 1992). Furthermore, cooperative teams synergistically perform at levels that are superior to the sum of the team members’ individual best efforts (Katzenbach and Smith, 1993). From an inter-firm arrangement perspective, Madhok and Tallman (1998) posit that greater appreciation of the relationship management process is needed to truly realize the potential value between two firms. Empirical evidence that close relationships, characterized by cooperation and commitment, lead to superior exchange performance, exists in the supply chain literature (Corsten et al., 2011, Paulraj et al., 2008, Prahinski and Benton, 2004, Shin et al., 2000, Carr and Pearson, 1999) and in the outsourcing literature (Handley and Benton, 2009). The effect of a middleman-mediated buyer-supplier relationship onto a buyer’s and a supplier’s performance has yet to be empirically analyzed.

HCOs have relationships with OEMs and in most cases these relationships are mediated by a middleman, the GPO. The effect of a relationship between an OEM and an HCO onto the performance of both the OEM and the HCO is expected to be positive, consistent with the aforementioned empirical evidence. It is anticipated that the presence of the
middleman will not hinder the determinants of the relational rents such as knowledge sharing routines, complementary capabilities and relation-specific assets in the form of the volume of inter-firm transactions (Dyer and Singh, 1998). Device manufacturers routinely engage physicians on product design teams. In addition, the manufacturing representatives provide training to physicians and nurses and are frequently present in the operating room to assist the surgical teams (O'Connor, 2011, Schneller and Smeltzer, 2006, Burns, 2002). These are fitting examples of two of the determinants of relational rent: knowledge sharing routines and complimentary capabilities (Dyer and Singh, 1998). In short, based on the relational view and consistent with the extant empirical studies, it is expected that, once established through the mediation of the GPO, a more cooperative and committed relationship between the OEM and the HCO will lead to improved performance of both the OEM and the HCO.

H4a: The relationship between the OEM and the HCO has a positive effect on the performance of the OEM.

H4b: The relationship between the OEM and the HCO has a positive effect on the performance of the HCO.

2.2.2.2 GPO-HCO relationship and performance

A typical relationship between a GPO and an HCO is different than a typical relationship between an OEM and an HCO in a number of ways. First, there are usually no relationship-specific assets in the relationship between a GPO and an HCO since there are technically no inter-firm transactions. GPOs use their collective purchasing clout to
negotiate lower unit prices of products such as capital equipment. They function as a “funnel for contracting between product suppliers and a large number of hospital buyers” (Burns, 2002). In other words, an HCO buys from an OEM, not from a GPO and thus there are no relationship-specific assets in the typical GPO-HCO relationship. Second, the type of information exchange between a GPO and an HCO may not result in joint learning since for most HCOs the basic value from the relationship is the GPO-negotiated price and provided benchmark information with regard to price (Schneller and Smeltzer, 2006, Burns, 2002). While GPOs seek to provide HCOs with additional services, the HCOs often fail to take advantage of them (Burns, 2002). Third, GPOs and HCOs typically do not combine their complementary resources like OEMs and HCOs do. In other words, while OEMs involve HCOs to design the next generation of equipment and HCOs involve OEMs to assist with service in the operating room (Burns and Lee, 2008), most GPOs and HCOs do not have this type of a relationship that takes advantage of complementary capabilities. According to Dyer and Sing (1998), idiosyncratic relationships that generate supernormal profits through relational rents are characterized by investments in relationship specific assets, substantial knowledge exchange resulting in joint learning and the combining of complementary capabilities. Based on the described differences between an OEM-HCO relationship and a GPO-HCO relationship, the argument can be made that the GPO-HCO relationship may not have these characteristics and may therefore not generate relational rent for either partner. Dyer and Sing (1998) indicate that without the aforementioned characteristics, a relationship can be defined as an arm’s-length market relationship and that under those conditions it is easy
for firms to switch trading partners. Indeed, HCOs typically belong to an average of 2.6 GPOs, tend to “cherry-pick” the GPO’s contracts and may switch when they perceive another GPO has a better-priced portfolio or a broader product selection (Burns, 2002). Contracts between OEMs and GPOs typically last at least 3-5 years (Burns, 2002). An HCO’s longer term commitment to and sense of cooperation with a GPO may thus well be driven by the HCOs preference for that GPO’s product portfolio. Simply put, an HCO may be in a long-term relationship with a GPO because of its contracted OEM and product portfolio, not because of the intrinsic dividends the relationship with this GPO may pay. In other words, a GPO-HCO relationship may be long-term, but not strategic and may therefore not generate the relational rents for the HCO or for the GPO. Consequently, it would be imprudent to invoke the “Theory of the Relational View” to hypothesize an effect of this unique middleman-buyer relationship on the performance of either party. A null-hypothesis is therefore used for the effect of HCO-GPO relationship onto GPO performance and HCO performance:

\( H4c: \text{The relationship between the GPO and the HCO does not affect the performance of the HCO.} \)

\( H4d: \text{The relationship between the GPO and the HCO does not affect the performance of the GPO.} \)
2.2.3 Dependence and GPO power

When an organization outsources an activity or a function, it typically enters into a multi-year commitment to a service provider (Handley and Benton, 2009), in a strategic decision to reject the internalization of an activity (Gilley and Rasheed, 2000). The outsourcing of an activity involves partnerships in which there is a close interaction between buyer and provider (Bensaou, 1999). A buying organization’s level of dependence on the service provider is driven by the magnitude of the exchange (Pfeffer and Salancik, 1978; El-Ansary and Stern, 1972; Pugh et al., 1969), the concentration of the exchange, or the number of exchange partners (Kumar et al., 1998; Burt, 1982), and the relative ease of switching service providers (Boyle and Dwyer, 1995; Frazier and Rody, 1991; Buchanan, 1992). When HCO’s buy a larger percent of their annual purchasing volume through GPO-negotiated contracts and when GPO-switching costs are low, the dependence on their GPO increases.

As noted in Section 2.1.6, the power of a party is considered a direct function of dependence (Emerson, 1962). When a party is in a position of relative power, this party is likely to exploit the situation to its advantage (Emerson, 1962; Frazier and Rody, 1991; Ireland and Webb, 2007) and use adversarial tactics such as mediated power because of a decreased fear of retaliation (Blau, 1964). Some recent studies have found that dependence does not always lead to the use mediated power on the part of the dependence-advantaged party (e.g., Provan and Gassenheimer, 1994; Geyskens et al. 1996; Gulati and Sytch, 2007). However, in the healthcare supply chain, GPOs per
definition use various forms of mediated power to increase their members’ compliance with negotiated contracts. GPOs reward HCOs with end-of-year rebates or will withhold these rebates in case HCOs opt to buy outside of the (Burns, 2002). In addition, GPOs will hold HCOs to their contracts to increase commitment and compliance (Burns, 2002). These are examples of reward power, coercive power and legal legitimate power, together classified as mediated power, as described in Section 2.1.1 (Maloni and Benton, 2000; Brown et al., 1995). Taken together, we hypothesize that this use of mediated power of a middleman, rather than a buyer or supplier as in the extant literature, will increase when the dependence of the power target, the HCO, onto the middleman increases.

Hypothesis 5: As the HCO’s dependence on its GPO increases, the GPO’s use of mediated power increases.

When buying organizations outsource a business function, their dependence on the provider is driven by the extent to which alternative sources exist and by the conditions creating switching difficulties (Boyle and Dwyer, 1995; El-Ansary and Stern, 1972; Brown et al., 1983). When HCOs outsource the first two steps of their procurement process to GPOs, they become dependent on this GPO. As HCOs spend a larger percentage of their annual purchasing dollars through GPO-negotiated contracts and as their GPO-switching costs are higher, their dependence on GPOs’ services is higher. HCOs that outsource the first two steps of the procurement process to a GPO typically reduce their procurement staff that would be conducting procurement tasks such as
testing, researching, negotiating and purchasing items on their own (Schneller and Smeltzer, 2006). Increased dependence on the GPO thus tends to be associated with lower levels of purchasing resources. Recall that expert power refers to the perception that one organization holds expertise or information that is valued by another organization (Maloni and Benton, 2000; French Raven, 1959). As HCOs reduce their procurement staff and thereby skills, they increasingly value the procurement expertise and benchmarking information offered to them by the GPO.

Furthermore, HCO procurement professionals tend to view pricing practices of their suppliers as irrational and opportunistic and believe that GPOs have historically delivered lower prices to them than they would have achieved on their own (Burns, 2002). Recall that referent power involves one organization’s desire to be associated with another for recognition by association (Maloni and Benton, 2000; French Raven, 1959). HCOs that turn to GPOs to outsource the first two steps of the procurement process and increase their dependence on the GPO, appear thus to seek identification with the GPO and want to be associated with the GPO in their quest for lower prices from the OEM, thereby lending referent power to the GPO. In more general terms, it has been shown that when organizations highly depend on each other, the levels of identification with each other increases and their values, attitudes and goals tend to converge (Mizruchi, 1989; Turner et al., 1979). Based on these arguments, we hypothesize that an increase in a buying organization’s (HCO’s) dependence on a middleman (GPO) is associated with an increase in the HCO’s assessment of the GPO’s referent power and expert power.
Hypothesis 6: As the HCO’s dependence on its GPO increases, the GPO’s non-mediated power increases.

2.2.4 Dependence on the GPO and the OEM

It has long been held that organizations perform a strategic evaluation of the long term implications of outsourcing an activity. In Section 2.2.3 it was argued that a buyer’s outsourcing of the procurement function to a middleman will lead to some extent to the buyer’s dependence on the middleman. A long term implication of outsourcing a procurement function to a middleman may however not only affect the buyer’s dependence on the middleman, but also the buyer’s dependence on the supplier. Outsourcing often involves the disposal or transfer of human and physical resources (Handley and Benton, 2009), leading to a risk of capability erosion (Dierickx and Cool, 1989; Quinn and Hilmer, 1994). Indeed in the healthcare supply chain, HCOs who join a GPO typically save money by not having to employ the necessary support staff to test, research, negotiate and purchase items on their own (Schneller and Smeltzer, 2006). As HCO’s increase their dependence on the GPO and risk procurement capability erosion, it is postulated to affect an HCO’s dependence on the supplier (OEM). Using the procurement service of a middleman (GPO) reduces the number of alternative supplier sources for the buyer since the GPO generally only selects two or three suppliers for a given product (Burns et al., 2002). The availability of alternative sources or the degree of replaceability of a partner has been shown to increase the buyer’s dependence on a
supplier (Brass, 1984; Kumar et al., 1995). GPOs reward HCOs with end-of-year rebates when HCOs use fewer of the contracted suppliers. Through these so-called standardization rebates, GPOs encourage HCOs to further reduce their number of exchange partners and to thereby increase the procurement volume with the remaining partner(s). The number of exchange partners and the fraction of business done with a partner directly affect the dependence of the buyer on the supplier (Kumar et al., 1998; Burt, 1982). Lastly a smaller purchasing staff and consequently reduced purchasing expertise, associated with the procurement outsourcing to the GPO (Schneller and Smeltzer, 2006), is postulated to negatively affect the HCO’s perceived ease of switching suppliers. The relative difficulty of switching suppliers is an indicator of the buyer’s dependence on the supplier (Boyle and Dwyer, 1995; Frazier and Rody, 1991; Buchanan, 1992). Therefore, based on these collective arguments, it is hypothesized that as a buyer (HCO) outsources the first two steps of its procurement process to a procurement service provider (GPO) and increases its dependence on the GPO, the buyer’s dependence on the supplier (OEM) increases.

*Hypothesis 7: As the HCO’s dependence on its GPO increases, the HCO’s dependence on the OEM increases.*

### 2.2.5 Dependence and OEM power

As noted in Section 2.1.6, a buying organization is said to be more dependent on its supplier if the organization purchases from a single or few suppliers, if the organization
has access to few alternative suppliers and if the switching costs are high. The healthcare supply chain, in particular the medical equipment supply chain, can be characterized as a reverse oligopoly, or a supplier focused oligopoly. Typically, buying organizations have access to a larger number of suppliers, such as in the automobile industry. However, in the medical equipment supply chain, HCOs have access to only a handful of OEMs, which by the definition of dependence discussed in Section 2.1.6 increases the dependence of the HCO onto the OEM. The HCO’s dependence on the OEM may further increase due to the outsourcing of the first two steps of the procurement process, as argued for hypothesis 3. HCOs often times depend on their OEMs for equipment training to physicians and nurses and OEMs are frequently present in the operating room to assist the surgical teams. In addition, OEMs routinely engage physicians on product design teams (O Connor, 2011; Schneller and Smeltzer, 2006; Burns, 2002). Dependent relations have been found to elevate partners’ levels of identification with each other and their values, attitudes and goals tend to converge (Mizruchi, 1989; Turner et al., 1979). The desire to identify with and be associated with a partner is known as referent power, a form of non-mediated power as described in Section 2.1.1 (Maloni and Benton, 2000; Frazier and Summers, 1984). In addition, a dependent buyer is shown to have a high need for technological expertise from their suppliers (Caniels and Gelderman, 2007). Expert power is defined as the power target’s believe that the power source is an expert and holds information or expertise that is valued by the target (Maloni and Benton, 2000; Frazier and Summers, 1984). Furthermore, to avoid costs generated by a disruption of a
dependent relation, actors in such a relationship are more likely to prefer non-coercive, or non-mediated forms of power (Gundlach and Cadotte, 1994).

The social psychology literature provides some additional support for this argument. An individual’s high level of dependence on a partner may generate a high level of commitment to the relationship (Rusbult et al., 1991; Kelley, 1979). Furthermore, structural patterns of interdependence may account for the emergence of relationship specific motives. An individual’s high level of dependence on a partner may generate a focus on the long term, on effective conflict resolution and the willingness to forego self-interest (Lawler and Yoon, 1993; Rusbult et al., 1991; Kelley, 1979; Gulati and Sytch, 2007). Empirical evidence exists of a strong association between relationship commitment and non-mediated power (Benton and Maloni, 2005; Maloni and Benton, 2000; Brown et al., 1995). Taken together, the arguments above suggest that a buying organization’s (HCO’s) dependence on the supplier (OEM) is positively associated with the HCO’s assessment of the OEM’s non-mediated power.

**Hypothesis 8: As the HCO’s dependence on the OEM increases, the HCO’s assessment of the OEM’s non-mediated power increases.**

### 2.3 Analytical literature

A number of studies investigate the issue of market segmentation for remanufactured products. Majumder and Groenevelt (2001) use a game theory approach and investigate pricing/remanufacturing decisions of OEM facing competition local third-party
remanufacturer. The authors assume that new and remanufactured products offered by the OEM are indistinguishable. Ferguson and Toktay (2006) also use a game theory approach to consider pricing and remanufacturing decisions for an OEM who faces competition from a local remanufacturer. The authors derive conditions under which remanufacturing is profitable and analyze strategies that deter a third-party remanufacturer’s entry into the secondary market. Ferrer and Swaminathan (2006) study joint pricing of new and remanufactured products using two-period and multi-period models. The authors explore the effect of various parameters in the Nash equilibrium and find that, among other results, if remanufacturing is very profitable, an OEM may forego some of the margin of new products by lowering the price and selling additional units to increase the flow of cores available for remanufacturing. In each of these studies the authors assume that the customer cannot distinguish between new and remanufactured products, that the same price can be charged for both and that remanufacturing is used as a savings vehicle for the manufacturing of the product. In contrast, in the healthcare supply chain and in the current study, refurbished products are offered to secondary markets and refurbishing is thus used for incremental revenue. In addition, service profits of both new and remanufactured products are considered as OEMs who offer service contracts to their customers are partly offering remanufactured products to further increase their service revenue.

Debo et al. (2005) investigate the joint pricing and production technology selection problem faced by an OEM who considers introducing a remanufacturable product in a market that consists of heterogeneous customers. The authors propose that the proportion
of used products that can be remanufactured can be increased by applying more expensive production technology. They find, similar to Ferrer and Swaminathan (2006), that it may be helpful to sell new products below unit cost, to generate supply of remanufactured products. The authors also find that high production costs, low remanufacturing costs and low incremental costs to make a product remanufacturable are key technology drivers. In the current study all returned/collection products can be remanufactured, motivated by the practices of OEMs in the medical equipment supply chain and consistent with for example Ferguson and Toktay (2006) and Ferrer and Swaminathan (2006).

Another study that investigates the OEM’s incentive to interfere with the secondary market is by Oraiopoulos et al. (2012). The authors introduce a relicensing fee that OEMs can use to deter entrants of the secondary market. Using a game theoretic approach, the authors aim to understand how OEM’s incentives and strategies related to the secondary market are shaped, contingent on competitive advantage, product characteristics, and consumer preferences. The authors characterize conditions that favor stimulating or deterring the secondary market and find that OEMs should not shut down the secondary market under a range of conditions. In contrast, in the healthcare supply chain, the OEMs do not collect relicensing fees from third-party brokers who may be refurbishing their products. Instead, OEMs may be selling returned cores to third-party brokers, as part of the disposition decision or they may be acquiring supplemental cores from third-party brokers to meet demand for refurbished products.
Heese et al. (2005) analyze the profitability of remanufacturing under OEM competition. The authors find that by taking back and reselling refurbished products, an OEM can increase profit margins and sales, to the detriment of non-interfering competitor. Using a game theoretic approach they show that remanufacturing can be a profitable strategy for the first moving firm, if the underlying cost structure and market share are appropriate. Vorasayan and Ryan (2009) model the sale, return, refurbishment and resale processes in an open queuing network and formulate a mathematical program to find the optimal price and proportion to refurbish. The authors examine the optimality conditions to characterize the different situations in which it is optimal to refurbish none, some or all of the returned products. The authors consider the competition between new and refurbished products in the context of a competitive market for new products and jointly optimize price and quantity of refurbished products from the manufacturer’s perspective. The setting considered by the authors involves short life cycle, cheap electronic consumer products such as PCs, sold through on-line stores. This is a distinctly different setting compared to the digital imaging equipment supply chain, where life cycles are long, service contracts are an important driver for refurbishing and the items are expensive capital products.

Some studies take into account the market growth over time and investigate remanufacturing issues using product life cycles. Debo et al. (2006) for example study the impact of product life cycles on remanufacturing decisions in the context of a monopoly. The authors investigate the integrated dynamic management of a portfolio of new and remanufactured products that progressively penetrate a potential market over the
product life cycle. The authors assume that remanufactured products cannibalize the sales of new products and find that slow diffusing products are the best candidates for remanufacturing. Copulsky (1976) defines cannibalization as the extent to which one product’s customers are gained at the expense of customers of other products offered by the same firm. Mason and Milne (1994) propose an approach for measuring cannibalization based on the concept of “niche” in Ecology. The niche of each brand describes the customers the brand is competing for and cannibalization may occur when two or more brands have overlapping niches. In the healthcare supply chain setting, the impact of product life cycles also needs to be considered, in particular on the disposition decision, as will be discussed in Chapter 6. Geyer et al. (2007) develop an economic model, consider a price-independent life-cycle and focus on finding the optimal component durability to maximize savings from remanufacturing. The authors model and quantify the cost savings potential of production systems that collect, remanufacture and remarket end-of-use products as perfect substitutes while facing the fundamental supply-loop constraints of limited component durability and finite product life cycles. The authors show that coordination of product cost structure, collection rate and component durability are essential for maximization of production cost savings from remanufacturing. In contrast, in the current study an OEM’s objective in offering refurbished products is not to gain manufacturing savings to offer a perfect substitute, but rather to gain access to additional customers.

A study that considers pricing of new and remanufactured products in a dynamic setting, considering product life cycles and also service revenue is Robotis et al. (2011). The
authors investigate the optimal leasing price and leasing duration decisions for an OEM who jointly optimizes the profits from leasing the product/service bundle along with maintenance revenues and remanufacturing savings. The authors show that the optimal pricing strategy is a skimming strategy and find that the effect of remanufacturing savings on the pricing decision and the length of the leasing duration changes significantly depending on the duration of the product life cycle. 100% of the end-of-lease products are returned to the OEM and the customers do not differentiate between new and remanufactured products. Remanufacturing is again used as a production cost savings vehicle rather than a product and service revenue increasing strategy. In contrast to the earlier mentioned studies, the authors investigate the effect of the size of the production capacity. Another important difference between the current study and the study by Robotis et al. (2011) is that leasing is uncommon in the healthcare supply chain, which has a complicating effect on the return flow of cores.

Over the last two decades a considerable amount of research has been conducted in the area of product returns forecasting. A distinctive difference between manufacturing and remanufacturing is the uncertainty with respect to the inputs of the remanufacturing process, i.e. the returned products. One such uncertainty is the timing and quantity of returned products. Forecasting the proportions of product returns is important for procurement decisions, capacity planning, and disposal management (Clottey et al., 2012). Representative literature in this stream includes Goh and Varaprasad (1986) who consider the relationship between sales and returns of returnable bottles; Kelle and Silver (1989) who develop a model for the procurement of reusable containers; Toktay et al.
who use Bayesian methods to estimate parameters for the distribution of product returns and Clotey et al. (2012) who also apply Bayesian methods, but with a continuous, exponential, delay function to capture the delay between sales and returns, where Toktay et al. (2000) use a geometric delay function. The ability to forecast returns is an important part of a refurbishing operation. Developing the appropriate forecasting method for the digital imaging equipment returns, however, is beyond the scope of the current study. Using a game theoretic approach, Atasu et al. (2008) consider demand related issues of an OEM’s remanufacturing strategy, including the “green segment size”, market growth rate and consumer valuations for the remanufactured products. The authors show that thresholds exist for these demand characteristics above which remanufacturing is profitable. The notion that markets are not composed of perfectly homogenous price takers, that remanufactured products are not perfect substitutes for new products and that customers of new and remanufactured products are segmented and have minimal overlap is empirically supported by Guide and Li (2010). The authors show that the common assumption of a fixed market where sales of remanufactured goods must take away from new product market share may not always be justified. Managers at Xerox firmly believe that new, remanufactured, and repaired products do not compete for the same fixed market share, but rather allow Xerox to reach market segments that they could not serve by offering only new equipment. B2B purchasers demand an approximately 10% discount for remanufactured products, yet these customers typically do not come at the expense of new product sales (Atasu et al., 2010). If there are many functionality-oriented customers in a market, remanufactured product can expand market share and profits
rather than cannibalize existing sales. Consistent with these three studies, in the current study the assumption will be made that refurbished equipment does not compete for the same market share. This will be described in more detail in Chapter 6.

Another relevant stream of literature investigates joint product/service bundles. Cohen and Whang (1997) adopt a game theoretic framework where an OEM competes with a third party service operator for the after-sales service. The choice parameters include product price, quality of after-sales service and the price to be charged for the after-sales service. One of the implications includes the notion that a customer will stay with an OEM for service until after the warranty expires, but ultimately leaves for a low cost independent shop. Another implication is that a large portion of the OEM’s profits come from service and that the OEM may low-ball the product price in expectation of future profits from service if the warranty is short. The current study will also consider the effect of long term service profit on current period decision making. However, the consideration of a refurbishing operation, which includes the disposition decision and the cores acquisition process, constitutes a departure from the Cohen and Whang (1997) study.

Karmarkar (1978) investigates design and planning decisions for an OEM that offers service contracts to a buyer. Future costs of replacement and repair are analyzed and a mixed exponential distribution is suggested as a possible time-to-failure model for part failure. Using product cost and reliability and the expected cost of repair, an OEM who offers service contracts can ensure that he derives benefits from the offering. The future cost of service and the pricing of service contracts are important components of
successful servicing operation. In the current study, the OEM offers service contracts for not only new but also refurbished equipment. The actual estimation of the cost of service and repair of both new and refurbished equipment is beyond the scope of the study. Through an economic analysis, Guide et al. (2003) present how to determine the optimal acquisition and selling prices, along with the quantity of used product acquisitions in the cellular phone industry. The authors show that the quantity and quality of the product returns can be influenced by varying quality-dependent acquisition prices and that demand can be influenced by varying the selling price. In the current study, in contrast, cores are collected from customers and acquired from third-party brokers. In addition, in the current study involves expensive long life cycle capital equipment rather than cheap and short life cycle cell phones.

In summary, in most of the remanufacturing studies mentioned above, the authors assume that new and remanufactured products offered by the OEM are indistinguishable and, furthermore, none of the remanufacturing studies other than Robotis et al. (2011) consider environments where revenue from service contracts is a significant contributor to the overall profit of the firm. In addition, a considerable number of studies investigate remanufacturing challenges in environments that are distinctly different compared to the medical equipment supply chain. IT equipment (e.g., Oraiopoulos et al., 2012) typically has a much shorter life cycle compared to medical equipment. Printer toner cartridges (e.g., Majumder and Groenevelt, 2001) do not include service contracts, have short life cycles and are inexpensive compared to digital imaging equipment. Single use cameras (e.g., Ferrer and Swaminatham, 2006) are also inexpensive, are not sold with long term
service contracts and have short life cycles, similar to cell phones (e.g., Guide et al., 2003, Galbreth and Blackburn, 2006, 2010, Guide and Van Wassenhove, 2001). Other studies investigate environments with products which are refurbished many (3-120) times (Geyer et al., 2007), compared to only once for medical equipment. Even others consider short lifecycle, cheap, electronic consumer products such as PCs that are sold through online stores (Vorasayan and Ryan, 2006), or, compared to digital imaging equipment, cheap hospital beds that are not sold with service contracts (Heese et al., 2005).
Chapter 3 Methodology

As described in Chapter 1, the dissertation consists of an empirical study and an analytical study. The primary components of the empirical study include data gathering through a survey questionnaire, followed by data analysis using factor analysis and structural equation analysis, respectively. The questionnaire development process, along with the sample selection, and the administering of the survey is described later in this chapter. The testing of the measurement models and the results of the structural models for both empirical parts of the dissertation are presented in Chapters 4 and 5, respectively. Prior to the start of the data gathering process through a survey questionnaire, extensive field work was conducted. In the remainder of this chapter, the field study will first be discussed, followed by an overview of the methodology of the empirical study and the analytical study.

3.1 Field study

Investigation of the healthcare supply chain started with site visits of OEMs of digital imaging equipment and with visits to a local healthcare organization. During the site visits interviews were conducted with managers and executives from various functional
areas. Plant tours were given at several OEM sites. In addition, phone interviews were conducted with a number of OEM executives. Summaries of the various interviews and site visits are included in Appendix A.

The topics during the interviews included medical equipment refurbishing, relationships between the buyers (HCOs), suppliers (OEMs) and service providers (GPOs) and HCO procurement processes. Two primary findings from the field work which partly motivated the subsequent research in this dissertation include the following:

1. Group Purchasing Organizations (GPOs) play an important and powerful mediating or interceding role in the relationship between the buyers in the healthcare supply chain (HCOs) and the suppliers (in this case the OEMs). Furthermore, only four suppliers, the OEMs, control the medical equipment market leading to a limited number of options for the buyers (HCOs) and thus a powerful position for the suppliers.

2. HCOs’ interest in refurbished equipment has been increasing. OEMs have over the last 10 years developed refurbishing capabilities to meet this growing demand. An important problem for OEMs involves the offering of both new and refurbished equipment and service contracts. The supply of cores, or end-of-life equipment, is typically the constraint for the OEMs and the revenue from service contracts for both new and refurbished equipment is significant. The decisions an OEM has to make with respect to the pricing of new products and thereby the number of new products sold, disposition of returned cores, number of cores to
purchase from third-party brokers and whether or not to hold inventory of refurbished products, are complex.

The finding with respect to the HCO’s relationships with both the GPO and the OEM in part motivated the empirical component of the dissertation. As explained in Chapter 2, existing research in the marketing literature and supply chain management literature has investigated the role of power in oligopolies such as the automotive industry, where the supply chain is characterized by a few powerful buyers who can buy directly from many suppliers. The healthcare supply chain and in particular the medical equipment supply chain however, can be characterized as a reverse oligopoly or supplier-focused oligopoly, where many buyers have access to only a few powerful suppliers. Furthermore, the buyers’ access to these powerful suppliers is typically interceded, or mediated, by powerful middlemen, the GPOs. The role of power in this type of a supply chain and the effect of relationships among the supply chain members onto the performance of the respective members had to the best of our knowledge yet to be investigated. The extensive field work, in particular the interviews with OEM and HCO executives, first revealed the unique characteristics of the medical equipment supply chain as it pertains to relationships and power balances between the supply chain members. The empirical component of the dissertation, involves an investigation of these relationships and power balances in the medical equipment supply chain. The data collection process, including sample selection, measurement instrument development and the administering of the questionnaire will be discussed in Section 3.2.
The finding with respect to the increase in demand for refurbished medical equipment and the OEM’s managerial problem with respect to offering new and refurbished equipment and service contracts for both new and refurbished equipment has directly motivated the analytical part of the dissertation. While in the empirical component of the dissertation, the healthcare supply chain is analyzed from the HCO’s perspective, the analytical study investigates the problem of jointly managing new and refurbished equipment and service contracts in the healthcare supply chain, from the OEM’s perspective. In Section 3.3 the methodology of the analytical study will be discussed.

3.2 Empirical study

3.2.1 Data collection

To test the hypotheses presented in the Chapter 2, primary data was collected from HCOs. Specifically, the sample of target respondents for the study consisted of senior level managers and executives responsible for procurement of digital imaging equipment for HCOs, covering all 50 states in the US. The multiple contact strategy suggested by Dillman (2000) was employed and a total of 1891 procurement professionals in HCOs nationwide were invited to participate. From March to April 2012 four email contacts were made with the target respondents including an invitation letter with the link to the web survey and brief follow up letters at intervals of one to two weeks following the invitation letter.
Target respondents were asked in the correspondence to inform the researchers if they had been inappropriately identified for participation in the survey. In total 260 target respondents indicated that they were not qualified to be a participant. Reasons included change of jobs, retirement or just no sufficient involvement in digital imaging equipment procurement. Of the remaining 1631 target respondents, a questionnaire was returned by 276 respondents, for a response rate of 16.9%. 14 of the respondents returned incomplete surveys, resulting in a usable sample of 262. The response profile is presented in Table 3.
Table 3 Response profile

<table>
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<tr>
<th>Title of respondent</th>
<th>Percent</th>
<th>HCO size</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>CXO</td>
<td>1%</td>
<td>&lt; 200 beds</td>
<td>31%</td>
</tr>
<tr>
<td>Vice president</td>
<td>9%</td>
<td>200-600 beds</td>
<td>37%</td>
</tr>
<tr>
<td>Director</td>
<td>70%</td>
<td>600-1000 beds</td>
<td>13%</td>
</tr>
<tr>
<td>Senior Manager</td>
<td>1%</td>
<td>&gt; 1000 beds</td>
<td>20%</td>
</tr>
<tr>
<td>Manager</td>
<td>11%</td>
<td>other</td>
<td>8%</td>
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<td>Teaching status</td>
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<tr>
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<td>45%</td>
<td>For profit</td>
<td>14%</td>
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<tr>
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</table>

<table>
<thead>
<tr>
<th>GPO usage for digital imaging equipment</th>
<th>Percent</th>
<th>Digital Imaging OEM</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% of annual volume</td>
<td>6%</td>
<td>GE</td>
<td>33%</td>
</tr>
<tr>
<td>1- 25% of annual volume</td>
<td>19%</td>
<td>Philips</td>
<td>26%</td>
</tr>
<tr>
<td>25%-50% of annual volume</td>
<td>18%</td>
<td>Siemens</td>
<td>26%</td>
</tr>
<tr>
<td>50%-75% of annual volume</td>
<td>29%</td>
<td>Toshiba</td>
<td>12%</td>
</tr>
<tr>
<td>&gt;75% of annual volume</td>
<td>28%</td>
<td>Other</td>
<td>2%</td>
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<table>
<thead>
<tr>
<th>GPO service</th>
<th>% respondents using service</th>
<th>GPO used for Digital imaging equipment</th>
<th>Percent</th>
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<tbody>
<tr>
<td>Access to discounted prices</td>
<td>95%</td>
<td>Novation</td>
<td>26%</td>
</tr>
<tr>
<td>Benchmarking</td>
<td>75%</td>
<td>Premier</td>
<td>22%</td>
</tr>
<tr>
<td>Contract management</td>
<td>60%</td>
<td>MedAssets</td>
<td>22%</td>
</tr>
<tr>
<td>Decision support tools</td>
<td>50%</td>
<td>AmeriNet</td>
<td>10%</td>
</tr>
<tr>
<td>Materials management</td>
<td>49%</td>
<td>Health Trust</td>
<td>9%</td>
</tr>
<tr>
<td>Education</td>
<td>36%</td>
<td>GNYHA</td>
<td>3%</td>
</tr>
<tr>
<td>Technology assessment</td>
<td>34%</td>
<td>Child Health Corp.</td>
<td>1%</td>
</tr>
<tr>
<td>Clinical resource management</td>
<td>33%</td>
<td>Yankee Alliance</td>
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</tr>
<tr>
<td>Operations consulting</td>
<td>31%</td>
<td>Other</td>
<td>5%</td>
</tr>
<tr>
<td>Equipment repair or disposal</td>
<td>27%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technology life cycle management</td>
<td>15%</td>
<td></td>
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</tr>
<tr>
<td>Process design</td>
<td>12%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insurance services</td>
<td>10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leasing versus capital procurement of digital imaging equipment</td>
<td>Percent</td>
<td>Equipment depreciation term</td>
<td>Percent</td>
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<tr>
<td>Leasing</td>
<td>14%</td>
<td>5 years</td>
<td>25%</td>
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<tr>
<td>Capital procurement</td>
<td>86%</td>
<td>7 years</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 years</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Other</td>
<td>8%</td>
</tr>
</tbody>
</table>
Assessments of data normality did not lead to any evidence to cause concern. To evaluate the potential non-response bias among the valid informants, first a set of comparisons (independent t-tests) between answers from early and late respondents was made (Armstrong and Overton, 1977). Further analysis was done to compare the response sample to the HCOs in the American Hospital Association (AHA) along the dimension of hospital size (# beds), teaching status and for profit status. The analyses revealed no observable differences that would lead to a concern of significant non-response bias. It is therefore concluded that the sample appropriately represented the target population of American HCOs.

3.2.2 Measurement instrument

The survey instrument was developed using previously tested and validated instruments with minor wording changes applied where appropriate. The response categories for the survey were 7-point Likert scales (1=strongly disagree, 7=strongly agree). Since the scales used in this study were all modified from existing scales, a rigorous methodology was applied to ensure the validity and reliability of the instrument. This assessment is discussed in Chapter 4 for the scales used in Part 1 of the empirical study and in Chapter 5 for the scales used in Part 2 of the empirical study. In Part 1 the effect of a GPO’s mediated and non-mediated power onto the relationship between the GPO and the HCO is analyzed. In addition, the effect of an OEM’s non-mediated power onto the OEM-HCO relationship is assessed. For each of the three types
of mediated power bases (coercive, reward and legal legitimate power) and both types of
non-mediated power (expert and referent power) adapted versions of the multi-item
scales from previous studies focused on inter-firm power were used (Handley and
the final items used for these and the other constructs in both Part 1 and Part 2.
The extant empirical supply chain literature provides support for measuring relationships
between buyers and suppliers as a multi-dimensional construct (Handley and Benton,
and Pearson, 1999). In the current study the relationships between an OEM and an HCO
and between a GPO and an HCO, respectively, were measured as two-dimensional
reflective constructs, using adapted versions of the multi-item constructs for cooperation
and commitment from the prior work of (Handley and Benton, 2009, Prahinski and
The performance of the OEM, the HCO and the GPO were measured using existing,
multi-dimensional constructs. For the performance of the HCO, the validated constructs
from prior work by Li and Benton (2003) were adapted. Measures include holding patient
costs down (Williams Jr. et al., 1998, Flood and Scott, 1987, Fetter et al., 1980),
achieving high labor productivity (Siferd and Benton, 1994, Trivedi and Warner, 1976,
Warner and Prawda, 1972) and maintaining higher capacity utilization levels (Griffith et
al., 1976). To measure the performance of the OEMs, existing scales from the literature
(Cannon et al., 2010, Prahinski and Benton, 2004, Cannon and Perreault Jr., 1999) were
adapted, ensuring that performance with respect to product quality and value, service
quality and responsiveness to changes were captured. Finally, to measure the performance of the GPOs, an adapted version of the OEM-performance scale was used, accounting for the fact that the GPO offers services rather than a product.

In Part 2 of the empirical component of the dissertation, the effect of an HCO’s dependence on a GPO onto the GPOs mediated and non-mediated power is analyzed. In addition, the effect of an HCO’s dependence on the GPO onto the HCOs dependence on an OEM is investigated. Lastly, the effect of the HCO’s dependence on the OEM onto the OEM’s non-mediated power is analyzed. For the three types of mediated power bases (coercive, reward and legal legitimate power) and the two non-mediated power bases (expert and referent power), adapted versions of scales used in previous empirical inter-organizational power studies were used (Handley and Benton, 2012a, 2012b; Maloni and Benton, 2000).

Consistent with extant empirical literature, dependence on both the GPO and on the OEM was measured as a multi-dimensional construct (Caniels and Roeleveld, 2009; Gulati and Sytch, 2007). The items used in the dependence constructs reflect the magnitude of the exchange (Pfeffer and Salancik, 1978; El-Ansary and Stern, 1972; Pugh et al., 1969), the concentration of the exchange, or the number of exchange partners (Kumar et al., 1998; Burt, 1982) and the perceived anticipated switching difficulties that the HCO would face, should they need to switch GPOs or OEMs (Handley and Benton, 2012a, Brown et al., 1983, El-Ansary and Stern, 1972).

To test the hypotheses developed in Chapter 2, a two-stage structural equation modeling (SEM) approach is applied (Anderson and Gerbing, 1988), where in the first stage the
reliability and validity of the measurement model are established and in the second stage the nomological validity of the structural model is assessed and hypothesized relationships are tested. Structural equation modeling is in particular appropriate to simultaneously measure the multiple hypothesized relationships in one comprehensive model. This testing of the measurement model and the results of the structural model for Part 1 of the empirical component of the dissertation is presented in Chapter 4 and the results for Part 2 are presented in Chapter 5.

3.3 Analytical study

The challenges around new manufacturing and refurbishing in the medical equipment supply chain are unique, compared to the extant literature, for a number of reasons: (1) volumes are relatively lower, (2) prices are higher (>\$1MM for new MRI equipment), (3) four OEMs control the market, (4) residence time, or useful life with the customer is long (typically 4-7 years), (5) service contracts for both new and refurbished products contribute significantly to the overall profit of the OEM, (6) products are only refurbished once.

An important problem facing a medical equipment OEM can be described as follows: How should an OEM jointly manage new and refurbished products along with service contracts for new and refurbished products. Stated differently, how can an OEM in an environment with low volume, expensive products and multi-year service contracts, maximize the profit from new and refurbished products and service contracts for both
new and refurbished products? The OEM needs to make critical decisions with respect to the number of new items sold, the disposition of returned/collected cores, the number of items bought from third-party brokers and the amount of inventory of finished refurbished products. In Chapter 6 an analytical model will be presented to begin to provide insight in these decisions faced by each of the four digital imaging equipment OEMs.

First cost and revenue streams associated with the various processes in an OEM’s manufacturing-refurbishing environment will be formulated and the subsequent analysis will provide insights into the drivers to determine to what extent demand for refurbished product should be fulfilled and how (carrying inventory of refurbished products versus ensuring that demand equals the number of refurbished products). The effect of the profit of service contracts on the decision to fulfill demand for refurbished product will be investigated and an expression will be developed for the fraction of collected end-of-life products that should be disposed of or sold to third-party brokers. A case study is presented, based on adapted data gathered from one of the OEMs through interviews and site visits, to illustrate the analytical model.
Chapter 4 Power in the healthcare supply chain

This chapter presents the analysis and results of part 1 of the empirical component of the dissertation. In part 1 the role of power in the healthcare supply chain is investigated. The testing of the measurement model will first be presented. Next, the results of the structural model will be discussed, followed by the managerial implications of the study.

4.1 Measurement instrument

4.1.1 Measurement model quality

Content validity of the measurement model was established through extensive literature review and review of the questionnaire by OEM industry experts, HCO executives and by academicians.

Next, following the two-step approach by Anderson and Gerbing (1988) first the measurement model is purified and tested. For this exploratory factor analysis a pilot data set of 62 responses on the original measurement model is used and subsequently the model is refined as needed. In the second step of the two-step approach by Anderson and
Gerbing (1988) a confirmatory analysis on the refined model is performed using the larger hold-out dataset of the remaining 200 responses.

4.1.1.1 Exploratory factor analysis

Maximum likelihood factor analysis at the individual factor level was used to determine convergent validity of the measurement scales. Recommendations in the literature regarding factor loadings vary somewhat. The lowest significant factor loading to define the construct is considered to be 0.30 (Hair, 1998, Guadagnoli and Velicer, 1988). Others suggest a loading greater than 0.40 (Carmines and Zeller, 1979). In addition, Corrected Item to Total Correlation (CITC) is used to evaluate the reliability of each item in each construct. CITC is a measure of internal consistency and is the correlation of each item to the overall scale. The recommended CITC value is 0.50 or higher (Hair, 1998). Using these guidelines, several manifest variables were removed from the measurement model. Poor factor loadings and lower than desired CITCs resulted in removal of two items from the OEM- cooperation construct and three items from the GPO cooperation construct. The measurement model was re-specified by implementing the aforementioned modifications. The CITC values and factor loadings of the remaining items in the adjusted scales all improved and were above the suggested thresholds. In addition, the reliability of each construct was deemed appropriate as measured by Cronbach’s alpha, since the values were all well above the minimum threshold for existing scales (0.70) (Carmines and Zeller, 1979, Nunnally, 1978). Lastly, Eigen values for each of the factors were greater than 2.0 and the Average Variance Extracted (AVE) ranged from 59% to
89% (Fornell and Larcker, 1981). In short, the analysis indicates that the re-specified measurement model is valid and reliable.

4.1.1.2 Confirmatory factor analysis

Structural equation modeling (LISREL) was used to analyze the refined measurement model and the structural model. This method was selected because in the measurement model, confirmatory factor analysis affords a stricter interpretation than traditional methods (Anderson and Gerbing, 1988). Furthermore, in the structural model it enables researchers to analyze the relationships among multiple exogenous and endogenous variables and between endogenous variables simultaneously.

The multiple measures of absolute and incremental model fit shown in Table 4 reflect a reasonably fitting measurement model (Hu and Bentler, 1999, MacCallum et al., 1996, Bentler and Bonett, 1980).

Table 4 Confirmatory factor analysis - model fit

<table>
<thead>
<tr>
<th>Model fit criterion</th>
<th>Value</th>
<th>Suggested range</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMSEA point estimate</td>
<td>0.077</td>
<td>≤0.08</td>
</tr>
<tr>
<td>RMSEA 90% confidence interval</td>
<td>(0.073;0.082)</td>
<td>(0.00;0.08)</td>
</tr>
<tr>
<td>NFI</td>
<td>0.91</td>
<td>≥0.90</td>
</tr>
<tr>
<td>NNFI</td>
<td>0.94</td>
<td>≥0.90</td>
</tr>
<tr>
<td>CFI</td>
<td>0.95</td>
<td>≥0.90</td>
</tr>
<tr>
<td>IFI</td>
<td>0.95</td>
<td>≥0.90</td>
</tr>
</tbody>
</table>
4.1.1.3 Second order factors

Consistent with previous empirical research focused on relationships between buyers and suppliers (Handley and Benton, 2009, Prahinski and Benton, 2004), second order factors were used for the relationships between the OEM and the HCO and between the GPO and the HCO, respectively. Second order factors are latent constructs that explain the covariance between two or more first-order constructs. Theoretically, covariance between the first-order constructs cooperation and commitment can be explained by the underlying second order construct, relationship. In more general terms, second order factors can capture external influences that are common to first order factors (Bollen, 1989). Table 5 indicates the significant correlation among OEM cooperation and OEM commitment and among GPO cooperation and GPO commitment, respectively, further supporting the use of second order factors in the model.

Both second-order factors, OEM-HCO relationship and GPO-HCO relationship, are modeled to affect their two associated first order factors, cooperation and commitment, consistent with the empirical supply chain literature (Benton, 2009, Prahinski and Benton, 2004). To avoid under-identification, the path coefficients from relationship to cooperation and to commitment were set equal to each other for both second order factors (Gorsuch, 1983).
In addition to the content validity and the assessment of the model fit, the construct validity needs to be assessed. To ensure proper convergent validity, a common recommendation is that t-values for the factor loadings of manifest variables on their latent factors represent a p-value <0.01 (Anderson and Gerbing, 1988). A factor loading of 0.40 again was used as a threshold for proper convergent validity (Carmines and Zeller, 1979). Table 4.3 shows that the minimum factor loading is 0.54 and the lowest t-
value is 7.79. Scale reliability for each scale was determined using Cronbach’s alpha.

Table 6 shows that Cronbach’s Alpha values are all greater than 0.70, which is the minimum desired level for established scales (Carmines and Zeller, 1979).

Average Variance Extracted (AVE) and composite reliability are additional measures of construct reliability (Fornell and Larcker, 1981). Results for both measures indicate that reliabilities of the constructs are strong. One construct, OEM Cooperation, has an AVE lower than the recommended threshold of 0.50, but is still acceptable at 0.45 (Menor et al., 2007, Hatcher, 1994). Lastly, discriminant validity, the third component of construct validity, was assessed by examining the inter-factor correlation matrix (Table 5). The point estimates and standard errors presented in Table 5 can be used to calculate 95% confidence intervals for each of the inter-factor correlations. None of the confidence intervals contain 1.0 (Anderson and Gerbing, 1988). In an additional examination of discriminant validity, sets of Confirmatory Factor Analysis models were compared for each inter-construct correlation, where in one model the correlation of a pair of latent variables is constrained to equal 1.0 and in the other model the correlation was free to vary (Venkatram, 1989; O’Leary-Kelly and Vokurka, 1998). In each case, the $\chi^2$ value for the unconstrained model was significantly lower than the value for the constrained model at $p<0.001$, providing additional evidence of discriminant validity for the measurement model (Bagozzi et al., 1991).
<table>
<thead>
<tr>
<th>Scale</th>
<th>Item</th>
<th>Factor loading</th>
<th>t-value</th>
<th>Cronbach's alpha</th>
<th>Composite reliability</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPO Commitment</td>
<td>GPOCOMM1</td>
<td>0.91</td>
<td>16.53</td>
<td>0.944</td>
<td>0.942</td>
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Continued
Table 6 continued

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<th>0.75</th>
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<td>15.63</td>
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<td></td>
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<tr>
<td>OEMPERF5</td>
<td>0.94</td>
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<td>17.35</td>
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<th>H_PERF1</th>
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<th>9.09</th>
<th>0.800</th>
<th>0.804</th>
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<td>H_PERF2</td>
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<td>13.25</td>
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<td>H_PERF3</td>
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<td>11.49</td>
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<th>GPO Performance</th>
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<th>0.936</th>
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<td>GPOPEFR3</td>
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<td></td>
<td>18.97</td>
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</table>

4.1.1.5 Common methods variance

In this study single informants from the HCOs were used to collect the data. If measures of the predictor and criterion variables are provided by the same respondent, self-reporting bias may occur. This type of common method bias may result from any artifactual covariance between the predictor and criterion variable, produced by the fact that the respondent providing the measure of these variables is the same (Podsakoff et al., 2003). A statistical test recommended by Podsakoff et al. (2003) was therefore conducted to determine whether or not unacceptable levels of common methods variance exist in the data. An additional unmeasured “methods” factor, i.e. a factor associated with the respondent, was introduced into the measurement model to control for a latent methods effect. The measurement model did not significantly change. All items continued to load
significantly onto their intended latent factors. It was therefore concluded that any level of common methods variance that may exist in the data is not a significant concern.

4.2 Analysis and results

The structural model contains 3 performance variables; the performance of the OEM, the performance of the HCO and the performance of the GPO, respectively. The performance of the OEM is based on the rating of equipment quality and value, responsiveness and service quality. The GPO’s performance is based on the rating of process quality and service quality. The HCO’s performance is based on the rating of cost, productivity and capacity utilization, relative to competitors. Factor analysis was used to develop these latent performance measures. The final factor loadings for the three performance constructs were all greater than 0.60 and Cronbach’s alpha, composite reliability and AVE values presented in Table 6 supported good construct reliability. The overall fit of the structural model was measured using multiple measures, as with the measurement model. The results for Root Mean Squared Error (RMSEA) (0.079) and RMSEA 90% confidence interval (0.075; 0.084) indicate sufficient evidence of reasonable absolute model fit. The figures for normed fit index (NFI) (0.91), non-normed fit index (NNFI) (0.94), comparative fit index (CFI) (0.94) and incremental fit index (0.94) support good incremental model fit. Table 7 and Table 8 show the results of the structural model and Figure 4 presents the standardized coefficients graphically. Solid lines indicate a significant coefficient and
dashed lines are used for those path coefficient that are not significantly different from zero (p>0.1). The level of statistical power of the structural model was determined following the algorithm suggested by MacCallum et al. (1996). The resulting power is greater than 0.999, exceeding the commonly desired threshold of 0.80 (MacCallum et al., 1996).

Figure 4 Structural model results
In the remainder of this section the results for the individual hypotheses will be discussed.

4.2.1 Hypothesis 1: OEM non-mediated power and the HCO –OEM relationship

The two types of non-mediated OEM power, referent and expert power, were both hypothesized to have a positive effect on the relationship between the HCO and the OEM. As procurement professionals in HCOs increase admiration for their supplier, the OEM, and as they wish to be associated with them, they intrinsically seek a closer relationship with them. An increased desire to be associated with the OEM is thus expected to lead to a long term commitment and a better sense of cooperation on the part of the HCO procurement professional. A closer relationship with the HCO is likely to materialize in future revenues for the OEM in the form of maintenance and spare parts as well as capital equipment replacement.

To test the hypothesized effect of referent power on the HCO relationship, the statistical significance of path $\gamma_6$ is assessed. The standardized coefficient from OEM referent power to Relationship with OEM ($\gamma_6=0.28; t$-value$= 3.05$) is highly significant at $p<0.01$. 
### Table 7 Power-relationship hypotheses summary

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Structural model path</th>
<th>Standardized coefficient</th>
<th>t-value</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-mediated OEM power:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEM referent power → HCO-OEM relationship</td>
<td>ϒ6</td>
<td>0.28</td>
<td>3.05***</td>
<td>H1a supported</td>
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<td>OEM expert power → HCO-OEM relationship</td>
<td>ϒ7</td>
<td>0.53</td>
<td>5.61***</td>
<td>H1b supported</td>
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<td><strong>Non-mediated GPO power:</strong></td>
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<td></td>
</tr>
<tr>
<td>GPO referent power → HCO-GPO relationship</td>
<td>ϒ1</td>
<td>0.22</td>
<td>1.57*</td>
<td>H2a supported</td>
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<td>GPO expert power → HCO-GPO relationship</td>
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<td>0.59</td>
<td>3.01***</td>
<td>H2b supported</td>
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<td><strong>Mediated GPO power:</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPO reward power → HCO-GPO relationship</td>
<td>ϒ3</td>
<td>0.02</td>
<td>0.4</td>
<td>H3a not supported</td>
</tr>
<tr>
<td>GPO coercive power → HCO-GPO relationship</td>
<td>ϒ4</td>
<td>-0.14</td>
<td>-1.05</td>
<td>H3b not supported</td>
</tr>
<tr>
<td>GPO legal legitimate power → HCO-GPO relationship</td>
<td>ϒ5</td>
<td>-0.1</td>
<td>-0.85</td>
<td>H3c not supported</td>
</tr>
</tbody>
</table>

*** p<0.01; ** p<0.05; * p<0.1

Similarly, as procurement professionals in HCOs value the expertise of OEMs, they are expected to be drawn to a closer relationship with the OEM. To test the hypothesized effect of expert power on the HCO relationship, the statistical significance of path ϒ7 is assessed.

The standardized coefficient from OEM expert power to Relationship with OEM (ϒ7=0.53; t-value= 5.61) is strongly significant at p<0.01. Hypothesis 1a and 1b both thus receive strong statistical support.
4.2.2 Hypothesis 2: GPO non-mediated power and the HCO–GPO relationship

The effect of non-mediated power in the healthcare supply chain was also analyzed in the HCO–GPO relationship. Specifically, the GPO’s expert power was hypothesized to positively affect the relationship between the GPO and the HCO. Recall that GPOs provide HCOs with a set of services, from basic price negotiation to contract management, operations consulting, benchmarking and process design for example (Burns, 2002). HCO procurement managers consistently strive for cost savings, cost analysis and cross references (Schneller and Smeltzer, 2006). The expertise held by the GPO in terms of procurement leadership for example and the access to benchmarking information was expected to intrinsically place the GPO into an expert power position, which was expected to enhance the relationship between the GPO and the HCO. This hypothesis is evaluated by assessing the statistical significance of path $\Upsilon_2$. The standardized path coefficient from GPO expert power to Relationship with GPO ($\Upsilon_2=0.58$, t-value =2.72) is significant at $p<0.01$. Hypothesis 2b thus receives strong statistical support. GPO expert power has a significant positive effect on the relationship between the GPO and the HCO.

Similarly, referent power was hypothesized to positively affect the relationship between the GPO and the HCO. Many HCO procurement professionals believe that OEMs’ pricing practices are opportunistic and irrational, that GPOs have delivered lower prices than they would have achieved on their own and that OEMs would keep their prices high without pressure from the GPOs (Burns, 2002). One of the primary reasons for HCOs to
use the services of a GPO is thus to join forces against the opportunistic OEM, intrinsically providing referent power to the GPO. Burns claims that this situation has bound HCOs more closely to GPOs (Burns, 2002). To test the hypothesized positive effect of referent power on the relationship between the HCO and the GPO, the statistical significance of path Y1 is assessed. The standardized path coefficient from GPO referent power to Relationship with GPO (Y1=0.22, t=1.57) is significant at p<0.1. The study offers statistical evidence that GPO referent power has a significant positive impact on the relationship between the GPO and the HCO.

4.2.3 Hypothesis 3: GPO mediated power and the HCO–GPO relationship

Mediated power on the part of the GPO was hypothesized to negatively affect the relationship between the GPO and the HCO. Recall that reward, coercion and legitimate power sources are mediated in that the power target’s decision making and behavior are external to the target and are provided upon the condition that the target does what the source wishes (Brown et al., 1995). GPOs seek long term commitment or compliance from the HCOs, and their agreement to use a specific supplier for a contracted product (Burns, 2002). They attempt to achieve this compliance in different ways, essentially using different types of mediated power. Two of the largest GPOs, Premier and Novation, for example, are known to differ in their compliance achieving approaches. While Premier enforces compliance, Novation uses more of a voluntaristic approach. The power base primarily used by Premier can best be described as coercive, while Novation appears
to use strictly reward based power. HCOs that are members of investor-owned GPOs on the other hand generally cannot order anything other than what is on the GPO contract (Burns, 2002). Stated differently, an investor GPO can exercise legal legitimate power over the HCO’s procurement professional. To test whether the three types of mediated power have a negative effect on the relationship between the GPO and the HCO, the significance of the three path coefficients from GPO reward power, GPO coercive power and GPO legal legitimate power, respectively, to Relationship with GPO are evaluated. The path coefficient between GPO reward power and Relationship with GPO ($\gamma_3=0.02$, t-value=0.4) is not significant in the structural model. There is no statistical evidence that GPO reward power affects the relationship between the HCO and the GPO and hypothesis 3a is therefore not supported. Furthermore, the average scores on the items of the GPO-reward power construct are all significantly less than four (see Appendix B), indicating that HCOs do not appear to perceive their GPO to use reward power. End-of-year rebates as rewards for contract compliance, for example, are not perceived as a measure of a GPO’s reward power by HCO procurement professionals, nor do they significantly affect the relationship between the GPO and the HCO.

Next, the path coefficient between GPO coercive power and relationship with the GPO ($\gamma_4=-0.14$, t=-1.05) is in the hypothesized negative direction, yet the effect is not statistically significant. The study does not provide sufficient evidence of a negative effect of coercive power on the relationship between the GPO and the HCO. Here again, the average scores on the items of the GPO-coercive power construct are all less than 4 (see Appendix B), indicating that HCOs do not appear to perceive their GPO to use
coercive power. Hypothesis 3b is not supported. GPOs appear to be successful in managing the HCO’s assessment of a potential negative effect from coercive power on their relationship with the HCOs.

Finally, the path coefficient between the third type of mediated power, legal legitimate, and the relationship between with the GPO ($Y^5 = -0.1, t = -0.85$) is also in the hypothesized negative direction, but the effect is again not statistically significant. The results of the statistical analysis therefore do not provide sufficient evidence of a negative effect of a GPO’s legal legitimate power on the relationship between the GPO and the HCO.

Average scores of the items of the GPO legal legitimate power construct are again less than four (see Appendix B), indicating that on average HCOs do not appear to perceive their GPO to use legal legitimate power. Hypothesis 3c is thus also not supported.

4.2.4 Hypothesis 4: Relationship-performance

In this study the effect of improved relationships between the medical equipment supply chain members on their respective performance was investigated. Specifically, it was hypothesized, using the theoretical lens of the Relational view, that a more committed and more cooperative relationship between the supplier (OEM) and the buyer (HCO) would lead to an improved performance of both the supplier and the buyer, even if the relationship is interceded by a middleman. Given the characteristics of the relationship between the GPO and the HCO as described in Chapter 2, a null hypothesis was developed for the effect of the GPO-HCO relationship onto the performance of both the
HCO and the GPO. Since relationships between GPOs and HCO are typically long-term yet have a number of the characteristics of an arms-length relationship, it was argued that a more committed and cooperative GPO-HCO relationship may not translate into increased GPO or HCO performance.

Table 8 Relationship-performance hypotheses summary

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th>Structural model path</th>
<th>Standardized coefficient</th>
<th>t-value</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCO-OEM relationship → OEM performance</td>
<td>67</td>
<td>0.59</td>
<td>7.10***</td>
<td>H4a supported</td>
</tr>
<tr>
<td>HCO-OEM relationship → HCO performance</td>
<td>68</td>
<td>0.3</td>
<td>3.29***</td>
<td>H4b supported</td>
</tr>
<tr>
<td>HCO-GPO relationship → HCO performance</td>
<td>63</td>
<td>0.06</td>
<td>0.76</td>
<td>H4c not rejected</td>
</tr>
<tr>
<td>HCO-GPO relationship → GPO performance</td>
<td>64</td>
<td>0.61</td>
<td>5.62***</td>
<td>H4d rejected</td>
</tr>
</tbody>
</table>

*** p<0.01; ** p<0.05; * p<0.1

The standardized coefficient of the path between Relationship with OEM and OEM performance (β7=0.59, t-value=7.10) provides strong statistical evidence of a positive effect of OEM-HCO relationship onto OEM performance. Hypothesis 4a is strongly supported. As predicted, better cooperation between the OEM and the HCO as well as a long term commitment from the HCO to the OEM translates into better OEM performance.

Next, the effect of this same OEM-HCO relationship was also hypothesized to positively affect the HCO’s performance. This hypothesis is tested by evaluating the statistical significance of path β8. The standardized path coefficient from Relationship with OEM to HCO performance (β8=0.3, t-value=3.29) is highly significant at p<0.01. Based on this
result, Hypothesis 4b is strongly supported. Therefore, there is strong statistical evidence to suggest that there is a positive effect of the relationship between the OEM and the HCO onto the HCO’s performance.

The third relationship-performance hypothesis considers the effect of the relationship between a middleman (GPO) and the buyer (HCO) onto the HCO’s performance. To test this hypothesis, the significance level of path β3 is evaluated. The standardized path coefficient between Relationship with GPO and HCO performance (β3=0.06, t-value=0.76) is found to be statistically insignificant. Based upon this result, null-hypothesis 4c cannot be rejected. The study does not offer statistical evidence that a more cooperative and more committed relationship between the middleman (GPO) and the buyer (HCO) is associated with better performance of the buyer (HCO).

Finally, the fourth relationship-performance hypothesis considers the effect of a more committed and cooperative GPO-HCO relationship onto the GPO’s performance. This hypothesis is directly tested by assessing the statistical significance of path β4. The standardized path coefficient from Relationship with GPO to GPO performance (β4=0.61, t-value=5.62) is highly significant at p<0.01. Therefore, null hypothesis 4d is rejected. The relationship between the middleman (GPO) and the buyer (HCO) has a significant positive effect on the middleman’s (GPO’s) performance. Cooperation between the GPO and the HCO and long term commitment from the HCO to the GPO translates into an improved perceived GPO performance.
4.2.5 Indirect effects of power bases onto HCO performance

One of the advantages of structural equation modeling is that it allows for an analysis of the indirect effects of the various exogenous latent variables upon the endogenous variables. Table 4.6 shows the standardized indirect effects of the seven exogenous power base variables upon the perceived HCO performance. The results show that both types of the OEM’s non-mediated power bases have a statistically significant indirect positive effect upon the HCO’s performance and that the indirect effects of all five GPO power bases onto the HCO’s performance are not significant.

4.3. Discussion and managerial implications

4.3.1 Non-mediated OEM power and OEM-HCO relationship

Non-mediated OEM power was hypothesized to have a positive effect on the relationship between the OEM and the HCO. The results of the structural model strongly support this hypothesis. As OEMs are perceived to be more powerful by the HCO procurement professionals, as they recognize the value the OEMs can offer through their equipment expertise and overall business acumen, they intrinsically seek to form a closer relationship with these OEMs. Furthermore, the HCO procurement professionals appear to value the identification with their OEMs, which manifests itself into a better relationship between the OEM and an HCO. Long term commitment from a buyer to a
supplier becomes increasingly important when margins are tightening and competition is fierce. In an environment where a significant portion of the revenue for an OEM is generated from post-sales maintenance and spare parts and from replacement sales, the importance of the long term commitment from the buyer is magnified. The managerial implication of these findings is therefore substantial. Suppliers, in this case the OEMs, can strengthen the relationship with their customers, here the HCOs, and inherently the long term commitment from the customer, by enhancing their levels of expert and referent power. It should be understood that expert and referent power occur as a natural part of buyer-seller business transactions and that there is generally no direct intention from the source, in this case the OEM (Benton and Maloni, 2005). As an OEM develops strategies that will increase the HCO’s perception that the OEM has expertise and information that is of interest to the HCO, like product support, training, maintenance expertise, the OEM’s expert power is inherently expected to increase, leading to a strengthened OEM-HCO relationship. Similarly, an OEM’s referent power will inherently increase if, based on an OEM’s overall business strategy, the HCO desires identification with the OEM for recognition by association (Maloni and Benton, 2000). In summary, non-mediated power in the dyad between the supplier (OEM) and buyer (HCO) in the medical equipment supply chain has a significant positive effect on the relationship between the supply chain members, which is consistent with findings in earlier studies (Maloni and Benton, 2000). However, the current study shows that it is the supplier who can have the non-mediated power rather than the buyer. Recall from Section 1.2 that one of the characterizing differences between the healthcare supply chain and
traditional supply chains involves the number of suppliers relative to the number of buyers. The healthcare supply chain is an example of a supply chain with many buyers (HCOs) and a few suppliers (OEMs). Specifically, in the digital imaging equipment supply chain four major suppliers (GE, Toshiba, Philips and Siemens) have oligopolistic control over the buyers in the HCO market which consists of more than 5700 hospitals (AHA, 2012). Simply put, one could imagine the healthcare supply chain as an inverted version of a traditional supply chain such as the automobile supply chain (Figure 5).

To the best of our knowledge, the current study is the first to provide empirical evidence of a positive effect of a powerful supplier’s non-mediated power onto the relationship between the supplier and the buyer.

Another significant contribution to the power and buyer-supplier relationship literatures considers the notion that the OEM-HCO relationship is mediated by a middleman (GPO). To the best of our knowledge, the current study is the first to provide empirical evidence of a positive effect of non-mediated power onto a middleman-mediated buyer-supplier relationship.
4.3.2 *Non-mediated GPO power and GPO-HCO relationship*

It was hypothesized that non-mediated GPO power would have a positive effect on the relationship between the GPO and the HCO. The results from the statistical analysis support this hypothesis for both expert power and referent power. One of the strategic aims of GPOs is to increase the commitment of the HCO members (Becker, 2005, Burns,
2002). A long term commitment from the HCO to the GPO translates into a greater volume of GPO-mediated purchases and thereby higher contract-administration fees paid by the OEM to the GPO. Based on this finding, GPOs would desire to understand what expertise HCOs value to further enhance their expert power and thereby the relationship with the HCO. Determining the HCO-desired services seems to have been a major focus of the GPOs. According to Schneller and Schmeltzer (2006), GPOs have been trying to distinguish themselves through a range of new service offerings. They also indicate that some analysts believe that GPOs have been overly focused on new services rather than the achievement of better prices. Burns et al. (2002) however indicate that HCOs often fail to take advantage of the wide array of services. Stated differently, while GPOs have focused on developing and offering new services for the HCOs, arguably to improve their expert power, HCOs have not adopted the new services to the extent that GPOs would desire. Burns et al. (2002) suggest a number of reasons for the slow adoption of new GPO service offerings, including a belief that HCOs may be too disorganized to act as a coherent buyer, that executives responsible for materials management in the HCO lack the influence and ability to serve as supply chain leaders in the HCO and that HCOs may not be able or willing to push hard in the area of supply chain. One may carefully speculate about the slow adoption of new GPO service offerings, based on the findings of the analysis. The results of this large-scale empirical study indicate that expert power positively affects the GPO-HCO relationship. Therefore, if an HCO does not adopt a given service offering, one may suspect either that the HCO does not value that particular GPO expertise or that the HCO inherently is not seeking to enhance the GPO-HCO
relationship beyond its current state. Stated differently, the HCO may intrinsically not associate that particular service offering with a potential GPO expert power increase or the HCO may not be attempting to improve the GPO-HCO relationship.

The effect of GPO referent power onto the relationship between the GPO and the HCO was found to be positive and significant. This finding could be interpreted as some evidence that HCOs may find that GPOs support them in reducing the “irrational and opportunistic prices of the OEMs” (Burns, 2002). The referent power this provides to the GPO positively affects the relationship between the GPO and the HCO. This finding is consistent with the literature (Maloni and Benton, 2000, Skinner et al., 1992, Frazier and Rody, 1991, Hunt et al., 1987).

In summary and in more general terms, this study provides statistical evidence of a positive effect of a middleman’s non-mediated power onto the relationship between the middleman and a buyer. The marketing channel literature and supply chain management literature have offered wide support for this effect in a buyer-supplier relationship and in a manufacturer-retailer relationship. This study contributes to the literature by establishing that the positive effect of non-mediated power onto a relationship also occurs in a middleman-buyer relationship. To the best of our knowledge, the current study is the first to provide empirical evidence of a positive effect of a middleman’s expert and referent power onto the strength of the relationship between a buyer and a middleman.
4.3.3 Mediated GPO power and GPO-HCO relationships

It was hypothesized that the three types of a GPO’s mediated power, reward, coercive and legal legitimate power, respectively, each have a negative effect on the relationship between a GPO and an HCO. The results of the structural equation modeling analysis did not offer support for these hypotheses. The managerial implications of this finding are intriguing. As previously discussed, a GPO’s primary aim is to attain long term commitment and compliance with the negotiated contracts from the member organizations, the HCOs. GPOs have multiple methods at their disposal to achieve this compliance, from end-of-year rebates, i.e. reward power, to coercion to, in some cases, legal legitimate power. Interestingly however, the HCOs on average do not perceive a negative effect of mediated power on the relationship they have with their GPOs. Earlier studies in traditional settings have found significant negative effects of mediated power on the relationship between supply chain members (Maloni and Benton, 2000, Brown et al., 1995). According to the current study however, powerful middlemen, like GPOs, are able to use extrinsic forms of motivation to influence and bring about direct action from the buyer, in other words use mediated power (Brown et al., 1995), without a negative effect on the relationship. Representatives of a buying firm may have different expectations entering into a relationship with a middleman than they do engaging into a relationship with a supplier. According to Emerson (1962), the power of one party to control or influence the actions of another resides in control over the things he values. If one of the parties in a relationship has this advantage, it is likely that she will increase the
use of adversarial tactics, or mediated power, because of a decreased fear of retaliation (Blau, 1964). The findings of the current study are thus not consistent with this view. At least three possible explanations appear to exist for this surprising finding. First, HCOs may believe that they do not depend on a GPO for the access to lower prices from OEMs, that they can accomplish their procurement goals without the support of a GPO and that the GPO thus does not have a power advantage over the HCO. Following this logic, HCOs would likely not perceive a GPO to use mediated power nor experience a negative effect of mediated power on their relationship with the GPO. Second, a possible power advantage of one party will be manifest only if the party makes some demand and only if this demand runs counter to the other party’s desires. In other words, some resistance would have to be overcome by the party with the power advantage (Emerson, 1962). It is conceivable that a buyer, in this case the HCO, enters a long term relationship with a middleman, here a GPO, understanding that she will have to comply with the GPO’s contract, and that she does not put up resistance against the middleman’s wishes, i.e. using the supplier under contract for a given product. Simply put, the HCO may not mind that there are only one or two suppliers to choose from for a certain product. In other words, there is no resistance from the HCO that the GPO has to overcome. By the definition of Emerson (1962), the HCO would not perceive the GPO to have a power advantage, would not perceive mediated power to be used by the GPO and would not perceive their relationship with the GPO to be negatively affected. Alternatively, and in contrast, a third possible explanation is based on the logic of embeddedness (Gulati and Sytch, 2007). According to this view, a party’s high level of
dependence on the other party may generate a high level of commitment to the relationship, leading to the adoption of an orientation toward the long term (Rusbult et al., 1991). Following this logic, procurement professionals in a relationship with a middleman may find themselves highly dependent on the middleman, therefore committed to a long term relationship and not perceiving the middleman’s compliance-achieving tactics as mediated power use. It is worth reiterating that a GPO per definition applies mediated power, either coercive, reward or legal legitimate power or a combination of the power bases. The current study has found empirical evidence that in a relationship between a middleman and a buyer, a middleman’s usage of mediated power may not be interpreted by the buyer as such and may not negatively affect the relationship.

4.3.4 Relationship-performance

The final set of hypotheses considered the effect of relationships between members of the medical equipment supply chain onto their respective performances.

4.3.4.1 OEM-HCO relationship effect on OEM and HCO performance

The relationship between the OEM and the HCO is positively associated with the performance for both the OEM and the HCO. Improved cooperation between OEMs and HCOs and a strong long term commitment from an HCO to the OEM pays dividends to the OEM and to the HCO. These findings are consistent with extant empirical literature
The current study contributes to the supply chain literature by providing empirical evidence for a positive effect of a buyer-supplier relationship onto both the buyer’s and the supplier’s performance, when the relationship is interceded by a middleman. It can be argued, using the theoretical lens of the Relational view (Dyer and Singh, 1998), that buyers and suppliers can form an idiosyncratic relationship and thus generate supernormal performance through relational rents, even if their relationship is interceded by a middleman. Transaction specific investments, knowledge exchange resulting in joint learning and complimentary capabilities, pay dividends for supply chain partners in the form of enhanced performance, even in the presence of a middleman.

4.3.4.2 GPO-HCO relationship effect on GPO and HCO performance

The relationship between the GPO and the HCO was found to positively affect the GPO’s performance. In a middleman-buyer relationship, the middleman, the GPO in this study, benefits from a long term commitment from and close cooperation with the HCO. When HCOs are committed for a longer period to the GPO, and more closely cooperate with them, provide them with planning information, and have open and honest dispute resolution, the perceived GPO performance increases. The GPO is able to use enhanced cooperation with and commitment from HCOs to improve its service quality and performance in their dealings with the OEMs. Simply put, if a GPO can gain long term commitment from an HCO and cooperate closely with an HCO, it is better equipped to
offer high quality service to the HCO and negotiate better with OEMs. This result is consistent with the extant buyer-supplier relationship literature. The current study contributes to this literature stream by providing empirical evidence of a positive effect of a more committed and cooperative relationship onto a middleman’s performance.

One of the most intriguing results of this study considers the effect of the relationship between the GPO and the HCO onto the HCO’s performance. This effect did not receive statistical support from the results of this study with the path coefficient from GPO relationship to HCO performance being not significant. The null-hypothesis was developed based on the notion that, while a GPO-HCO relationship may be long term, and while an HCO may be committed to buying through the GPO-contracted programs, the relationship may not be a strategic relationship. In other words, it may not meet the defining characteristics of a long term strategic, idiosyncratic, relational rent-generating relationship (Dyer and Singh, 1998). The current study provides empirical evidence that a cooperative and committed relationship between a middleman (GPO) and a buying organization (HCO) does not significantly contribute to the performance of the buying organization. The managerial significance of this finding is highly relevant. Recall that the effect of non-mediated GPO power did positively affect the GPO-HCO relationship. However, this relationship does not translate into an improved performance for the HCO. HCOs on average tend to rate their relationships with the GPOs as positive (see Appendix B). Stated differently, HCOs are committed to their GPO, indicate to be cooperating with their GPO and yet, based on the results, they do not perceive that this relationship pays direct dividends to their own performance. GPOs increasingly offer other services for the
HCOs beyond lower prices and contract management. Examples include materials management, operations consulting, benchmarking and technology management programs (Burns, 2002). The findings of the current study however implicitly indicate that HCOs do not perceive a direct performance improvement from their dealings with the GPO. An HCO’s long-term commitment to and sense of cooperation with a GPO may thus indeed be driven by the HCO’s preference for that GPO’s product portfolio. Stated differently, an HCO may be in a long-term relationship with a GPO because of its contracted OEM and product portfolio.

An HCO’s decision to have a GPO perform specific steps of the procurement process can be seen as a strategic outsourcing decision. According to the Resource Based View (RBV), when making this outsourcing decision, an HCO would have considered which resources and capabilities would contribute to the development of a sustainable competitive advantage (Barney, 1991). Furthermore, the HCO would have evaluated its core competences and how a particular business activity, here the procurement function, would be related to the successful achievement of broader strategic objectives (Quinn and Hilmer, 1994). For those HCOs that have outsourced the first two steps of the procurement process (of digital imaging equipment) to a GPO, the outcome of the strategic evaluation was presumably that this function was not a core competence and would be better performed by a GPO. However, markets and environments evolve and capabilities considered not core today may become core in the future (Helper et al., 2000). Given the ever increasing pressure on HCOs to reduce cost while maintaining quality care and given the fact that procurement of supplies and equipment accounts for
40% of HCO spending (Burns, 2002), an HCO may want to re-evaluate the decision to treat the procurement function as non-core. Based on the outcome of the current study, the average HCO does not perceive a relationship with the GPO to positively affect the HCO’s performance. More than ever, a reconsideration of the role a GPO should play in the procurement function of an HCO is of strategic importance. A recent statement from Brent Johnson, Chief Purchasing Officer for Intermountain Healthcare supports this notion: “a best practice is to take control of your corporate supply chain strategy and use your GPO as a tool, rather than the whole strategy” (Lipowicz, 2012).
Chapter 5 Dependence and power in the Healthcare supply chain

This chapter presents the analysis and results of part 2 of the empirical component of the dissertation. Part 2 of the empirical study further investigates the healthcare supply chain and specifically analyzes the effect of dependence, first in a relationship where the powerful actor is a middleman (GPO), rather than a buyer or a supplier and second where the relationship between a buyer (HCO) and a supplier (OEM) is interceded by a middleman (GPO). The testing of the measurement model will first be presented. Next, the results of the structural model will be discussed, followed by the managerial implications of the study.

5.1 Measurement model quality

An extensive literature review and a review of the survey questionnaire by OEM executives, HCO procurement professionals, hospital procurement association representatives and academicians established the content validity of the measurement model. Next an exploratory factor analysis was performed with a pilot data set (n=62), followed by a confirmatory analysis using the larger holdout sample (n=200) (Anderson and Gerbing, 1988).
5.1.1 Exploratory factor analysis

In the first step of the approach suggested by Anderson and Gerbing, using the pilot data set, maximum likelihood factor analysis was applied to assess the convergent validity of the constructs. Factor loadings and Corrected Item to Total Correlation (CITC) were analyzed and based on established guidelines two items from the Dependence on OEM construct and two items from the Dependence on GPO construct were removed (Hair, 1998; Guadagnoli and Velicer, 1988; Carmines and Zeller, 1979).

After subsequent re-specification of the measurement model, CITC values and factor loadings improved and were above the recommended thresholds. Construct reliability was assessed using Cronbach’s alpha. Values were all greater than the minimum 0.70 threshold for existing scales (Carmines and Zeller, 1979; Nunnally, 1978). Values for Average Variance Extracted (AVE), another indicator of reliability (Fornell and Larcker, 1981) were all greater than 0.40 (Menor et al., 2007; Heckler and Hatcher, 1996). The measurement model resulting from the exploratory factor analysis was deemed valid and reliable.

5.1.2 Confirmatory factor analysis

Using the larger holdout sample, the convergent validity, reliability and discriminant validity of the refined measurement model was analyzed. Through the maximum likelihood method within Lisrel 9.10 confirmatory factor analysis and structural equation
modeling analysis were performed, which will be discussed in Section 5.2. The factor loadings and associated t-values in Table 9 represent proper construct validity (Carmines and Zeller, 1979). The factor loadings for one of the Dependence on OEM items and one of the Dependence on GPO items are low but still above the lowest significant threshold of 0.30 to define a construct (Hair, 1998; Guadagnoli and Velicer, 1988). The Cronbach’s Alpha values indicate acceptable scale reliability (Carmines and Zeller, 1979). Furthermore, the Average Variance Extracted (AVE) and composite reliability measures for all power constructs provide additional evidence of strong construct reliability (Fornell and Larcker, 1981). An AVE greater than 0.50 is ideal, although 0.40 and above is considered acceptable (Menor et al., 2007; Fornell and Larcker, 1981). The AVE for Dependence on OEM is greater than 0.40 and the AVE for Dependence on GPO falls marginally below this threshold. However, all other measures for Dependence on GPO support adequate validity and construct reliability.

While the RMSEA point estimate is slightly higher than desired for good model fit, other absolute and incremental fit measures shown in Table 9 indicate a reasonably well fitting measurement model (Hu and Bentler, 1999; MacCallum et al., 1996; Bentler and Bonett, 1980).
Table 9 Confirmatory factor analysis results

<table>
<thead>
<tr>
<th>Construct</th>
<th>Item</th>
<th>Loading</th>
<th>t-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OEM referent power</strong></td>
<td>oem_ref1</td>
<td>0.783</td>
<td>12.816</td>
</tr>
<tr>
<td>Cronbach's α=0.88</td>
<td>oem_ref2</td>
<td>0.884</td>
<td>15.377</td>
</tr>
<tr>
<td>Composite reliability=0.88</td>
<td>oem_ref3</td>
<td>0.871</td>
<td>15.028</td>
</tr>
<tr>
<td>AVE=0.72</td>
<td>oem_ref2</td>
<td>0.884</td>
<td>15.377</td>
</tr>
<tr>
<td><strong>OEM expert power</strong></td>
<td>oem_exp1</td>
<td>0.751</td>
<td>12.098</td>
</tr>
<tr>
<td>Cronbach's α=0.88</td>
<td>oem_exp2</td>
<td>0.893</td>
<td>15.576</td>
</tr>
<tr>
<td>Composite reliability=0.88</td>
<td>oem_exp3</td>
<td>0.890</td>
<td>15.500</td>
</tr>
<tr>
<td>AVE=0.72</td>
<td>oem_exp2</td>
<td>0.893</td>
<td>15.576</td>
</tr>
<tr>
<td><strong>Dependence on OEM</strong></td>
<td>oem_dep1</td>
<td>0.346</td>
<td>4.561</td>
</tr>
<tr>
<td>Cronbach's α=0.65</td>
<td>oem_dep2</td>
<td>0.862</td>
<td>11.364</td>
</tr>
<tr>
<td>Composite reliability=0.70</td>
<td>oem_dep3</td>
<td>0.737</td>
<td>9.868</td>
</tr>
<tr>
<td>AVE=0.47</td>
<td>oem_dep2</td>
<td>0.862</td>
<td>11.364</td>
</tr>
<tr>
<td><strong>GPO reward power</strong></td>
<td>gpo_rew1</td>
<td>0.807</td>
<td>13.192</td>
</tr>
<tr>
<td>Cronbach's α=0.87</td>
<td>gpo_rew2</td>
<td>0.859</td>
<td>14.428</td>
</tr>
<tr>
<td>Composite reliability=0.88</td>
<td>gpo_rew3</td>
<td>0.845</td>
<td>14.093</td>
</tr>
<tr>
<td>AVE=0.70</td>
<td>gpo_rew2</td>
<td>0.859</td>
<td>14.428</td>
</tr>
<tr>
<td><strong>GPO coercive power</strong></td>
<td>gpo_coe1</td>
<td>0.846</td>
<td>14.728</td>
</tr>
<tr>
<td>Cronbach's α=0.92</td>
<td>gpo_coe2</td>
<td>0.933</td>
<td>17.32</td>
</tr>
<tr>
<td>Composite reliability=0.93</td>
<td>gpo_coe3</td>
<td>0.913</td>
<td>16.681</td>
</tr>
<tr>
<td>AVE=0.81</td>
<td>gpo_coe2</td>
<td>0.933</td>
<td>17.32</td>
</tr>
<tr>
<td><strong>GPO legal legitimate power</strong></td>
<td>gpo_leg1</td>
<td>0.788</td>
<td>13.184</td>
</tr>
<tr>
<td>Cronbach's α=0.91</td>
<td>gpo_leg2</td>
<td>0.939</td>
<td>17.463</td>
</tr>
<tr>
<td>Composite reliability=0.91</td>
<td>gpo_leg3</td>
<td>0.920</td>
<td>16.846</td>
</tr>
<tr>
<td>AVE=0.78</td>
<td>gpo_leg2</td>
<td>0.939</td>
<td>17.463</td>
</tr>
<tr>
<td><strong>GPO referent power</strong></td>
<td>gpo_ref1</td>
<td>0.879</td>
<td>15.329</td>
</tr>
<tr>
<td>Cronbach's α=0.86</td>
<td>gpo_ref2</td>
<td>0.708</td>
<td>11.180</td>
</tr>
<tr>
<td>Composite reliability=0.87</td>
<td>gpo_ref3</td>
<td>0.887</td>
<td>15.563</td>
</tr>
<tr>
<td>AVE=0.69</td>
<td>gpo_ref2</td>
<td>0.708</td>
<td>11.180</td>
</tr>
<tr>
<td><strong>GPO expert power</strong></td>
<td>gpo_exp1</td>
<td>0.738</td>
<td>11.841</td>
</tr>
<tr>
<td>Cronbach's α=0.85</td>
<td>gpo_exp2</td>
<td>0.846</td>
<td>14.480</td>
</tr>
<tr>
<td>Composite reliability=0.87</td>
<td>gpo_exp3</td>
<td>0.899</td>
<td>15.905</td>
</tr>
<tr>
<td>AVE=0.69</td>
<td>gpo_exp2</td>
<td>0.846</td>
<td>14.480</td>
</tr>
<tr>
<td><strong>Dependence on GPO</strong></td>
<td>gpo_dep1</td>
<td>0.897</td>
<td>14.155</td>
</tr>
<tr>
<td>Cronbach's α=0.75</td>
<td>gpo_dep2</td>
<td>0.816</td>
<td>12.574</td>
</tr>
<tr>
<td>Composite reliability=0.73</td>
<td>gpo_dep3</td>
<td>0.442</td>
<td>6.170</td>
</tr>
<tr>
<td>AVE=0.39</td>
<td>gpo_dep2</td>
<td>0.816</td>
<td>12.574</td>
</tr>
<tr>
<td>Overall Fit indices: RMSEA=0.0946; χ2 /df=2.79; NNFI=0.903; CFI=0.919; IFI=0.919; RMR=0.082</td>
<td></td>
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</tbody>
</table>
The inter-factor correlation matrix is presented in Table 10. For each of the inter-factor
correlations, 95% confidence intervals were calculated and none contained 1.0, providing
some evidence of acceptable discriminant validity (Anderson and Gerbing, 1988). In an
additional examination of discriminant validity, sets of Confirmatory Factor Analysis
models were compared for each inter-construct correlation (Bagozzi et al., 1991).
In one model the correlation of a pair of latent variables was constrained to equal 1.0 and
in the other model the correlation was free to vary (O'Leary-Kelly and Vokurka, 1998;
Venkatraman, 1989).

<table>
<thead>
<tr>
<th>Table 10 Inter-factor correlations</th>
</tr>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>1. OEM referent power</td>
</tr>
<tr>
<td>-</td>
</tr>
<tr>
<td>2. OEM expert power</td>
</tr>
<tr>
<td>3. Dependence on OEM</td>
</tr>
<tr>
<td>4. GPO reward power</td>
</tr>
<tr>
<td>5. GPO coercive power</td>
</tr>
<tr>
<td>6. GPO legal legitimate power</td>
</tr>
<tr>
<td>7. GPO referent power</td>
</tr>
<tr>
<td>8. GPO expert power</td>
</tr>
<tr>
<td>9. Dependence on GPO</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>
The $\chi^2$ value for the unconstrained model was significantly lower than the value for the constrained model at $p<0.001$ in each of the cases, offering additional evidence of adequate discriminant validity for the measurement model.

5.1.3 Second-order factors

The use of meta-constructs, or second-order latent factors, for mediated and non-mediated power has been validated in multiple prior studies. Specifically, in the case of mediated power, the power source seeks influence or control through the explicit application of pressure (Brown et al., 1995; Maloni and Benton, 2000). The three individual bases of mediated power (reward, coercive and legal legitimate) have been postulated to be used jointly (Raven and Kruglanski, 1970). Empirical evidence exists to support this notion (e.g., Frazier and Summers, 1984; Handley and Benton, 2012a). In the healthcare supply chain, GPOs reward HCOs with end-of-year rebates for buying through GPO-negotiated contracts (Burns et al., 2002) and will withhold these rebates and can take legal action if an HCO buys from suppliers that are not under contract with the GPO. Reward and coercion can in general be seen as two sides of the same coin (Maloni and Benton, 2000; Handley and Benton, 2012a). The GPO’s end-of-year rebate can be considered a reward. Threatening to withhold the end-of-year rebate from the in compliant HCO may be interpreted as coercion. Empirical evidence exists that the two types of non-mediated power (expert power and referent power) typically also occur collectively (Maloni and Benton, 2000; Frazier and Summers, 1984; Handley and Benton, 2012a). To
validate that the use of second-order factors for mediated and non-mediated power is prudent for the current study, a statistical evaluation was conducted through comparison of the fit of the first-order model with the fit of the more restrictive second-order model. The ratio of the $\chi^2$ for the first-order model to the $\chi^2$ for the second-order model is called the target coefficient (T) (Marsh and Hocevar, 1985). This measure gives an indication of the degree to which the second-order model accounts for the relations among the first-order factors. Confirmatory factor analyses for both the first and second-order models result in $\chi^2$'s of 951 and 1039, respectively, yielding a T coefficient of 0.915. The second order model therefore accounts for the vast majority of the relations among the OEM’s referent and expert power, the relations among the GPO’s expert and referent power and the relations among the GPO’s coercive, reward and legal legitimate power. Furthermore, in the confirmatory factor analysis of the second-order model, the paths from the three second-order factors (OEM non-mediated power, GPO non-mediated power and GPO mediated power) to their respective first-order factors are all significant at $p<0.001$, providing additional support for the use of the second-order factors for mediated power of the GPO and non-mediated power of both the GPO and the OEM (Venkatraman, 1989).

5.1.4 Common methods variance

During the data collection phase of the study, HCO procurement professionals were asked to answer survey questions about both exogenous and endogenous variables,
potentially causing a risk of common methods bias. This bias was partially controlled through the design of the survey instrument (Podsakoff et al., 2003). Several questions, such as items in the dependence constructs, were reverse coded and items from exogenous and endogenous constructs were spatially separated. To test for unacceptable levels of common methods variance in the data, an additional methods factor was introduced into the measurement model to test for a latent methods effect (Podsakoff et al., 2003). Through a confirmatory factor analysis, each manifest variable was specified to load onto the unmeasured methods factor, in addition to the specified theoretical factor for each variable. Since in each case items continued to load significantly onto their respective intended theoretical construct and since factor loadings onto the theoretical construct were significantly higher than onto the unmeasured methods factor, it was concluded that any level of common methods variance that may exist in the data was not of significant concern.

5.2 Analysis and results

Using structural equation modeling (LISREL 9.10) the hypothesized relationships between the various latent variables were tested. The overall fit of the structural model was assessed using multiple measures, as with the measurement model. The results for the root mean squared error of approximation (RMSEA) (0.100), RMSEA 90% confidence interval (0.0933; 0.107) provide evidence for marginal fit. The measures for non-normed fit index (NNFI) (0.89), comparative fit index (CFI) (0.90) and incremental
fit index (IFI) (0.90) support reasonable incremental model fit. Based on the collective overall fit measures and the theoretical support, the structural model was deemed acceptable and no revisions were made. The results of the structural model are shown in Table 11 and Figure 6. In the remainder of this section the results for the individual hypotheses will be discussed.

Figure 6 Structural model results
5.2.1 HCO’s dependence on the GPO and GPO power.

It was hypothesized that as the HCO’s dependence on the GPO increases, the HCO’s assessment of the GPO’s mediated power increases. When HCOs outsource the first two steps of the procurement process to a GPO they typically reduce their procurement staff and inherently increase their dependence on the GPO. This dependence is exacerbated when HCOs spend a larger percentage of their annual purchasing volume through GPO-negotiated contracts and when they use fewer GPOs. It is worth noting that GPOs per definition use mediated forms of power to ensure that HCO members comply with their negotiated contracts. GPOs hand out or withhold end-of-year rebates to HCOs or in some cases hold HCOs to their legal contracts to increase the extent to which HCOs buy products from OEMs that are under contract with the GPO (Schneller and Smeltzer, 2006; Burns, 2002). As HCOs depend more on their GPO, the HCO’s assessment of the GPO’s mediated power usage is expected to increase.

To test this hypothesized effect of Dependence on the GPO onto GPO Mediated Power, the statistical significance of path $\gamma_1$ is assessed. The standardized coefficient from Dependence on GPO to GPO Mediated Power ($\gamma_1=-0.37; t$-value= -4.356) is highly significant at $p<0.01$ however not in the hypothesized direction. An HCO’s increased dependence on the GPO was expected to lead to an increase in the GPO’s mediated power. Instead, the GPO’s mediated power significantly decreases as the HCO’s dependence on the GPO increases. Hypothesis 5 is not supported.
As an HCO depends more on its procurement service provider, the GPO, it will perceive less mediated power from the GPO.

As HCOs outsource the specification step and the supplier selection step of their procurement process to the GPO, they increase their dependence on the GPO. The outsourcing of the 2 steps of the procurement process are typically associated with a decrease in purchasing expertise and resources and the HCO’s increased dependence on the GPO was therefore expected to be associated with an increase in the HCO’s assessment of the GPO’s expert power. In addition, the outsourcing of the two procurement tasks to the GPO was argued to increase the HCO’s association with the GPO in the quest for lower prices from the OEM, thereby expecting an increase in referent power as a result of increased dependence on the GPO. To test this hypothesized effect of Dependence on the GPO onto GPO Non-Mediated Power, the statistical significance of path $\gamma_2$ is assessed. The standardized coefficient from Dependence on
GPO to GPO Non-Mediated Power ($\gamma^2=0.23$; $t$-value= 2.412) is highly significant at $p<0.01$. Hypothesis 6 thus receives strong statistical support. An HCO’s dependence on the GPO has a significant positive effect on the HCO’s assessment of the GPO’s non-mediated power.

5.2.2 HCO’s dependence on the GPO and the OEM

An HCO’s dependence on a GPO was hypothesized to be positively associated with the HCO’s dependence on an OEM. When an HCO outsources the first two steps of the procurement function to the GPO, only those OEMs who are under contract with the GPO will be considered by the HCO as possible suppliers. As the dependence on the GPO increases, it is expected to become more difficult for the HCO to switch OEMs. Stated differently, dependence on a GPO leads to fewer alternative OEMs and to higher switching costs for the HCO, and is therefore expected to increase the HCO’s dependence on the OEM. To test this hypothesized effect, the significance of the path coefficient from Dependence on GPO to Dependence on OEM is evaluated. The standardized coefficient from Dependence on GPO to Dependence on OEM ($\gamma^3=0.18$; $t$-value= 1.876) is significant at $p<0.05$. The study offers statistical evidence that an HCO’s dependence on a GPO has a significant positive impact on the HCO’s dependence on the OEM. Hypothesis 7 is supported.
5.2.3 HCO’s dependence on the OEM and OEM power

The healthcare supply chain can be characterized as a reverse oligopoly or a supplier-focussed oligopoly, where the many buying organizations, HCOs, have access to a few suppliers, OEMs. This increases the dependence of an HCO onto an OEM. Furthermore, the HCO’s dependence on the OEM is exacerbated due to the outsourcing of the first two steps of the procurement process. It was hypothesized that the HCO’s dependent relationship with the OEM would elevate the HCO’s identification with the OEM, and would increase the need for the OEM’s technological expertise, thereby increasing the HCO’s assessment of the OEM’s referent and expert power, respectively.

To test whether an HCO’s dependence on the OEM increases the HCO’s assessment of the OEM’s non-mediated power, the significance level of path β1 is evaluated. The standardized path coefficient between Dependence on OEM and OEM Non-Mediated power (β1=0.38, t=3.032) is found to be strongly significant at p<0.01. Hypothesis 8 is strongly supported.
5.3. Discussion and managerial implications

5.3.1 Implications of HCO’s dependence on GPO and mediated GPO power

The inter-organizational power research established that the power of one party over another is a function of dependence (Frazier and Rody, 1991; Emerson, 1962). In a situation of dependence asymmetry, and of resulting power disparity, adversarial action is more likely (Gulati and Sytch, 2007). Blau (1964) stated that an actor possessing a dependence advantage – and hence the more powerful actor in a relationship- will increase its use of adversarial tactics because of a decreased fear of retaliation. Simply put, this stream of literature would suggest that a powerful supply chain partner would increase their use of mediated power as the power target becomes more dependent on said partner. A GPO per definition uses mediated power to increase an HCO’s compliance with GPO-negotiated contracts with the OEM. GPOs reward HCOs through discounts and end-of-year rebates or withhold these rebates if HCOs buy outside of the contracts. In addition, GPOs will at times require their hospital members to comply 100% with GPO contracts (Burns, 2002). These GPO practices are examples of reward, coercion and legal legitimate power, respectively. It was hypothesized that as the HCO’s dependence on a middleman, the GPO, increases, the GPO’s use of mediated power increases.
Surprisingly, this hypothesis was not supported. In fact, the results of the analysis indicate that the more dependent an HCO is on a GPO, the lower the GPO’s use of mediated power is, as assessed by the HCO.

While an increase in a power target’s dependence on a power source typically leads to an increase in the power source’s use of mediated power, as shown in the extant inter-organizational power literature, the current study suggests that the power target may not detect that use of mediated power or may even assess the use of mediated power to decrease as the dependence on the power source increases. One may carefully speculate that the results of the current study appear to show that a more dependent supply chain partner tends to consciously or unconsciously turn a blind eye to a powerful partner’s ambiguous behavior or the powerful partner’s use of mediated power.

Existing operations management and marketing research has established a negative effect of one party’s use of mediated power onto the other party’s assessment of the quality of and satisfaction with the relationship between the two parties (e.g., Maloni and Benton, 2000; Benton and Maloni, 2005; Brown et al., 1995; Boyle et al., 1992). The finding of decreased mediated power as a result of increased dependence thus carries important managerial and theoretical implications. Apparently a buyer’s dependence on a provider may change that buying organization’s assessment of the provider’s typical relationship-damaging behavior, in other words, use of mediated power. Buying organizations should be cognizant of the fact that as they outsource steps of the procurement process, as the HCOs do, to a procurement service provider and become increasingly dependent on this provider, the buyers may fail to interpret the provider’s tactics in a negative manner. Our
finding compliments the results of Caniels and Gelderman (2007) who found that supplier-dominated partnerships are perceived to be satisfactory from the perspective of the buyer. The GPO’s tactics, the use of mediated power to influence the HCO’s procurement actions, go apparently increasingly unnoticed as the HCO becomes more dependent on the GPO. Buying organizations such as HCOs should be aware of this effect and should realize that relationship satisfaction with a procurement provider may in part be driven by the buyer’s dependent position. Buying organizations should therefore consider this effect when performing strategic evaluations of risks and capabilities prior to making or reconsidering procurement service outsourcing decisions.

5.3.2 Implications of HCO dependence on GPO and non-mediated GPO power

As the HCO’s dependence on its GPO increases, the HCO’s assessment of the GPO’s use of non-mediated power was hypothesized to increase. The structural model provides strong support for this hypothesis. As HCOs spend a larger percentage of their annual purchasing dollars through GPO-negotiated contracts, as they deal with fewer GPOs and as their GPO-switching costs are higher, their dependence on GPOs’ services is higher. When procurement professionals at HCOs depend to a greater extent on GPOs, they lend more expert and referent power to the GPOs. HCOs that outsource the first two steps of the procurement process to a GPO, typically reduce their procurement staff that would be conducting procurement tasks such as testing, researching, negotiating and purchasing items on their own (Schneller and Smeltzer, 2006). Increased dependence on the GPO
thus tends to be associated with lower levels of purchasing resources. Recall that expert power refers to the perception that one organization holds expertise or information that is valued by another organization (Maloni and Benton, 2000; French Raven, 1959). Naturally, as HCOs reduce their procurement staff and thereby skills, they increasingly value the procurement expertise and benchmarking information offered to them by the GPO. Furthermore, HCO procurement professionals tend to view pricing practices of their suppliers as irrational and opportunistic and believe that GPOs have historically delivered lower prices to them than they would have achieved on their own (Burns, 2002). Recall that referent power involves one organization’s desire to be associated with another for recognition by association (Maloni and Benton, 2000; French Raven, 1959). HCOs that turn to GPOs to outsource the first two steps of the procurement process and increase their dependence on the GPO, appear thus to want to be associated with the GPO in their quest for lower prices from the OEM, thereby lending referent power to the GPO.

Previous research on the effect of power on outsourcing relationships indicates that a powerful buyer’s increase in dependence on the supplier, leads to an increase in the buyer’s non-mediated power in the relationship between the buyer and the supplier (Handley and Benton, 2012a). The current study contributes to the literature by providing empirical evidence of a positive association between a buying organization’s (HCO’s) dependence on a middleman (GPO) and the powerful middleman’s (GPO’s) non-mediated power, as assessed by the buyer. The managerial implications of this finding are highly relevant, especially considering the empirically validated positive effect of non-mediated power onto relationship quality, commitment and satisfaction (Benton and
Maloni, 2005; Brown et al., 1995; Hunt and Nevin, 1974). Buying organizations should be aware of the notion that the decision to outsource their procurement function, or specific steps of their procurement process, may place them in a dependence-disadvantaged position, which may lead them to view the procurement service provider as an expert with whom they prefer to be associated. Based on the aforementioned existing literature we may caution buying organizations that viewing the procurement service provider as an expert with whom they prefer to be associated, may increase their commitment to the provider, their sense of cooperation and their overall satisfaction with the relationship with the provider. As mentioned in the previous section, buying organizations should thus be aware that satisfaction with the relationship with a procurement service provider may in part be the indirect result of the dependent-disadvantaged position of the buying organization, caused by outsourcing the procurement function, or specific parts of the procurement process.

5.3.3 Implications of HCO dependence on GPO and HCO dependence on OEM

HCOs that become increasingly dependent on GPOs were hypothesized to subsequently become increasingly dependent on their OEM. The effect of a buying organization’s use of a procurement service provider onto the buyer’s dependence on the product supplier had to the best of our knowledge not previously been investigated. As an HCO chooses to outsource the first two steps of the procurement process to a GPO and reduces some of its procurement labor, skill and expertise (Burns, 2002), the HCO inherently depends to a
greater extent on the GPO’s services. Since middlemen like GPOs typically negotiate contracts for only two to three suppliers for a given product (Burns, 2002), relying on a GPO inherently reduces the number of available suppliers for a product. In other words, the dependence on a given GPO limits the available suppliers to only the suppliers with whom that GPO has negotiated contracts, leading to an increased dependence on those suppliers. The results of our structural equation model provide strong empirical support for this hypothesis. It has long been held that an organization’s power is a function of the counter party’s dependence on the relationship (Emerson, 1962). The current study therefore contributes to the inter-organizational power and dependence literature by providing the empirical evidence that a supplier’s (OEM’s) power over the buyer (HCO) is positively associated with the buyer’s dependence on the middleman (GPO). This notion carries important managerial implications. Buying organizations such as HCOs should be cognizant of the fact that outsourcing the procurement function to a procurement service provider such as a GPO may not only impact the relationship between the provider and the buyer, in particular the buyer’s dependence on the provider, but also the buyer’s dependence on the product supplier. An HCO’s procurement outsourcing decision typically is accompanied by a reduction in purchasing staff and expertise (Schneller and Smeltzer, 2006), to reduce short term costs. However, the long term effects of this decision include that HCOs will not only have GPOs perform procurement tasks such as supplier selection, product specification and testing and price negotiation, but will also find that switching suppliers will have become more difficult and that fewer suppliers are now available to them. According to the findings of our
study, after outsourcing the first two steps of the procurement process to a GPO, HCOs may thus find themselves dependent on not only the GPO but also the OEM. We define this effect as the dependence trap. Specifically, the dependence trap is defined as the phenomenon of a buying organization’s dependence on a procurement service provider leading to an increase in the buying organization’s dependence on the supplier, as a result of outsourcing the procurement function to the procurement service provider. The service outsourcing literature has recently warned against potential adverse effects of outsourcing one’s customer contact processes to a service provider (e.g., Li and Choi, 2009; Balakrishnan et al. 2008). The current study contributes to the service outsourcing literature by providing empirical evidence of a potential adverse effect, in the form of the dependence trap, of outsourcing one’s supplier contact processes to a service provider. Buying organizations should be aware of this dependence trap. Prior to outsourcing the procurement function to a procurement service provider, buying organizations such as HCOs should consider whether the expected benefits from this outsourcing arrangement will outweigh the disadvantages associated with a dependent position toward not only the procurement service provider but also the supplier.

5.3.4 Implications of HCO dependence on OEM and OEM non-mediated power

It was hypothesized that as an HCO’s dependence on the OEM increases, the OEM’s non-mediated power increases, as assessed by the HCO. The results of the statistical analysis provide strong empirical support for this hypothesis.
As buying organizations determine that their alternative resources are limited, they should be more vested in ensuring that the current relationship is successful (Cannon et al., 2010). Previous research has shown that if these buying organizations are the power sources in their relationships with their suppliers, they will subsequently rely less on mediated power and more on non-mediated power (Handley and Benton, 2012a). In the medical equipment supply chain however it is the supplier (OEM) who has the power in the relationship with the HCO. The current study thus contributes to the inter-organizational power literature by providing empirical evidence of a positive association between a buyer’s dependence on a powerful supplier and the supplier’s non-mediated power, as assessed by the buyer. This finding should be considered along with the dependence trap phenomenon, the notion that increased dependence on the procurement service provider is associated with increased dependence on the supplier as a result of the buyer’s decision to outsource the procurement function. Based on the results of the current study, it is apparent that a buying organization’s decision to outsource the procurement function to a service provider may indirectly lead to an increase in the buyer’s assessment of a supplier’s non mediated power. This category of power bases has in turn been shown to positively affect the quality of buyer-supplier relationships and the commitment to the relationship (Benton and Maloni, 2005; Maloni and Benton, 2000; Brown et al., 1995). One may carefully speculate here about a serious consequence of the dependence trap. When buying organizations outsource their procurement function to a service provider and become increasingly dependent on both the service provider and the supplier, the supplier’s non-mediated power may increase according to the assessment of
the buying organization. Since non-mediated power has been associated with positive effects on the relationship quality, the procurement outsourcing decision may indirectly bring the buyer closer to the supplier, through the dependence trap. Buying organizations should be aware of this effect and should take it into account when considering or reconsidering the procurement outsourcing decision to a procurement service provider. For strategic items such as digital imaging equipment, an HCO may currently lend the OEM referent and expert power, and likely even be satisfied with the relationship with the OEM, in part through the dependence trap. An HCO may however, in particular for strategic items such as expensive capital equipment, be better served to avoid or escape the dependence trap by developing internal procurement capabilities and subsequently exploring the market themselves, reviewing alternative suppliers and developing true strategic supplier relationships that are not interceded or mediated by a middleman such as a GPO. With caution, the findings of our study may be generalized to other environments. Procurement outsourcing adoption rates are still slow, but have significantly increased over the last few years, which suggests that we may be at an inflection point in industry (GEP, 2012). According to a recent survey of large organizations across various industries, buying organizations are increasingly looking for additional procurement capacity, along with specialized skills, subject matter expertise and process best practices from procurement service providers (GEP, 2012). Not surprisingly and consistent with our earlier discussion regarding dependence on the GPO and the relationship with the GPO, more than 90% of the respondents of this survey indicated to be satisfied with the procurement service providers. A buying organization’s
satisfaction with the relationship with the procurement service provider is by itself not a concern. However, the findings of the current study suggest that the buying organization’s dependence-disadvantaged position may contribute to the buyer’s satisfaction with the procurement service provider. As apparently organizations across industries are increasingly starting to consider procurement service outsourcing, we strongly recommend that the buying organizations include in their strategic evaluation the 

*dependence trap* and the associated effect it may have on the buyer’s assessment of provider and supplier use of power and thereby relationship satisfaction.
Chapter 6: Managing medical equipment manufacturing, refurbishing and service contracts

6.1 Introduction

The market for refurbished medical digital imaging equipment is at a high growth stage (Frost and Sullivan, 2010). With growth rates in the 7-8% ranges, the 4 main OEMs (Philips, Siemens, GE and Toshiba) as well as third-party brokers have developed their refurbishing capabilities. After-sales service contracts for refurbished equipment are important to attract customers. OEMs, which each provide the service contracts, therefore have a competitive edge over the third-party brokers. Examples of digital imaging equipment that is refurbished include X-ray equipment and Computed Tomography (CT), Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI) and ultrasound scanners. Private sector and small-sized hospitals are typically the major buyers of refurbished equipment. Some of the drivers of the increased demand for refurbished equipment include the increased number of procedures prescribed by hospital physicians, an increase in the number of private healthcare organizations and the financial recession and the associated increased pressure to reduce cost (Frost and Sullivan, 2010). According to the OEMs we interviewed during the field study, on
average the selling price of OEM-refurbished equipment is ~20% less than the price of comparable new equipment. Refurbishing can be categorized in two groups: (1) complete electromechanical refurbishing and (2) cosmetic refurbishing. Third-party brokers typically do not perform electromechanical refurbishing. During interviews with representatives from the four OEMs of digital imaging equipment, Philips, GE, Siemens and Toshiba, (see Appendix A) cosmetic refurbishing was several times popularly referred to as ‘spray-and-pray’. Each of the OEMs interviewed during the field study indicated that their firm performs the complete electromechanical refurbishing, coupled with the offering of service contracts.

It should be noted that business interests for the medical equipment OEMs are complex. OEMs typically view refurbished equipment as complementary to new equipment and find themselves competing with third-party brokers for offering refurbished equipment. As the demand for refurbished equipment has been increasing, the OEMs have each started to develop competitive strategies to embrace its existence and to take advantage of it. To protect brand image, OEMs perform the refurbishing of digital imaging equipment in house and develop strategies to enhance the customers’ brand loyalty towards the OEM. One manner in which OEMs develop the long term relationship with their customers and their loyalty towards the brand is through offering multi-year service contracts with the sale of the equipment. OEMs offer service contracts with the sale of both new as well as refurbished equipment. In some industries, the profit margin for the sales of service parts and after sales service far exceeds the margin on the sale of the product itself (Cohen and Wang, 1997). Decision making for a firm that offers service
contracts should thus focus on the product’s contribution to the firm’s results throughout the product’s life cycle, rather than the per-transaction contribution. In the case of digital imaging equipment, the lifecycle does not just include the initial sale and the service, but also the refurbished sale and the service of refurbished equipment. The typical length of a service contract offered by a medical equipment OEM is 3-5 years and the annual margins contribute significantly to an OEM’s overall performance. OEMs have indicated that one of the drivers of offering refurbished equipment is the guaranteed multi-year revenue generated by the service contracts. Representatives from the OEMs stated that offering refurbished equipment wins them ‘another socket’; in other words, additional revenue from service.

Existing literature has investigated the challenges with respect to offering both new and refurbished equipment, as described in Chapter 2. Majumder and Groenevelt (2001) investigate pricing/remanufacturing decisions of OEM facing competition local 3rd party remanufacturer. Ferguson and Toktay (2006) analyze strategies that deter a 3rd party remanufacturer’s entry into the secondary market. Ferrer and Swaminathan (2006) study joint pricing of new and remanufactured products and find that if remanufacturing is very profitable, an OEM may forego some of the margin of new products by lowering the price and selling additional units to increase the flow of cores available for remanufacturing. Debo et al. (2005) investigate the joint pricing and production technology selection problem faced by an OEM who considers introducing a remanufacturable product. The authors propose that the proportion of used products that can be remanufactured can be increased by applying more expensive production
technology. They find that it may be helpful to sell new products below unit cost, to generate supply of remanufactured products. In each of these studies, the authors assume that new and remanufactured products offered by the OEM are indistinguishable and furthermore, none of these studies consider environments where revenue from service contracts is a significant contributor to the overall profit of the firm. In addition, a considerable number of studies investigate remanufacturing challenges in environments that are distinctly different compared to the medical equipment supply chain. IT equipment (e.g., Oraiopoulos et al., 2012) typically has a much shorter life cycle compared to medical equipment. Printer toner cartridges (e.g., Majumder and Groenevelt, 2001) are relatively inexpensive, compared to medical equipment, do not include service contracts and have short life cycles. Single use cameras (e.g., Ferrer and Swaminatham, 2006) are also inexpensive, are not sold with long term service contracts and have short life cycles, similar to cell phones (e.g., Guide et al., 2003, Galbreth and Blackburn, 2006, 2010, Guide and Van Wassenhove, 2001). Others investigate environments with products which are refurbished many (3-120) times (Geyer et al., 2007), compared to only once for medical equipment. Even others consider short lifecycle, cheap, electronic consumer products such as PCs that are sold through online stores (Vorasayan and Ryan, 2006), or, compared to digital imaging equipment, cheap hospital beds that are not sold with service contracts (Heese et al., 2005). In contrast, digital imaging equipment is a business-to-business product that is in most cases sold with a service contract.
The challenges around new manufacturing and refurbishing in the medical equipment supply chain are unique, compared to the aforementioned existing literature, for a number of reasons: (1) volumes are relatively lower, (2) prices are higher (> $1MM for new MRI equipment), (3) four OEMs control the market, (4) residence time, or useful life with the customer is long (typically 4-7 years), (5) service contracts for both new and refurbished products contribute significantly to the overall profit of the OEM, (6) products are only refurbished once.

An important problem facing a medical equipment OEM can be described as follows: How should an OEM jointly manage new and refurbished products along with service contracts for new and refurbished products. Stated differently, how can an OEM in an environment with low volume, expensive products and multi-year service contracts, optimally manage offering new and refurbished products and service contracts for both new and refurbished products? To formulate the problem more specifically, a model of the typical setting of digital imaging equipment OEMs will first be provided in the next section.

6.2 Model

Figure 7 shows a model of the physical product flow and the service flow for an OEM of medical digital imaging equipment. Table 12 presents the notation used in Figure 7.
Figure 7 Physical flow and service flow of a product in the medical equipment supply chain.
The OEMs sell both new and refurbished equipment to customers ranging from large teaching HCOs to small private rural HCOs to outpatient imaging centers.

According to the executives we interviewed during the field study, the OEMs use one common Marketing & Sales organization for new and refurbished products to manage price coordination between the two categories of products. A large fraction of both new and refurbished products are sold with service contracts, which typically last three to five years. In a given period $t$, the OEM decides to sell $n_t$ new products, by choosing the price of new products accordingly. For a fraction $\lambda_t$ of these new products, HCOs will purchase multi-year service contracts that will generate costs and revenue over the length of the service contract.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
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<tbody>
<tr>
<td>$n_t$</td>
<td>Decision variable for number of new products sold in period $t$</td>
</tr>
<tr>
<td>$\lambda_t$</td>
<td>Fraction of new products that are sold with a service contract</td>
</tr>
<tr>
<td>$m_t$</td>
<td>Number of end-of-useful-life products returned to OEM/collected by the OEM in period $t$</td>
</tr>
<tr>
<td>$\delta_t$</td>
<td>Decision variable for fraction of returned products produced in period $t$, that are not refurbished, but scrapped or sold to brokers or competing OEMs</td>
</tr>
<tr>
<td>$A_t$</td>
<td>Decision variable for quantity of cores, originally produced in period $t$, purchased from third-party brokers</td>
</tr>
<tr>
<td>$Q_t$</td>
<td>Quantity of cores refurbished in period $t$</td>
</tr>
<tr>
<td>$I_t$</td>
<td>Number of refurbished products in inventory at end of period $t$</td>
</tr>
<tr>
<td>$D_t$</td>
<td>Demand for refurbished products at the end of period $t$, known at the end of period $t-1$</td>
</tr>
<tr>
<td>$\gamma_t$</td>
<td>Fraction of refurbished products that are sold with a service contract</td>
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The competition among OEMs is fierce and competing OEMs attempt to convert customers from other OEMs to their own brand. At the end of the residence time or the
useful time an HCO owns the equipment, the HCO will either trade the equipment in to the existing OEM or will buy equipment from another OEM and trade the old equipment as part of the sales agreement or will sell the equipment to a third-party broker. The OEM gives the HCO trade-in credit and may pay a collection fee.

When an OEM gets the equipment of a competing OEM, as part of sales agreement, the OEM will sell this equipment to a third-party broker. OEMs have shared with us during the field study that they typically do not refurbish equipment from competing OEMs. A complicating factor for an OEM’s planning and control of the refurbishing operation is that the end-of-life equipment return is uncertain. Since medical equipment is typically not leased by HCOs, end-of-life equipment may be returned by some HCOs after four years and by other HCOs not until after eight years or later. In any given period, an OEM will receive returned equipment that significantly ranges in age and it is thus important for an OEM to understand how the flow of returned equipment is related to the initial sales of the new equipment. Stated differently, since customers are heterogeneous and leasing is uncommon, the residence time of the products varies and products bought in period $t$ will therefore be returned to the OEM over a range of subsequent periods. In other words, $m_t$, the number of returned products in period $t$ is a random variable with a distribution that depends on the mean and the standard deviation of residence times at HCOs.

The availability of cores is a limiting factor to the extent to which OEMs can take advantage of the market for refurbished equipment. Some of the OEMs in the digital imaging equipment market, offer new products at reduced prices to increase the installed
base of new equipment in the market. This practice may lower the revenue from new
equipment sales, but may increase the market share and the installed base of new
equipment in the market. Furthermore, additional long-term service contracts may be
purchased which may strengthen the long term relationships between an OEM and an
HCO, potentially leading to more sustainable market share. In addition, if the installed
base of new equipment increases, the number of cores returned to the OEM or collected
by the OEM will increase as well, providing additional opportunities for refurbished
products and service contracts for refurbished products. The decision to increase the
number of new items sold by lowering the price of new products represents an important
and complex trade-off for digital imaging OEMs.

Another important, and related, decision the OEM has to make in each period t considers
what fraction of the cores from the HCOs, $m_t$, will be refurbished $(1-\delta_t)$ and what fraction
will be disposed of or scrapped, $\delta_t$. At the end of Section 6.3, an expression will be
derived for $\delta_t$. This disposition decision, i.e. the decision which of the cores received from
HCOs to dispose of and which ones to refurbished, is complex for an OEM of digital
imaging equipment, since a number of factors need to be considered. First, to meet the
demand for refurbished digital imaging equipment, an OEM can either refurbish the
returned items or refurbish the cores the OEM buys from a third-party broker, $A_t$. In
effect these two decisions determine how many items $Q_t$ the OEM will refurbish in
period $t$: $Q_t = (1-\delta_t)m_t + A_t$. Since the increasing demand for refurbished digital imaging
equipment (Frost and Sullivan, 2010), the supply of cores has come under pressure and
delivery performance of third-party brokers can therefore not be guaranteed. Second, if
demand for refurbished items cannot be met due to insufficient refurbished cores, the potential for lost revenue is significant. If an HCO is in the market for a refurbished piece of digital imaging equipment, the HCO will typically not buy a new item from the same OEM when the refurbished item is not available, but may instead buy a refurbished item from a competing OEM, along with a multi-year service contract for the refurbished equipment. In other words, if $Q_t$ is too low, demand for refurbished products will not be met, HCOs will buy equipment from a competing OEM and revenue from this unfulfilled demand for refurbished equipment $(D_t - Q_t)$ in period $t$ is lost. In addition, since for a fraction $\gamma_t$ of refurbished products, HCOs will purchase multi-year service contracts, revenue for the service contracts associated with the unfulfilled demand $\gamma_t(D_t - Q_t)$ will be lost. Third, if an OEM refurbishes too many items, exceeding demand for refurbished items for a given period, the holding costs in the form of capital costs will be high, due to the fact that the value of refurbished equipment is significant. In other words, if $Q_t$ is too high, the OEM will be charged with significant inventory charges for the inventory of refurbished items left after demand $D_t$ for refurbished product is fulfilled in period $t$ $(I_t = I_{t-1} - D_t + Q_t)$. Fourth, the “scrapping cost” for a given returned end-of-life item may in fact be negative. In other words, the OEM may decide to sell the returned item to a third-party broker, even if the item is of the OEM’s own brand, which will generate revenue rather than incur disposal cost. Two other factors are more strategic in nature. The stage of the particular product’s lifecycle needs to be considered. This factor is related to product development of new models of a similar product. One OEM representative shared with us that they may decide to develop and launch a 32-slice MRI machine, start the
refurbishment operation for the first returned items after approximately 5 years and start phasing the product out after 10-12 years, to affect demand for the next product, a 64-slice machine. In other words, while the to-be-scrapped fraction will in this scenario likely be low for items returned in years 5-6, the fraction will increase the closer the OEM will get to the end of the product life cycle of the current product line and the closer the OEM gets to the launch of the next model. A second, related, strategic factor involves service requirements. OEMs may decide that only a certain number of models will be serviced concurrently, due to for example the costs to maintain service spare parts, and may therefore wish to phase out certain models as the launch of the next model approaches.

In summary, a digital imaging equipment OEM’s problem and the problem addressed in this chapter, is how to manage the number of new items sold, the disposition decision, the number of items bought from third-party brokers and whether or not to hold inventory of finished refurbished products. In the remainder of this section, the assumptions will be discussed and formulations of cost and revenue streams will be developed. In the analysis in Section 3, an expression is derived for the disposition decision and insight is provided into the drivers that determine whether demand for refurbished product should be fulfilled and how. Lastly, in Section 4 a numerical example of the model in the form of a case study is presented.
6.2.1 Assumptions

In this section the assumptions and industry practices specific to the environment are stated and discussed. The industry practices are based on the interviews and site visits with OEMs (see Appendix A). The environment can be characterized as a digital imaging equipment OEM that manufactures and sells new equipment and service contracts to HCOs; refurbishes returned digital imaging equipment and acquired cores from third-party brokers and sells refurbished digital imaging equipment along with service contracts to HCOs.

Table 13 lists the industry practices and assumptions.

<table>
<thead>
<tr>
<th>Assumption / Industry practice</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Customer willingness to pay is known</td>
</tr>
<tr>
<td>2</td>
<td>Products are refurbished only once in their lifecycle</td>
</tr>
<tr>
<td>3</td>
<td>Products are purchased from OEMs, not leased</td>
</tr>
<tr>
<td>4</td>
<td>Separate markets exist for new and refurbished products</td>
</tr>
<tr>
<td>5</td>
<td>Refurbishing cost and sales price for a refurbished product are independent of age or source</td>
</tr>
<tr>
<td>6</td>
<td>An OEM’s cost to collect a core from an HCO is less than the cost to acquire a core from a third-party broker</td>
</tr>
<tr>
<td>7</td>
<td>The quantity of cores delivered by the third-party broker is uncertain</td>
</tr>
<tr>
<td>8</td>
<td>Demand for refurbished products and demand for service contracts for refurbished products is deterministic</td>
</tr>
</tbody>
</table>
Each of the assumptions and industry practices will be discussed below.

1. **Customer willingness to pay is known**

   It is important for an OEM to understand the HCO’s willingness to pay, in order to estimate how a reduction in price will affect the number of items sold. The marketing literature typically assumes that a consumer’s valuation of a product is uniformly distributed between 0 and 1, to capture a consumer’s heterogeneity in their willingness to pay (Desai and Purohit, 1998). Price sensitivity can be mapped into the differences in valuations. This method of capturing differences between consumers and their responses to price variations has been employed in the operations literature as well, in particular the remanufacturing literature (e.g., Ferguson and Toktay, 2006). To model the quantities of products purchased at a given price, customer utility functions may be used to derive demand functions that take into consideration the heterogeneity of consumers (see e.g., Ferguson and Toktay, 2006; Desai and Purohit, 1998). In this study, the assumption is made that digital imaging OEMs understand how to price new equipment to achieve a certain volume and the relationship between price and volume is not specifically modeled. Since four OEMs control the market for digital imaging equipment and on line databases exist that contain prices of equipment sold to HCOs per period, OEMs have the means to adjust prices to achieve desired volumes, to an extent.

2. **Products are refurbished only once in their lifecycle**

   According to the interviews conducted with representatives with the four OEMs, it is a common industry practice for each of the four OEMs to refurbish equipment such as MRI equipment only once. Equipment such as a 16-slice MRI machine is considered old or
obsolete technology after 5-7 years with one customer plus another 5-7 years with
another customer after being refurbished. It is likely that this practice also applies in other
industries where the residence time of the product with the customer is long, relative to
the total life cycle of product.

3. Products are purchased from OEMs, not leased
Another common industry practice in the medical equipment supply chain involves the
ownership of the equipment. While in some environments leasing of equipment, such as
construction equipment, transportation equipment and printers/copiers, is widely used
(Robotis et al., 2011), leasing in the medical equipment supply chain is uncommon.
According to interviews with the OEMs, the HCOs typically purchase the equipment
from the OEMs. Only one OEM indicated that some of their equipment is leased by their
customers. Leasing would substantially reduce the uncertainty with respect to the fraction
of sold items that is returned to or collected by the OEM.

4. Separate markets exist for new and refurbished products
The assumption is made that refurbished digital imaging equipment is sold to a different
market than new digital imaging equipment. According to OEM executives, HCOs who
are interested in refurbished equipment in a given period, would typically for budgetary
reasons not consider new equipment. According to Atasu et al. (2010), B2B purchasers
demand an approximately 10% discount for remanufactured products, yet these
customers typically do not come at the expense of new product sales. If there are many
functionality-oriented customers in a market, remanufactured product can expand market
share and profits rather than cannibalize existing sales. Atasu et al. (2008) argue that
markets are not composed of perfectly homogenous price takers, that remanufactured products are not perfect substitutes for new products and that customers of new and remanufactured products are segmented and have minimal overlap. Guide and Li (2010) further provide empirical evidence of this notion. Managers at Xerox firmly believe that new and remanufactured products do not compete for the same fixed market share, but rather allow Xerox to reach market segments that they could not serve by offering only new equipment (Guide and Li, 2010). In short, the assumption is made that cannibalization does not occur in the digital imaging equipment market. OEM executives have also indicated that it is a common industry practice to jointly manage the pricing of new and refurbished equipment, and thereby keep any cannibalization that may occur to a minimum.

5. *Refurbishing cost and sales price for a refurbished product are independent of age or source*

The assumption of constant, fixed cost of refurbishing and remanufacturing is commonly made in the remanufacturing literature (e.g., Jayamaran et al., 1999; Savaskan et al., 2004; Majumder and Groenevelt, 2001). Industry practice in the digital imaging equipment further supports this assumption. According to OEM executives interviewed during the field study (See Appendix A), electromechanical refurbishing of digital imaging equipment follows a relatively standard process where typically a standard list of parts and components are replaced, products are subjected to a standard set of tests and total processing times typically are relatively similar. This will be the case regardless of whether the item is acquired from an existing customer or a third-party broker and
regardless of the age of the product. In short, material costs and labor costs for electromechanical refurbishing of digital imaging equipment are independent of the age or the source of the core. According to OEM executives, a refurbished product that is 7 years old will, immediately after refurbishing, be indistinguishable from a refurbished item that is 5 years old, for example. In more general terms, the age of the product is post-refurbishing not an indicator of the value of the refurbished item, as long as it is the same model. The price of the refurbished item therefore does not depend on the age of the item.

6. *An OEM’s cost to collect a core from an HCO is less than the cost to acquire a core from a third-party broker.*

A common industry practice is that OEMs aim to collect cores directly from an HCO, rather than acquire it from a third-party broker, since the price charged by the broker will be higher than the trade-in credit or collection fee paid by the OEM to the HCO. A third-party broker will be able to acquire the core from the HCO for the same price as the OEM will, and the OEM will subsequently pay a mark-up to the broker when the core is bought from the third-party broker, rather than from the HCO.

7. *The quantity of cores delivered by the third-party broker is uncertain.*

As indicated earlier in this chapter, given the increasing demand for refurbished digital imaging equipment (Frost and Sullivan, 2010) the supply of cores has come under pressure and delivery performance of third-party brokers can therefore not be guaranteed. Uncertainty in the delivery of ordered cores should therefore be considered.
8. Demand for refurbished products and demand for service contracts for refurbished products is deterministic.

The assumption that demand for remanufactured products is deterministic is commonly made in the literature focused on inventory management in remanufacturing settings (e.g., Clottey et al., 2012; Toktay et al., 2000; Galbreth and Blackburn, 2006).

6.2.2 Cost and revenue streams

For a digital imaging OEM to determine how to manage the number of new items sold, the disposition decision and the number of items bought from third-party brokers, the OEM will have to have insight into the cost and revenue streams associated with manufacturing, refurbishing and service contracts. Cost and revenue of remanufacturing operations have been considered in previous studies in the remanufacturing literature (e.g., Ferrer, 1997; Ovchinnikov, 2011; Mitra, 2007; Toktay and Wei, 2011; Guide et al., 2003). None of these studies however consider environments where service contracts contribute significantly to the performance of the firm.

Table 14 presents additional notation that is used to model the revenue and cost of manufacturing and selling new products, collecting and disposing returned products, acquiring cores from third-party brokers, refurbishing cores, carrying inventory of refurbished products and providing service contracts for both new and refurbished products.
### Table 14 Additional notation

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T$</td>
<td>Product lifecycle</td>
</tr>
<tr>
<td>$L_N$</td>
<td>Service contract term for new products</td>
</tr>
<tr>
<td>$L_R$</td>
<td>Service contract term for refurbished products</td>
</tr>
<tr>
<td>$C_{N_t}$</td>
<td>Total cost of producing new product in period $t$</td>
</tr>
<tr>
<td>$C_{R_t}$</td>
<td>Total cost of refurbishing in period $t$</td>
</tr>
<tr>
<td>$C_{I_t}$</td>
<td>Total inventory carrying cost in period $t$</td>
</tr>
<tr>
<td>$C_{S_{N_t}}$</td>
<td>Total cost of providing service for new products sold in period $t$, over the length of the service contract</td>
</tr>
<tr>
<td>$C_{S_{R_t}}$</td>
<td>Total cost of providing service for refurbished products sold in period $t$, over the length of the service contract</td>
</tr>
<tr>
<td>$C_{C_t}$</td>
<td>Total cost of collecting end-of-useful-life products from customers in period $t$</td>
</tr>
<tr>
<td>$C_{D_t}$</td>
<td>Total cost of disposing end-of-useful-life products in period $t$</td>
</tr>
<tr>
<td>$C_{A_t}$</td>
<td>Total cost of acquiring cores from third-party brokers in period $t$</td>
</tr>
<tr>
<td>$R_{N_t}$</td>
<td>Total revenue from selling new products in period $t$</td>
</tr>
<tr>
<td>$R_{R_t}$</td>
<td>Total revenue from selling refurbished products in period $t$</td>
</tr>
<tr>
<td>$R_{S_{N_t}}$</td>
<td>Total revenue from providing service for new products sold in period $t$, over the length of the service contract</td>
</tr>
<tr>
<td>$R_{S_{R_t}}$</td>
<td>Total revenue from providing service for refurbished products sold in period $t$, over the length of the service contract</td>
</tr>
<tr>
<td>$P_{n_t}$</td>
<td>Price of new item in period $t$</td>
</tr>
<tr>
<td>$P_{r_t}$</td>
<td>Price of refurbished item in period $t$</td>
</tr>
<tr>
<td>$P_{s_{n_t}}$</td>
<td>Revenue from service of a new product in period $t$</td>
</tr>
<tr>
<td>$P_{s_{r_t}}$</td>
<td>Revenue from service of refurbished product in period $t$</td>
</tr>
<tr>
<td>$c_{n_t}$</td>
<td>Cost to produce a new product in period $t$</td>
</tr>
<tr>
<td>$c_{r_t}$</td>
<td>Cost to refurbish a core in period $t$</td>
</tr>
<tr>
<td>$c_{d_t}$</td>
<td>Disposal cost (can be positive or negative) of a product that was produced in period $t$</td>
</tr>
<tr>
<td>$c_{s_{n_t}}$</td>
<td>Cost of providing service for a new product in period $t$</td>
</tr>
<tr>
<td>$c_{s_{r_t}}$</td>
<td>Cost of providing service for a refurbished item in period $t$</td>
</tr>
<tr>
<td>$c_{a_t}$</td>
<td>Cost to collect an end-of-useful-life product, that was produced in period $t$, from the customer</td>
</tr>
<tr>
<td>$c_{I_t}$</td>
<td>Inventory carrying cost per item in period $t$</td>
</tr>
<tr>
<td>$\beta_k$</td>
<td>Fraction of new products that were produced $k$ periods prior to current period, that are returned in current period $t$</td>
</tr>
</tbody>
</table>
In what follows, the revenue and costs associated with the various processes throughout the lifecycle of a product are discussed. A timeline of the production, disposition and acquisition and refurbishing decisions is provided in Figure 8. This timeline will be discussed in the next sections. The discussion starts with the OEM’s collecting of end-of-useful-life products from the HCO in period t. The revenue and cost associated with manufacturing of new equipment and with service contracts for new equipment will be discussed at the end of the Section 6.2

Figure 8 Timeline for production, disposal, acquisition and refurbishing decisions
6.2.2.1 Collecting end-of-useful-life products

\( m_t \) is the number of items returned at time \( t \) by the customer to the OEM. A number of studies (e.g., Clottey et al., 2012, Toktay et al., 2000) describe that a general dynamic linear model (DLM) can be used to capture the dependence of returns on sales in previous periods. The general form of a DLM is:

\[
m_t = \sum_{k=1}^{t-1} \beta_k n_{t-k} + \epsilon_t \quad \text{for} \ t = 2, 3, ..., T
\]  

(1)

Figure 8 and Equation (1) show that the number of returns in period \( t \) (\( m_t \)) consists of fractions of the numbers of products that were sold in previous periods, where the sales in a given period \((t-k)\) contribute to the returns in period \( t \) by a term \( \beta_k \). In the case of digital imaging equipment, the typical residence time, or the time the HCO owns the equipment, is 5-7 years. Therefore, when estimating the returns for a given period, \( \beta_k \) for \( k=5, 6 \) and 7 will likely be larger than for \( k<5 \) or \( k>7 \). \( T \) is in general a finite period which consists of the number of periods of data available for estimation. In the case of digital imaging equipment, \( T \) may be interpreted as the total life cycle of a typical piece of digital imaging equipment such as an MRI machine (~15 years). The terms \( \epsilon_t \) typically are assumed to be white noise (normally distributed, independent of the \( n_t \) values, independent of each other, with a constant variance given by \( \sigma^2 \)) (Clottey et al., 2012). It is important for OEMs with internal refurbishing operations to be able to forecast the number of items that will be returned by HCOs in a given year. An accurate forecast of the returned items will be useful for sales & operations planning, capacity planning, production (refurbishing operation) planning and procurement planning. An integral part
in the OEM’s decision making process with respect to disposal versus refurbishing is being able to estimate or forecast the number of returned items. The timing of used product returns and the notion that used products will become available to the OEM at different points in the product life cycle makes the management of new and remanufactured products challenging (Debo et al., 2006). The OEM needs to be able to estimate what percentage of items sold in each of the periods leading up to the planning period will be returned to the OEM. In other words the OEM needs to be able to estimate the $\beta_k$ for the years leading up the planning period. If the number of terms in Equation (1) is small, in other words if the total lifecycle $T$ of the product is small, then the $\beta_k$’s can be estimated using ordinary least squares (OLS) (Clotey et al., 2012). For a detailed description on how to estimate the $\beta_k$’s, see Clotey et al. (2012) and Toktay et al. (2000). The collection costs in period $t$ are associated with returned items $m_t$ in period $t$, regardless of whether the item will be refurbished, scrapped or sold to third-party brokers. The collection costs represent the trade-in costs paid by the OEM to the HCO and any other costs associated with decommissioning. This trade-in cost depends on the age of the product, in other words on when the product was originally produced. The total collection cost in period $t$ is formulated as follows:

$$C_c_t = \sum_{k=1}^{t-1} c_{c_{t-k}} (\beta_k n_{t-k} + \varepsilon_t); \text{ for } t = 2, 3, ..., T$$ (2)
6.2.2.2 Disposal of collected end-of-useful-life products

In a given period \(t\), an OEM decides for the products collected from the HCOs from each of the previous periods \(t-k\) what fraction will be disposed of \((\delta_t-k)\) and what fraction will be refurbished \((1 - \delta_t-k)\). As described in Section 6.2.1, the disposition decision is a complex decision that takes into account a number of factors, and for which the objective is to maximize total profit from the refurbishing operation. The direct cost associated with the disposal of cores that will not be refurbished can be positive or negative. Equipment that was produced more recently has not depreciated as much as older equipment. The higher residual value may lead to a negative disposal cost, in other words, the OEM may be able to sell the item to a broker rather than to pay a disposal fee and the cost may thus be negative. The total disposal cost in period \(t\) is formulated as follows:

\[
C_{Dt} = \sum_{k=1}^{t-1} \delta_{t-k}(\beta_k n_{t-k} + \varepsilon_t)c_{d_{t-k}}; \text{ for } t = 2,3,...,T \tag{3}
\]

6.2.2.3 Acquiring cores from third-party brokers

Demand for refurbished products can be fulfilled by refurbishing end-of-useful-life products collected from HCOs or by refurbishing cores acquired from third-party brokers. The price paid for a core by the OEM to the third-party broker depends on the age \(k\) of the core at the time of the purchase. The total acquisition cost in period \(t\) can be formulated as follows:
Note that the both the costs paid for collected cores from HCOs and for acquired cores from third-party brokers depend on the age $k$ of the core, the period $t-k$ in which the products were originally produced.

6.2.2.4 Refurbishing of collected and acquired cores

In each period $t$, the total quantity of cores $Q_t$ that is refurbished by the OEM is the sum of the acquired cores from third-party brokers and the fraction of cores collected from HCOs that is not disposed of or sold to brokers. Since we assumed that refurbishing cost and sales price for a refurbished product are independent of age or source, the total cost of refurbishing in period $t$ is:

$$C_{R_t} = c_{R_t} Q_t = c_{R_t} \left( \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \epsilon_t) + A_{t-k} \right); \quad \text{for } t = 2,3, \ldots, T$$

(5)

6.2.2.5 Sales of refurbished products

The revenue from refurbished products in period $t$ depends on whether inventory of refurbished products from the previous period $t-1$ plus the quantity of cores refurbished in period $t$ is greater than or less than the demand for refurbished products in period $t$. The total revenue of refurbished products in period $t$ in both scenarios is given below.
**Scenario 1:** inventory of refurbished products from the previous period plus the quantity of refurbished products in the current period is equal to or greater than the demand for refurbished products; \( I_{t-1} + Q_t \geq D_t \):

\[
R_{R_t} = p_{rt} D_t; \text{ for } t = 2, 3, ..., T
\] (6)

**Scenario 2:** inventory of refurbished products from the previous period plus the quantity of refurbished products in the current period is less than the demand for refurbished products; \( I_{t-1} + Q_t < D_t \). In this scenario the amount of refurbished products sold is equal to inventory of refurbished products carried over from the previous period plus the quantity of cores refurbished in the current period:

\[
R_{R_t} = p_{rt} (I_{t-1} + Q_t) = p_{rt} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k \eta_{t-k} + \varepsilon_t) + A_{t-k} \right); \text{ for } t = 2, 3, ..., T
\] (7)

6.2.2.6 Providing service contracts for refurbished products

In each period \( t \) a fraction \( y_t \) of the demand for refurbished items includes demand for a service contract, which will have revenue and cost associated with it over the length of the contract. The cost and revenue associated with providing service contracts with refurbished products sold in period \( t \), is thus the sum of cost and revenue, respectively, over the length of the service contract, from period \( t \) through period \( t + L_R \). Both the revenue and cost associated with the service contracts depend on the fraction of the demand for refurbished products in period \( t \) that is fulfilled and the fraction of demand that includes a service contract. If all demand for refurbished product is met, the cost and
revenue associated with service contracts is simply the cost and revenue over the length of the service contract, for the fraction $\gamma_t$ of demand that includes demand for a service contract. However, if not all demand for refurbished product is met, i.e. if $I_{t-1} + Q_t < D_t$, then cost and revenue for service contracts over the length of the contract is only for the fraction $\gamma_t$ of the demand that is fulfilled, i.e. $I_{t-1} + Q_t$. The cost of providing service and thereby also the price OEMs charge for service contracts change throughout the term of the contract. Cost of service will increase as the equipment ages. In general, “time-to-failure” and expressions for repair costs over the course of a service contract can be modeled (Karmarker, 1978).

The cost and revenue for service contracts for refurbished products for both scenarios is formulated below.

**Scenario 1** $I_{t-1} + Q_t \geq D_t$:

\[
C_{Sr_t} = \sum_{i=0}^{L_R} \gamma_tD_t c_{sr_{t+i}}; for \ t = 2, 3, \ldots, T
\]  
(8)

\[
R_{Sr_t} = \sum_{i=0}^{L_R} \gamma_tD_t p_{sr_{t+i}}; for \ t = 2, 3, \ldots, T
\]  
(9)
Scenario 2 $I_{t-1} + Q_t < D_t$:

$$C_{SR_t} = \sum_{l=0}^{L_R} \gamma_t (I_{t-1} + Q_t) c_{SR_{t+l}}$$

$$= \sum_{l=0}^{L_R} \gamma_t c_{SR_{t+l}} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \epsilon_t) + \alpha_{t-k} \right); \text{for } t = 2,3,...,T$$

$$R_{SR_t} = \sum_{l=0}^{L_R} \gamma_t (I_{t-1} + Q_t) p_{SR_{t+l}}$$

$$= \sum_{l=0}^{L_R} \gamma_t p_{SR_{t+l}} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \epsilon_t) + \alpha_{t-k} \right); \text{for } t = 2,3,...,T$$

6.2.2.6 Carrying inventory of finished refurbished products

Carrying inventory of finished refurbished products only applies if the demand for refurbished products in period $t$ is less than the sum of the inventory of finished refurbished products from the previous period ($t-1$) and the quantity of cores refurbished in period $t$. The total inventory carrying costs for refurbished products both scenarios are formulated below.

Scenario 1 $I_{t-1} + Q_t \geq D_t$:

$$I_t = I_{t-1} + Q_t - D_t$$
The inventory carrying cost in period $t$ is:

$$C_t = c_t l_t = c_t (l_{t-1} + Q_t - D_t)$$

$$= c_t \left[ l_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \epsilon_t) + A_{t-k} \right] - D_t; \text{ for } t$$

$$= 2,3,...,T$$  \hfill (12)

**Scenario 2** $I_{t-1} + Q_t < D_t$:

The inventory of refurbished products in period $t$ and the inventory cost are equal to zero.

$$I_t = 0$$

The inventory carrying cost in period $t$ is:

$$C_t = c_t l_t = 0; \text{ for } t, 3, ..., T$$  \hfill (13)

6.2.2.7 Manufacturing and sales of new products

Any end-of-useful-life products collected from HCOs in period $t$, were newly produced by the OEM in periods $t-k$, for $k=1,2,...t-1$. The total cost and revenue of manufacturing and selling $n$ new products in period $t-k$ can be presented as follows:

$$C_{N_{t-k}} = c_{n_{t-k}} n_{t-k}; \text{ for } t = 2,3,...,T; k = 1,2,...,t-1;$$  \hfill (14)

$$R_{N_{t-k}} = p_{n_{t-k}} n_{t-k}; \text{ for } t = 2,3,...,T; k = 1,2,...,t-1;$$  \hfill (15)
6.2.2 Providing service contracts for new products

A fraction $\lambda_t$ of new items is sold in any period $t-k$ with a service contract, with associated cost and revenue over the length of the service contract of new items. The cost and revenue associated with providing service contracts with new products sold in period $t-k$, is thus the sum of cost and revenue, respectively, over the length of the service contract, from period-$k$ through period $t-k+L_N$. The OEM’s total cost and revenue associated with the service contracts for new products sold in period $t-k$ can be expressed as follows:

$$C_{S_{nt}} = \sum_{i=0}^{L_N} \lambda_{t-k} n_{t-k} c_{s_{nt-k+i}} ; \text{for } t = 2,3,\ldots,T; k = 1,2,\ldots,t-1$$  \hspace{1cm} (16)

$$R_{S_{nt}} = \sum_{i=0}^{L_N} \lambda_{t-k} n_{t-k} p_{s_{nt-k+i}} ; \text{for } t = 2,3,\ldots,T; k = 1,2,\ldots,t-1$$  \hspace{1cm} (17)

6.3 Analysis

In this section, the total profit for new products and service contracts for new products will first be determined. Next, the profit associated with refurbished products and service contracts for both scenarios discussed in the previous section will be derived. Recall that two scenarios consider whether or not demand for refurbished products can be fulfilled from the inventory of refurbished products, i.e. the inventory carried over from the previous period plus the quantity of cores refurbished in the current period. Through a break even analysis between the scenarios, insight will be provided with respect to the decision drivers regarding fulfilling demand for refurbished products. In addition, an
expression will be derived for the disposition decision of collected cores from HCOs. A detailed numerical example will be provided in the next section.

The profit associated with new products and with services for products produced in period \( t-k \) is the sum of the revenue from new products and service contracts sold in period \( t-k \) minus the costs associated with the manufacturing of those new products, minus the costs associated with providing the service. Based on equations 14-17 from the previous section, the profit associated with new products and services can thus be expressed as follows:

\[
P_{N_{t-k}} = R_{N_{t-k}} - C_{N_{t-k}} + R_{S_{n_{t}}} - C_{S_{n_{t}}}
\]

\[
= \left[ p_{n_{t-k}} - c_{n_{t-k}} + \lambda_{t-k} \left( \sum_{i=0}^{L_N} p_{s_{n_{t-k+i}}} - c_{s_{n_{t-k+i}}} \right) \right] n_{t-k}; \text{for } t
\]

\[
= 2,3,...,T; k = 1,2,...,t-1
\]

The profit associated with refurbished products and service contracts is the sum of the revenue from sold refurbished products and from service contracts for sold refurbished products, minus the collection cost, the disposal cost, the cores-acquisition cost, the refurbishing cost and the inventory cost. The profit depends on the extent to which demand for refurbished products and service contracts is fulfilled, in other words whether inventory of refurbished products plus quantity of refurbished products is greater than or equal to demand (scenario 1) or less than demand (scenario 2). The derivation of the profit for both scenarios is included in Appendix C.
**Scenario 1** $I_{t-1} + Q_t \geq D_t$:

As shown in Appendix C, the profit from refurbished products and service contracts in period $t$ in this scenario can be expressed as:

$$P_{R_t}(1) = D_t \left[ p_{r_t} + c_t + \gamma_t \left( \sum_{i=0}^{L_R} (p_{sr_{t+i}} - c_{sr_{t+i}}) \right) \right]$$

$$- \sum_{k=1}^{t-1} \left[ \left( c_{ct-k} + c_{rt} + c_t \right) + \delta_{t-k} (c_{dt-k} - c_{rt} - c_t) \right) (\beta_k n_{t-k} + \epsilon_t)$$

$$+ A_{t-k} (c_{at-k} + c_{rt} + c_t) \right) - c_t I_{t-1}; \text{ for } t = 2, 3, \ldots, T; k$$

$$= 1, 2, \ldots, t - 1 \quad (19)$$

**Scenario 2** $I_{t-1} + Q_t < D_t$:

As shown in Appendix C, the profit from refurbished products and service contracts in period $t$ in this scenario can be expressed as:

$$P_{R_t}(2) = \left( p_{r_t} - c_{rt} + \gamma_t \left( \sum_{i=0}^{L_R} p_{sr_{t+i}} - c_{sr_{t+i}} \right) \right) \sum_{k=1}^{t-1} \left( (1 - \delta_{t-k}) (\beta_k n_{t-k} + \epsilon_t) + A_{t-k} \right)$$

$$+ \left( p_{r_t} - c_t + \gamma_t \left( \sum_{i=0}^{L_R} p_{sr_{t+i}} - c_{sr_{t+i}} \right) \right) I_{t-1}$$

$$- \sum_{k=1}^{t-1} \left( c_{ct-k} + \delta_{t-k} c_{dt-k} \right) (\beta_k n_{t-k} + \epsilon_t) + A_{t-k} c_{at-k} \right) \text{ for } t$$

$$= 2, 3, \ldots, T; k = 1, 2, \ldots, t - 1 \quad (20)$$
Determining the break-even point between scenario 1 and scenario 2 provides insight in the importance of the parameters and decision variables in the digital equipment OEM’s refurbishing environment. The break even analysis is presented in Appendix C. The result of the analysis is:

\[
p_{rt} \left( D_t - I_{t-1} - \sum_{k=1}^{t-1} \left( 1 - \delta_{t-k} \right) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \\
\quad + c_l \left( D_t - I_{t-1} \right) \\
\quad - \sum_{k=1}^{t-1} \left( 1 - \delta_{t-k} \right) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) + \gamma_t \left( \sum_{i=0}^{L_R} (p_{sr_{t+i}} - c_{sr_{t+i}}) \right) D_t \\
\quad - I_{t-1} - \sum_{k=1}^{t-1} \left( 1 - \delta_{t-k} \right) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) = 0 \text{ for } t = 2,3, ..., T; k = 1,2, ..., t - 1
\] (21)

The above provides the following insight:

- The important drivers to determine whether demand for refurbished product should be fulfilled and how (carrying inventory of refurbished products or ensuring that demand equals the number of refurbished products) are:
  - Revenue from refurbished products \( p_{rt} \)
  - Inventory carrying costs \( c_l \)
  - Profit from a service contract \( \gamma_t \left( \sum_{i=0}^{L_R} (p_{sr_{t+i}} - c_{sr_{t+i}}) \right) \), which is determined by the fraction of demand that includes a service contract \( \gamma_t \), the length of the service contract \( L_R \), the margin of service throughout the contract \( p_{sr_{t+i}} - c_{sr_{t+i}} \).
• If the OEM holds no inventory \( (I_{t-1}=0) \), then, not surprisingly, the total quantity of refurbished cores, \( \sum_{k=1}^{t-1}(1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \), needs to equal or exceed the demand for refurbished cores \( D_t \).

• The OEM should always ensure that sufficient inventory is available, between carry-over inventory from the previous period and refurbished cores, to meet demand, unless there is a net loss from a service contract over the length of the contract that is greater than the sum of the revenue of a refurbished item plus the inventory cost of a refurbished item. In other words, unless \( \gamma_t (\sum_{i=0}^{t-R}(p_{sr_{t+i}} - c_{sr_{t+i}})) \) is negative and equals \( prt + cl \).

• With respect to the refurbished quantity, \( \sum_{k=1}^{t-1}(1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \), the following conclusions can be drawn:
  
  o The refurbished quantity is the sum of acquired plus collected-not disposed of products: The acquired quantity can be reduced by increasing the number of new products produced \( n_{t-k} \) for \( k=1,...,t-1 \). \( \beta_k \) of the quantity \( n_{t-k} \) produced in period \( t-k \) will be returned and collected in period \( t \). The quantities \( n_{t-k} \) in the various periods \( t-k \) can be manipulated by varying the prices of new products in periods \( t-k \). Since the refurbishing costs are equal for collected cores and acquired cores, the OEM should minimize the total costs associated with collecting cores, disposal and acquisition: \( \sum_{k=1}^{t-1} \left( (c_{ct-k} + \delta_{t-k} c_{dt-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) + c_{at-k} \). We assumed that it costs the OEM less to collect a core of a certain age from the HCO than...
to acquire it from the third-party broker, \( c_{c_{t-k}} \leq c_{a_{t-k}} \). Stated differently, the disposition cost for the fraction of returned cores that is disposed of, \( \delta_{t-k} c_{d_{t-k}} \) should be equal to or less than the savings associated with collecting the cores from the HCOs rather than from the third-party brokers, \( c_{a_{t-k}} - c_{c_{t-k}} \), otherwise the OEM should buy all cores from a third-party broker rather than collect them from HCOs. This leads to an expression for the fraction of collected products that can be disposed of or sold to third-party brokers:

\[
\delta_{t-k} \leq \frac{c_{a_{t-k}} - c_{c_{t-k}}}{c_{a_{t-k}} + c_{d_{t-k}}}
\]  

(22)

Equation (22) shows that if the OEM can get access to cheaper cores from their HCOs, a larger fraction of the returns can be disposed, for example for strategic reasons. Furthermore, as disposition costs decrease or even become negative, i.e. sold to brokers, a larger fraction of the returned cores can be disposed. After determining \( \delta_{t-k} \) and estimating \( \beta_k \) for \( k=1, \ldots, t-1 \), the OEM will be able to determine the quantity of cores to be acquired from third-party brokers, \( \sum_{k=1}^{t-1} A_{t-k} \), since \( D_t = \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \) and therefore \( \sum_{k=1}^{t-1} A_{t-k} = D_t - \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) \). The OEM should further maintain sufficient safety stock of inventory of finished refurbished products, to protect against consequences of inaccuracies of estimating \( \beta_k \) and against uncertainty in the delivery performance of the third-party brokers.
6.4 Case study

In this section a case study is presented to illustrate the model developed in the previous section. The case study is based on one of the OEMs of digital imaging equipment. The data used in the study have been adapted from data received from the OEM or from conversations with managers and executives from the OEM. The example is divided in two parts. The first part deals with the manufacturing of and the service contracts for new equipment and in the second part the model for the refurbishing and service contracts for refurbished equipment will be illustrated. In the various tables throughout the case, calculated data is shaded gray and sample calculations are provided where appropriate.

6.4.1 New manufacturing and service contracts for new equipment

New equipment is manufactured and sold throughout a 5-period, or 5-year, timeline and a fraction of the sold equipment includes service contracts. The OEM can affect the number of new products sold, by varying the price. In this case study the volumes vary throughout the 5 periods and the price is kept constant. In reality, the OEM will make price adjustments throughout the life cycle of the product to affect demand. Table 15 presents for periods 1 through 5, number of products sold, price per product, revenue period, cost per product and per period and profit per period. Table 16 shows the number of service contracts sold in each of the five periods. In this case study, the revenue and cost associated with a service contract is kept constant throughout the 4-period service
contract term. In other words, a service contract sold in period 1 will have the same revenue and cost throughout the service contract term, which is period 1 through 4. In reality an OEM’s revenue and cost may vary throughout the service contract term and revenue and cost associated with contracts sold in period $t$ will be different from contracts sold in period $t+1$. Table 17 shows the total revenue, cost and profit per period through the service contract terms for the contracts sold in periods 1-5. Since the service contract term in this case study is fixed and set at 4 periods, service revenue and cost is generated from period 1 through period 8. For example, in period 2 service revenue and cost is generated by active contracts, sold in periods 1 and 2.
Table 15 Manufacturing volumes, revenue, cost and profit

<table>
<thead>
<tr>
<th>Period</th>
<th># sold</th>
<th>$P_{nt}$ (per unit)</th>
<th>$\text{Total }*)$</th>
<th>$c_{nt}$ (per unit)</th>
<th>$\text{Total }**$</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$</td>
<td>$n_t$</td>
<td></td>
<td>$P_{nt}$ (per unit)</td>
<td>$\text{Total }*$)</td>
<td>$c_{nt}$ (per unit)</td>
<td>$\text{Total }**$</td>
</tr>
<tr>
<td>1</td>
<td>1000</td>
<td>1,000,000</td>
<td>1,000,000,000</td>
<td>700,000</td>
<td>700,000,000</td>
<td>300,000,000</td>
</tr>
<tr>
<td>2</td>
<td>1200</td>
<td>1,000,000</td>
<td>1,200,000,000</td>
<td>700,000</td>
<td>840,000,000</td>
<td>360,000,000</td>
</tr>
<tr>
<td>3</td>
<td>1300</td>
<td>1,000,000</td>
<td>1,300,000,000</td>
<td>700,000</td>
<td>910,000,000</td>
<td>390,000,000</td>
</tr>
<tr>
<td>4</td>
<td>1200</td>
<td>1,000,000</td>
<td>1,200,000,000</td>
<td>700,000</td>
<td>840,000,000</td>
<td>360,000,000</td>
</tr>
<tr>
<td>5</td>
<td>1100</td>
<td>1,000,000</td>
<td>1,100,000,000</td>
<td>700,000</td>
<td>770,000,000</td>
<td>330,000,000</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td></td>
<td>5,800,000,000</td>
<td>4,060,000,000</td>
<td>1,740,000,000</td>
<td></td>
</tr>
</tbody>
</table>

*) Using Equation 15; **) using Equation 14

Table 16 Service contracts for new products

<table>
<thead>
<tr>
<th>Period</th>
<th>Fraction of products sold with a service contract</th>
<th># of contracts***</th>
<th>Revenue (per unit, per period)</th>
<th>Cost (per unit, per period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t$</td>
<td>$\lambda_t$</td>
<td>$P_{nt}$ (per unit)</td>
<td>$c_{nt}$ (per unit)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$\lambda_1$</td>
<td>90%</td>
<td>900</td>
<td>150,000</td>
</tr>
<tr>
<td>2</td>
<td>$\lambda_2$</td>
<td>90%</td>
<td>1080</td>
<td>150,000</td>
</tr>
<tr>
<td>3</td>
<td>$\lambda_3$</td>
<td>90%</td>
<td>1170</td>
<td>150,000</td>
</tr>
<tr>
<td>4</td>
<td>$\lambda_4$</td>
<td>90%</td>
<td>1080</td>
<td>150,000</td>
</tr>
<tr>
<td>5</td>
<td>$\lambda_5$</td>
<td>90%</td>
<td>990</td>
<td>150,000</td>
</tr>
</tbody>
</table>

*** sample calculation: 900 = $\lambda_i n_t = 90\% \times 1000$
Table 17 Revenue, cost and profits from service

<table>
<thead>
<tr>
<th>Period</th>
<th># active contracts***</th>
<th>Revenue *)</th>
<th>Cost**)</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>900</td>
<td>135,000,000</td>
<td>67,500,000</td>
<td>67,500,000</td>
</tr>
<tr>
<td>2</td>
<td>1,980</td>
<td>297,000,000</td>
<td>148,500,000</td>
<td>148,500,000</td>
</tr>
<tr>
<td>3</td>
<td>3,150</td>
<td>472,500,000</td>
<td>236,250,000</td>
<td>236,250,000</td>
</tr>
<tr>
<td>4</td>
<td>4,230</td>
<td>634,500,000</td>
<td>317,250,000</td>
<td>317,250,000</td>
</tr>
<tr>
<td>5</td>
<td>4,320</td>
<td>648,000,000</td>
<td>324,000,000</td>
<td>324,000,000</td>
</tr>
<tr>
<td>6</td>
<td>3,240</td>
<td>486,000,000</td>
<td>243,000,000</td>
<td>243,000,000</td>
</tr>
<tr>
<td>7</td>
<td>2,070</td>
<td>310,500,000</td>
<td>155,250,000</td>
<td>155,250,000</td>
</tr>
<tr>
<td>8</td>
<td>990</td>
<td>148,500,000</td>
<td>74,250,000</td>
<td>74,250,000</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3,132,000,000</td>
<td>1,566,000,000</td>
<td>1,566,000,000</td>
</tr>
</tbody>
</table>

*) using Equation 17; sample calculation: 135,000,000 = 900 x 150,000 (where 150,000 is given in Table 16)

**) using Equation 16; sample calculation: 67,500,000 = 900 x 75,000 (where 75,000 is given in Table 16)

***) sample calculation: 3,150 = 900 + 1080 + 1170 (where 900, 1080 and 1170 are calculated in Table 16)
Comparing Table 15 and Table 17, it should be noted that a digital imaging equipment
OEM may generate profits from service that are comparable to the profits from sales of
the equipment. Furthermore, the OEM may increase the revenue from service contracts
by making price adjustments for the new equipment and thereby affecting the number of
new products sold and thus the number of service contracts sold. As shown in the next
section, the number of new products sold also affects the number of cores returned to the
OEM by the HCO, at the end of the equipment’s useful life.

6.4.2 Refurbishing and service contracts for refurbished equipment

The new products sold in periods 1 through 5, as described in Table 15, will at the end of
its useful life, be returned to the OEM or collected by the OEM in various periods. More
specifically, a fraction of the products sold will not be returned but instead sold by the
HCO to a competitor or to a third-party broker and the remaining fraction may be
returned to the OEM as early as 1 or 2 periods after purchase or late as 10 to 12 periods
after purchase. In this case study, the decisions with respect to refurbishing in period 6
will be illustrated. Table 18 shows, as an illustration of Equation 1 in Section 6.2.2.1,
when fractions of the products sold in periods 1 through 5 will be returned to the OEM or
collected by the OEM. In this case, new products are returned to the OEM as early as 1
period after sales and as late as 7 periods after sales. The percentages given in Table 18
correspond with the $\beta_k$s in Equation 1.
Table 18 Fractions of sold products returned to OEM at end-of-life ($\beta_k$)

<table>
<thead>
<tr>
<th>Period</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2%</td>
<td>4%</td>
<td>8%</td>
<td>16%</td>
<td>8%</td>
<td>4%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td>56%</td>
</tr>
<tr>
<td>2</td>
<td>2%</td>
<td>4%</td>
<td>8%</td>
<td>16%</td>
<td>8%</td>
<td>4%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td>56%</td>
</tr>
<tr>
<td>3</td>
<td>2%</td>
<td>4%</td>
<td>8%</td>
<td>16%</td>
<td>8%</td>
<td>4%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td>56%</td>
</tr>
<tr>
<td>4</td>
<td>2%</td>
<td>4%</td>
<td>8%</td>
<td>16%</td>
<td>8%</td>
<td>4%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td>56%</td>
</tr>
<tr>
<td>5</td>
<td>2%</td>
<td>4%</td>
<td>8%</td>
<td>16%</td>
<td>8%</td>
<td>4%</td>
<td>2%</td>
<td></td>
<td></td>
<td></td>
<td>56%</td>
</tr>
</tbody>
</table>

Table 19 Returned cores in period 6 and collection costs

<table>
<thead>
<tr>
<th>From period:</th>
<th># cores returned *) **)</th>
<th>Collection cost ***</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>132,000</td>
<td>10,560,000</td>
</tr>
<tr>
<td>2</td>
<td>192</td>
<td>158,400</td>
<td>30,412,800</td>
</tr>
<tr>
<td>3</td>
<td>104</td>
<td>190,080</td>
<td>19,768,320</td>
</tr>
<tr>
<td>4</td>
<td>48</td>
<td>228,096</td>
<td>10,948,608</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>273,715</td>
<td>6,021,734</td>
</tr>
<tr>
<td>Total:</td>
<td>446</td>
<td></td>
<td>77,711,462</td>
</tr>
</tbody>
</table>

*) using Equation 1; m6 = $\beta_1 x n_1 + ... + \beta_5 x n_5$

**) sample calculation: 192 = $\beta_2 x n_2 = 0.16 x 1200$ (where $\beta_2$ is given in Table 18 and $n_2$ is given in Table 15)

***) using Equation 2: $C_c_t = \sum_{k=1}^{t-1} c_{c_t-k} (\beta_k n_{t-k} + \varepsilon_t)$; sample calculation: 10,560,000 =0.08 x 1000 x 132,000
Specifically, the returned cores in period 6, \( m_6 \), consist of 8% of the products sold in period 1, 16% of the products sold in period 2, etc. In reality, the \( \beta_k \)s and thereby the number of returned cores will have to be estimated by the OEM as discussed in Section 6.2.2.1.

Using Table 15 and Table 18, the total number of cores returned in period 6 to the HCOs by the OEMs, or collected by the OEMs from the HCOs can be determined. The OEM pays the HCO a collection cost, or a trade-in credit, which is based on the age of the equipment. In this case study, the collection cost in period 6 for products sold in period 1 is set at 132,000. The collection cost for subsequent periods is set to increase by 20% per period. Table 19 shows the returned cores in period 6, when the cores were initially sold to the HCO, the collection cost per unit for each period, and the total collection cost.

As discussed in Section 6.1, an important and complex decision for the OEM is the disposition decision. In Section 6.3 an expression is developed for the fraction of returned cores that can be disposed of, \( \delta_t \), that were initially sold in period \( t \):

\[
\delta_{t-k} \leq \frac{c_{d_{t-k}} - c_{c_{t-k}}}{c_{a_{t-k}} + c_{d_{t-k}}}.
\]

As shown in this equation, the fraction can be determined based on the disposition cost \( c_{d_{t-k}} \), the collection cost \( c_{c_{t-k}} \) and the acquisition cost \( c_{a_{t-k}} \), i.e. the cost paid to the third-party broker for a core of the same age. Table 20 shows the collection cost, disposal cost and acquisition cost for products sold in period 1 through 5 and the fractions of returned cores that can be disposed of, using Equation 22.
Table 20 Collection, disposal and acquisition costs per unit and fraction disposed

<table>
<thead>
<tr>
<th>From period:</th>
<th>Collection cost</th>
<th>Disposal cost</th>
<th>Acquisition cost</th>
<th>Fraction disposed*) **)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( c_{ct} ) (per unit)</td>
<td>( c_{dt} ) (per unit)</td>
<td>( c_{at} ) (per unit)</td>
<td>( \delta_i )</td>
</tr>
<tr>
<td>1</td>
<td>132,000</td>
<td>5,000</td>
<td>220,000</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>158,400</td>
<td>5,000</td>
<td>264,000</td>
<td>0.4</td>
</tr>
<tr>
<td>3</td>
<td>190,080</td>
<td>5,000</td>
<td>316,800</td>
<td>0.4</td>
</tr>
<tr>
<td>4</td>
<td>228,096</td>
<td>5,000</td>
<td>380,160</td>
<td>0.4</td>
</tr>
<tr>
<td>5</td>
<td>273,715</td>
<td>5,000</td>
<td>456,192</td>
<td>0.4</td>
</tr>
</tbody>
</table>

*) using Equation 22: \( \delta_{t-k} \leq \frac{c_{at-k} - c_{ct-k}}{c_{at-k} + c_{dt-k}} \).

**) sample calculation: 0.4 = (220,000-132,000) / (220,000-5,000)
Table 21 Disposition decision and disposal costs

<table>
<thead>
<tr>
<th>From period:</th>
<th># cores returned</th>
<th>( \delta_t )</th>
<th># to be refurbished **)</th>
<th># disposed</th>
<th>( c_{dt} ) (per unit)</th>
<th>Total *)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
<td>0.4</td>
<td>48</td>
<td>32</td>
<td>5,000</td>
<td>160,000</td>
</tr>
<tr>
<td>2</td>
<td>192</td>
<td>0.4</td>
<td>115</td>
<td>77</td>
<td>5,000</td>
<td>384,000</td>
</tr>
<tr>
<td>3</td>
<td>104</td>
<td>0.4</td>
<td>62</td>
<td>42</td>
<td>5,000</td>
<td>208,000</td>
</tr>
<tr>
<td>4</td>
<td>48</td>
<td>0.4</td>
<td>29</td>
<td>19</td>
<td>5,000</td>
<td>96,000</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>0.4</td>
<td>13</td>
<td>9</td>
<td>5,000</td>
<td>44,000</td>
</tr>
<tr>
<td>Total:</td>
<td>446</td>
<td></td>
<td>268</td>
<td>178</td>
<td></td>
<td>892,000</td>
</tr>
</tbody>
</table>

*) using Equation 3: \( C_{Dt} = \sum_{k=1}^{t-1} \delta_{t-k}(\beta_k n_{t-k} + \epsilon_t)c_{dt-k} \) Sample calculation: 160,000 = 0.4 x 0.08 x 1000 x 5000

**) sample calculation 48= (1-0.4) x 80
The collection cost per core is lower than the acquisition cost, consistent with assumption 6. The collection costs are set at 60% of the acquisition costs for each of the 5 periods in this example. The OEM may want to dispose of collected cores for strategic reasons, as described in Section 6.1. According to Table 20, the OEM can dispose up to 40% of the returns from each of the periods, given the collection, disposal and acquisition costs used in this example.

Table 21 shows the results of the disposition decision and the total disposal costs in period 6, using the disposal percentages and disposal costs per core from Table 20 and the number of cores returned from Table 19.

Consistent with assumption 9, the demand for refurbished products is deterministic in this example. Assuming the demand for refurbished products in period 6 is 300, the number of cores to be acquired from third-party brokers can be determined, now that the disposition decision has been made. Consistent with assumption 5, the refurbishing cost for a core is independent of age. Since the acquisition cost of a core decreases with age, the OEM prefers to buy older, and thus cheaper, from the third-party broker. The total number of cores to be acquired from the broker is the difference between the deterministic demand and the number of cores that were determined to be refurbished in the disposition decision. In this example, the number of cores to be acquired is thus 300 - 268 = 32. The number of cores acquired shown in Table 22 represent an example of when the 32 cores acquired from the brokers could have initially been produced. In reality this distribution will depend on the broker’s availability of cores. Table 22 also shows the total acquisition costs for period 6.
Table 22 Acquisition costs

<table>
<thead>
<tr>
<th>From period:</th>
<th># acquired</th>
<th>$c_{at}$ (per unit)</th>
<th>Total *)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>220,000</td>
<td>2,200,000</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>264,000</td>
<td>1,848,000</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>316,800</td>
<td>1,900,800</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>380,160</td>
<td>1,900,800</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>456,192</td>
<td>1,824,768</td>
</tr>
<tr>
<td>total</td>
<td>32</td>
<td></td>
<td>9,674,368</td>
</tr>
</tbody>
</table>

*) using Equation 4: $C_{At} = \sum_{k=1}^{t-1} A_{t-k} c_{at-k}$
Table 23 Refurbishing cost

<table>
<thead>
<tr>
<th># not disposed of</th>
<th># acquired</th>
<th>Total # refurbished</th>
<th>$c_{rt}$ (per unit)</th>
<th>Total *) **)</th>
</tr>
</thead>
<tbody>
<tr>
<td>268</td>
<td>32</td>
<td>300</td>
<td>150,000</td>
<td>45,000,000</td>
</tr>
</tbody>
</table>

*) using Equation 5; $C_{rt} = c_{rt}Q_t = c_{rt}(\sum_{k=1}^{t-1}(1 - \delta_{t-k})(\beta_k n_{t-k} + \epsilon_t) + A_{t-k})$

**) sample calculation: $c_{r6}Q_6 = 150,000 \times 300$; where $Q_6$ is the total number of refurbished products in period $6 = \sum_{k=1}^{6}(1 - \delta_{6-k})(\beta_k n_{6-k} + \epsilon_6) + A_{6-k} = 268 + 32$, where 268 is the total number of collected products that will be refurbished which is calculated in Table 21 and 32 is the acquired cores from the broker, as determined in Table 22.
Table 23 shows the refurbishing cost based on the per-unit refurbishing cost used in this example.

Using Equation 7, \( R_{R_t} = p_{r_t} D_t \) and a per unit revenue \( p_{r_6} \) of $700,000 per refurbished product, the total revenue from refurbished sold products \( R_{R_6} \) is \( 300 \times 700,000 = 210,000,000 \), if \( D_6 \) equals exactly the number of refurbished products \( Q_6 \).

A fraction \( \gamma_6 \) of sold refurbished products in period 6 are sold with service contracts. If \( \gamma_6 \) is 80%, and the number of sold service contracts for refurbished products is thus 240. The per-period revenue and cost per service contract are $100,000 and $50,000, respectively.

The revenue and cost of 4-period service contracts for refurbished products sold in period 6 are shown in Table 24.
Table 24 Revenue and cost from service contracts for refurbished products

<table>
<thead>
<tr>
<th>Period</th>
<th>Revenue (per unit)</th>
<th>Total *) **)</th>
<th>Cost (per unit)</th>
<th>Total ***) ****)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>100,000</td>
<td>24,000,000</td>
<td>50,000</td>
<td>12,000,000</td>
</tr>
<tr>
<td>7</td>
<td>100,000</td>
<td>24,000,000</td>
<td>50,000</td>
<td>12,000,000</td>
</tr>
<tr>
<td>8</td>
<td>100,000</td>
<td>24,000,000</td>
<td>50,000</td>
<td>12,000,000</td>
</tr>
<tr>
<td>9</td>
<td>100,000</td>
<td>24,000,000</td>
<td>50,000</td>
<td>12,000,000</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>96,000,000</td>
<td></td>
<td>48,000,000</td>
</tr>
</tbody>
</table>

*) using Equation 9 or 11; \( R_{Sr_t} = \sum_{i=0}^{L_R} y_t D_t p_{sr_{t+i}} \) or \( \sum_{i=0}^{L_R} y_t (l_{t-1} + Q_t)p_{sr_{t+i}} \), depending on fraction of demand fulfilled.

**) Sample calculation: assuming \( Q_0 = D_6 \): \( R_{Sr_6} = \sum_{i=0}^{4} y_6 D_6 p_{sr_{6+i}} = (0.80 \times 300 \times 100,000) + \ldots + (0.80 \times 300 \times 100,000) = 4 \times 24,000,000 = 96,000,000. \)

*) using Equation 8 or 10; \( C_{Sr_t} = \sum_{i=0}^{L_R} y_t D_t c_{sr_{t+i}} \) or \( \sum_{i=0}^{L_R} y_t (l_{t-1} + Q_t)c_{sr_{t+i}} \) depending on fraction of demand fulfilled.

**) Sample calculation: assuming \( Q_0 = D_6 \): \( C_{Sr_6} = \sum_{i=0}^{4} y_6 D_6 c_{sr_{6+i}} = (0.80 \times 300 \times 50,000) + \ldots + (0.80 \times 300 \times 50,000) = 4 \times 12,000,000 = 48,000,000. \)
The total revenue, cost and profit associated with refurbishing cores, selling refurbished equipment, selling service contracts in period 6 and servicing refurbished equipment for HCOs from period 6 through period 9 is summarized in Table 25. The total cost of refurbished products in period 6 is the sum of collection costs, disposal costs, acquisition costs and refurbishing costs. Looking at the profit per refurbished product in this case study, it is intuitive that OEMs should ensure that demand for refurbished product can be met, especially given the notion that unfulfilled demand is lost, as described in Section 6.2. If inventory is unavailable and demand is unfulfilled, not only is the revenue of a refurbished product lost, but also the profit from a service contract over the term of the contract. To illustrate the results of the break-even analysis, consider the following: as described in Section 6.3, the only scenario in which inventory does not need to be available, is if the profit of a service contract is negative and would balance out the lost revenue from a refurbished product and the “saved” or unspent inventory costs. Using an inventory holding cost of 6% of the cost of a refurbished product, the holding cost of an average unit is 6% of the average cost of a refurbished unit, which is the total refurbishing cost divided by the number of refurbished products, which equates to 0.06*(133,277,830 / 300)= $26,656. The net loss of a service contract over the term of the contract should thus be equal to the revenue of a refurbished unit plus the “saved” holding cost, which is $700,000+ $26,656= $726,656, for an OEM not to have inventory of refurbished product on hand to meet demand. It is clear that given the numbers in this case study, a periodic, or annual net service loss of $726,656/4=$181,664 is an unlikely
scenario. In this case study the OEM should ensure that demand for refurbished product can be met.
Table 25 Revenue, cost and profit from refurbished products and service contracts

<table>
<thead>
<tr>
<th>Category</th>
<th>Total revenue</th>
<th>Total cost</th>
<th>Total profit *)</th>
<th>Profit per product **)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Products</td>
<td>210,000,000</td>
<td>133,277,830</td>
<td>76,722,170</td>
<td>255,741</td>
</tr>
<tr>
<td>Service</td>
<td>96,000,000</td>
<td>48,000,000</td>
<td>48,000,000</td>
<td>200,000</td>
</tr>
<tr>
<td>Total</td>
<td>306,000,000</td>
<td>181,277,830</td>
<td>124,722,170</td>
<td>455,741</td>
</tr>
</tbody>
</table>

*) sample calculation, assuming $Q_6=D_6$; $P_{R_6} = R_{R_6} + R_{SR_6} - (C_{C_6} + C_{D_6} + C_{A_6} + C_{R_6})$, where:

$R_{R_6}$ = revenue from refurbished products = 210,000,000 = 300 x $700,000$

$R_{SR_6}$ = revenue from service contracts = 96,000,000, as calculated in Table 24

$C_{SR_6}$ = cost for service contracts = 48,000,000, as calculated in Table 24

$C_{C_6} + C_{D_6} + C_{A_6} + C_{R_6} =$ collection + disposal + acquisition + refurbishing cost = 77,711,462 + 892,000 + 9,674,368 + 45,000,000 = 133,277,830, as calculated in Table 19, Table 21, Table 22 and Table 23, respectively.

$P_{R_6} = R_{R_6} + R_{SR_6} - (C_{C_6} + C_{D_6} + C_{A_6} + C_{R_6}) = 210,000,000 + 96,000,000 - 48,000,000 - 133,277,830 = 124,722,170$

**) sample calculation 1: 255,741 = 76,722,170/300, where 300 is $Q_6=D_6$; sample calculation 2: 200,000 = 48,000,000 / 240, where $240 = \gamma_6 D_6 = 0.80 \times 300$
Chapter 7 Summary

In this dissertation the influence of inter-organizational power and dependence in the medical equipment supply chain and the challenges faced by Original Equipment Manufacturers’ (OEMs’) with respect to offering new and refurbished medical equipment along with service contracts are investigated. The dissertation consists of a two-part large-scale empirical study to analyze the influence of power and dependence and an analytical model that is developed to investigate the OEM’s joint manufacturing-refurbishing problem.

7.1 Empirical study

7.1.1 Overview

The empirical component of the dissertation is the first large scale empirical study that investigates the effect of dependence and inter-organizational power on relationships between and performance of members of supply chains that can be characterized as reverse oligopolies, controlled by powerful middlemen. The healthcare supply chain consists of many buying organizations (HCOs) and relatively few powerful procurement
service providers (GPOs) and few powerful suppliers (OEMs). This places the HCO in a dependent position in the relationship with the GPO and the relationship with the OEM. The role of power in a GPO-driven reverse oligopoly such as the healthcare supply chain had prior to the current study not been analyzed. In the extant literature concerning the role of power, it is typically the buyer who has the power advantage over the supplier. In the healthcare supply chain however, the HCO does not have the power advantage, given the dependence on both the GPO and the OEM as mentioned earlier. Buying organizations such as healthcare organizations (HCOs) are increasingly outsourcing of the first two steps of their procurement function to procurement service providers such as Group Purchasing Organizations (GPOs), often times in an effort to save costs. A rich body of academic research has developed over the last few decades investigating the challenges and opportunities of outsourcing initiatives. In recent years researchers have in particular started to investigate the effects of outsourcing one’s customer service functions, where direct contact with an organization’s customers now occurs through the customer service provider. However, to date little if any research has been conducted to investigate the effects of outsourcing one’s procurement process, where it is not the contact with the buying organization’s customer but the contact with the buying organization’s supplier that now occurs through a procurement service provider as a result of the outsourcing initiative.

Data was collected from 276 procurement professionals from US HCOs to begin to address these voids in the literature. Factor analysis and structural equation modeling was used to analyze the data.
Drawing from the power and dependence, inter-organizational power, buyer-supplier relationships research in the marketing and supply chain management literature and the outsourcing literature, a conceptual model and hypotheses were developed concerning the buying organization’s (HCO’s) dependence on both a procurement service provider (GPO) and on a supplier (OEM) and its effect on the use of power by the service provider and the supplier, as perceived by the buying organization. Furthermore, an OEM’s inter-organizational power and a GPO’s inter-organizational power were hypothesized to influence the OEM-HCO relationship and the OEM-GPO relationship, respectively. Lastly, hypotheses were developed with respect to the effects of relationship management, measured through relationship commitment and cooperation, onto the performance of the respective health care supply chain members.

7.1.2 Conclusions and managerial implications

This study contributes significantly to the academic literature and can support decision making of healthcare procurement professionals. There are a number of contributions of this study.

1. A well-defined conceptual health care supply chain model that is strongly grounded in theory was developed and tested.
2. The study provides a holistic view of medical equipment supply chain relationships from an empirical survey research methodology perspective. The study reveals the quantitative relationships among the medical equipment supply chain members. Specifically, the statistics from the structural equation model provide medical procurement professionals with a quantitative sense of the various supply chain member relationships.
3. The study extends the power-dependence body of literature by investigating the effect of dependence onto inter-organizational power in a relationship between a buying organization and a middleman, a GPO. The results of the study show as a buying organization’s dependence on a GPO increases, the typically relationship-damaging mediated power of a middleman decreases and the typically relationship-improving non-mediated power of a middleman increases, as assessed by the buying organization.

4. Another contribution to the power-dependence literature involves the effect of dependence onto inter-organizational power in a relationship between a buying organization and a supplier, where the relationship is interceded by a middleman. The study provides empirical evidence of a positive association between the powerful supplier’s non-mediated power and the buying organization’s dependence on the supplier, as assessed by the buying organization.

5. The study contributes to the outsourcing literature, in particular the stream focused on triadic supply chain research and the outsourcing of service processes. The results of the study suggest that when the dependence of a buying organization on a procurement service provider increases, which occurs when the organization outsources specific steps of the procurement process to the service provider, the buying organization’s dependence on not only the procurement service provider but also the supplier increases.

6. A contribution to the healthcare supply chain literature is the development and empirical validation of a theoretical model of dependence and power in the health care supply chain.

Some important managerial implications for managers and executives of buying organizations in general and HCOs in particular follow from the study. Many organizations, HCOs and organizations in other industries, are considering outsourcing procurement functions to service providers.

- When performing strategic evaluations of current and future capabilities, core competencies and risks, buying organizations should consider the effects of dependence on the service provider, as a result of the procurement outsourcing decision. The dependence on the service provider affects the buying organization’s assessment of the provider’s use of power, which has been shown
to affect an organization’s perception of the quality of and satisfaction with a supply chain relationship.

- The organization’s dependence on the procurement service provider increases the dependence on the supplier, a phenomenon which we call the dependence trap. The dependence on the supplier in turn again affects the buying organization’s assessment of the supplier’s power, which has been shown to affect the quality of and satisfaction with the relationship, as indicated above. Stated differently, executives of buying organizations considering or reconsidering procurement outsourcing decisions are cautioned that satisfaction with the relationship with procurement service providers as well as suppliers may in part and indirectly be caused by the organization’s dependence on the provider and the supplier.

- Healthcare organizations (HCOs) and original equipment manufacturers (OEMs) both benefit in terms of performance from a relationship that is characterized by long term commitment from the HCO and close cooperation between the two supply chain members. OEMs can enhance this relationship with the HCO by developing expertise that is valued by HCOs and by developing attractive business strategies that will lead to the HCOs desire to be associated with the OEM. This inherent non-mediated power from the OEM was found to positively affect the relationship between the OEM and the HCO.

- While a close relationship between the Group purchasing organization (GPO) and the HCO positively affects the GPO’s performance, it does not enhance the performance of the HCO. HCOs should conduct a strategic evaluation of their procurement outsourcing practices and determine for which product groups the service of a GPO is prudent. Based on the findings of this study, the GPO’s involvement in capital equipment purchasing does not appear to have a direct positive effect on the HCO’s performance.

### 7.1.3 Future research

As with any study, limitations of the current study exist, which in turn provide opportunities for future research. The data gathered for testing of the hypotheses are cross sectional, limiting the extent to which causality of the relationships tested in this study may be claimed. Future studies could validate the findings of this study by tracking buying organizations’ dependence on procurement service providers and suppliers and
the assessment of the use of power of the provider and the supplier, as the buying
organizations increase their procurement outsourcing.

7.2 Analytical study

7.2.1 Overview

An analytical model was developed with respect to a managerial problem faced by each
of the four major OEMs of medical digital imaging equipment. Prior to the survey data
collection, an extensive field study was conducted. Managers and executives from the
four major OEMs of digital imaging equipment were interviewed, plant tours were
conducted and HCO managers and executives from various functional areas were
interviewed. It became apparent that in recent years HCOs have become increasingly
interested in refurbished equipment, as a means to reduce capital spending. The market
for refurbished medical digital imaging equipment is at a high growth stage (Frost and
Sullivan, 2010). With growth rates in the 7-8% ranges, the 4 main OEMs (Philips,
Siemens, GE and Toshiba) as well as third-party brokers have developed their
refurbishing capabilities. After-sales service contracts for refurbished equipment are
important to attract customers. The OEMs, each providing these service contracts,
therefore have a competitive edge over the third-party brokers.
Challenges faced by medical equipment OEMS with respect to offering new
manufacturing and refurbishing are unique when compared to remanufacturing and
refurbishing settings investigated in the extant literature, in part due to the fact that multi-year service contracts for both new and refurbished products contribute significantly to the overall profit of the medical equipment OEM. An important problem for an OEM in the medical equipment supply chain investigated in this dissertation can be described as follows: How should an OEM jointly manage new and refurbished products along with service contracts for new and refurbished products? Stated differently, how can an OEM in an environment with low volume, expensive products and multi-year service contracts, optimally manage new and refurbished products and service contracts for both new and refurbished products? The OEM needs to make critical decisions with respect to the number of new items sold, the disposition of returned/collected cores, the number of items bought from third-party brokers and the amount of inventory of finished refurbished products.

7.2.2 Conclusions and managerial implications

Equations for the cost and revenue streams associated with the various processes in an OEM’s manufacturing-refurbishing environment were formulated and a subsequent analysis and case study to illustrate the equations were provided. The equations for the cost and revenue streams along with the illustrations in the case study provide the OEMs with a systematic approach to decision making in the digital imaging equipment manufacturing and refurbishing environment. In addition, some of the insights obtained through the analysis and case study are:
Drivers to determine whether demand for refurbished product should be fulfilled and how (carrying inventory of refurbished products versus ensuring that demand equals the number of refurbished products) are:

- Revenue from refurbished products
- Inventory carrying costs
- Profit from service contracts, determined by the fraction of demand that includes a service contract, the length of the service contract, the price and the cost of service throughout the contract.

The OEM should always ensure that sufficient inventory is available, between carry-over inventory from the previous period and refurbished cores, to meet demand, unless there is a net loss from a service contract over the length of the contract that is greater than the sum of the revenue of a refurbished item plus the inventory cost of a refurbished item.

With respect to the refurbished quantity, the following conclusions can be drawn:

- The refurbished quantity is the sum of acquired plus collected-not disposed of products: The acquired quantity can be reduced by increasing the number of new products in earlier periods. A fraction of the quantity produced in any given period will be returned and collected. The new product quantities in the various periods can be manipulated by varying the prices of new products.
- Since the refurbishing costs are equal for collected cores and acquired cores, the OEM should minimize the total costs associated with collecting
cores, disposal and acquisition. An expression was developed for the fraction of collected products that should be disposed of or sold to third-party brokers.

7.2.3 Future research

The model of the OEM’s manufacturing-refurbishing environment presented in Chapter 6 can be extended in a number of ways. First, one of the distinctive characteristics of the medical equipment supply chain is that a fraction of the OEMs new equipment sold to HCOs includes a multi-year service contract. HCOs that buy a service contract will conceivably return the end-of-useful-life product back to the OEM in a more predictable, less uncertain, manner, compared to the HCO that merely purchases the equipment. When estimating the flow of returns of end-of-useful-life equipment, an OEM should take this characteristic into consideration. A fruitful extension of the model is thus the forecasting of the return flow in an environment where a fraction of customers purchase a multi-year service contract. Second, another distinctive characteristic of the medical equipment supply chain is that demand for refurbished products and thereby the demand for cores has been increasing, which may be expected to affect the delivery performance of the third-party cores brokers. Uncertainty in the input flows for the OEM’s refurbishing operation thus exists in both the return flow of cores and the flow of supplemented cores acquired from brokers. Future analytical models of an OEM’s remanufacturing-refurbishing environment such as the environment investigated here
should incorporate this uncertainty when analyzing required inventory of refurbished finished products. Finally, a third extension is to include Group Purchasing Organizations (GPOs) in the model. There are at least two ways in which the presence of the GPO affects the OEM. First, the contract administration fees paid by the OEM to the GPO, as explained in Chapter 2, may affect the OEM’s revenue. Second, HCOs who buy equipment from the OEM through GPO-negotiated contracts will be more dependent on the OEM, as was concluded in the empirical part of this dissertation. This increased dependence on the OEM will presumably manifest itself in brand loyalty. This will affect future sales, and with respect to the refurbishing operation, positively affect the return flow of the end-of-useful-life equipment. Stated differently, an HCO who buys equipment through GPO-negotiated contracts is more likely to buy from the same OEM again and thus return the end-of-useful-life equipment to the OEM, thereby reducing some of the uncertainty in the return flow.
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Appendix A: Field study summaries
Appendix A Field study summaries

OEM1

Executive #1 7-13
Thursday, July 14, 2011
9:25 AM

- Responsible for "US equipment remarketing"
- All competing OEMs in imaging systems are in refurbishing
- Since mid 90s, medical equipment refurbishing has been increasing. There was a catalyst in 2006/2007: deficit reduction act in US congress; reimbursement changes and not only imaging facilities, but also hospitals became more interested in buying refurbished. Axiom is here now to cut cost.
- One of the challenges in the refurbishing business is that there is only so much existing equipment in the market. It is a replacement business game.
  - When comparing OEMs, OEM1 has less equipment in the market, so less used equipment comes back from customers.
  - Equipment is usually only refurbished once. Lifecycle is ~5-7 yrs, after that it is old technology
- Imaging equipment is the main type of medical equipment that is being refurbished by all OEMs. "modalities" can range in the $1-2MM
  - Ultrasound
  - Nuclear medicine (like PET)
  - MR
  - Intervention X-ray (cardiac)
  - Digital x-ray
  - Surgical c-arms
- The refurbishing business model does not really work for other medical equipment
- Sales process:
  - District sales force carries everything
  - Account manager performs needs analysis, takes into consideration the customer's budget
• Account manager has ~25-30 hospitals
• Specialist in products support account managers

• Concern for cannibalization:
  ○ This is a concern in lower priced segments, like ultrasounds
  ○ Reality is if the customer is truly in that segment, from a budget perspective, he will either get the refurbished product from OEM1 or from the competitor

• 30-35% of hospitals are willing to go pre-owned

• Third-party brokers:
  ○ Refurbishing Market is not completely owned by the OEMs
  ○ There are 100s of brokers, but a limited number of major ones;
  ○ The brokers will take the competitors' products when OEM1 gets them from the customer, and the same happens with the competitors

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Executive #2 7-22
Friday, July 22, 2011
12:00 PM

1. Do you work with GPOs?
2. How do GPOs affect sales of refurbished equipment?
3. Do hospitals that work through GPOs buy refurbished equipment?
4. What type of hospital buys OEM1’s refurbished equipment?
5. How is OEM1 attempting to reach more customers to sell refurbished equipment, or are they?

• OEM1 works with GPOs
  ○ A good portion of their orders come through GPOs

• Hospitals can be part of multiple GPOs

• Vendors negotiate contracts with GPOs
  ○ They want to be "on contract" with the GPO for when customers are buying
  ○ OEM1 sometimes gets beat out of the GPO, when their offer is not good enough, when the requirement of the GPO is too great

• Different types of GPOs; some hospitals can be owned by the organization, like Healthtrust Purchasing group, or community health systems. These organizations own hospitals and medical facilities and can work like a GPO

• Refurbished equipment:
  ○ Selling refurbished equipment through a GPO is not the same as selling new
  ○ OEMs are restricted by inventory and there is a range of models and products that might or might not become available to be refurbished (and offered for sale through the GPO)
  ○ Many GPOs are not interested in previous models, but some are in interested in current technology
Since there is such a broad portfolio that spans all modalities, it is too much to consolidate for a GPO. Instead, OEM1 negotiates a discount with the GPO for their refurbished products, a specific discount, but not specific for each item. Details of what is being bought refurbished is then based on what's available, it's not a specific model. A significant portion of refurbished equipment is sold through GPOs; some GPOs are interested but definitely not all. Refurbished equipment is always represented to the GPO, but the degree to which they are interested varies by GPO. Degree of compliance (on the buyers' side; the extent to which they buy through the GPO) and the strength of power of the GPO can be a limiting factor with regards to the demand for refurbished equipment. If hospitals are owned, they are inclined and encouraged to look at refurbished. Prime candidates are small, rural hospitals, but mid-size and large hospitals are becoming increasingly interested as well. The mid-size and large hospitals increasingly have as their strategy to buy refurbished as their backup equipment or secondary equipment. This trend has been in place for a number of years. Vendors have migrated to the 'value segment', producing lower cost equipment, for example in China. Refurbished is not the only answer. Vendors have come out with new equipment portfolios, addressing this large scale trend of lower cost. OEM1 calls it 'meaningful innovation'- it has to increase reimbursements or lower cost, else it's not a meaningful innovation.

OEM1 visit 8-10
Wednesday, August 10, 2011
1:00 PM

- Trends:
  - They have seen a shift as of this year; increase in refurbishing of CT and MR, because:
    - Market trend
    - Innovation of new products, which drives trade-ins (without new products, there are no trade-ins)
- Operational:
  - OEM1 develops an annual plan which is updated each quarter. The actuals never match the planned volume primarily because of the supply of cores is and demand variability.
They sell directly to end customers, only some through GPOs
Primary customers are small physician offices ('doc in box') and imaging centers
Often times systems that come back are trade-ins or systems coming off of a lease contract. OEM1 also buys from brokers.
There is some concern about market cannibalization. They work closely with the business units on pricing and incentives to manage this.
Production/ planning:
  - There are target times for each system
Customers can’t distinguish the quality; the systems look like new.
Life cycle:
  - There are major revolutionary changes every 3-5 years
On average, systems are refurbished once.
Service is done in house and warranty is the same as for new equipment
Brokers:
  - Some sell as is, some offer service. Most of them are interested in quick transactions
Radiation dose is an important concept in this industry
Question asked by manager:
  - What do customers want? Do they want a tiered down version instead of fully refurbished? A 'certified' system instead of fully refurbished? There seems to be a market for systems between 'as-is' and fully refurbished.
Brokers:
  - Some sell to end user, some to other OEMs, some buy equipment for parts, to either sell parts or use them for their own service organization/ offering. Some brokers also refurbish. Especially in nuclear medicine, some do a good job. It can be challenging competing with them, since they also provide service
16 slice scanner is currently the workhorse on the market. New Higher slice scanners, like 64 and 128, 256 are usually going to teaching hospitals.
  - The 16 slice was new ~$1MM, but now new ~$500k. It was developed 5/6 years ago
  - Hospitals will replace that scanner with another 16slice or a 64 or 128 slice.
Question:
  - What is it that the end user is looking for? there seems to be demand between as is and fully refurbished; how much and what are they willing to pay for it?
Customers:
- Academic hospitals. They are often part of IDNs. They are not really their target market.
- Outpatient imaging. Still a good portion, but these centers have been integrated into delivery networks through vertical integration by hospitals.
- Main segment is budget constrained, acute care facilities of all types, especially since the last 5-7 years. They often belong to at least 1 GPO.

Refurbishing is complementary to the new business. The optimal model:
- Minimize the cannibalization, defuse intelligently the assets that are traded in and come back from the customer.
- Minimize cannibalization by keeping the price point not too far from new.
- A sale of a new piece of equipment possibly generates 4 streams on revenue:
  - The sale of the new equipment
  - Service revenue of the new equipment
  - Sale of the refurbished/ remarketed equipment
  - Service of the remarketed equipment

Forecast:
- Supply is the limiting factor
- Over the last 10 years refurbishing by OEMs has become a reality; during that time the market for refurbished equipment has been underserved, because of supply. Now that new technology development has taken off in the last 5 or so, the supply of cores has increased.

Disruption:
- There is a normalization of procedures in hospitals. The growth in procedures has slowed down.
- The value market had been underserved. Until recently, the focus was on new technology, for teaching hospitals primarily. There's now an increase in forward production of 'value equipment', right-sized for a lighter footprint, cheaper and easier / cheaper to maintain and operate. Interestingly however, this equipment is still more expensive than refurbished current equipment. This 'value equipment' hasn't taken off as much as OEM1 (and competitors) would like to see. Customers are still interested in 'horse power' (as in cars). The physician could play a role in this, but it depends on the circumstances, the type of hospital and ownership for example.
• OEM1 does compete with brokers/refurbishers who sell OEM1 equipment. It is important to sell off the trade-ins to the 'right' brokers. The executive believes that OEM1 has some opportunities in that area.
  • Converting customers:
    ▪ Difficult; you have to show your track record. It could turn into a price war, bcs ultimately it is also about the service contracts
    ▪ The industry is characterized by an oligopoly. There are a few OEMs who control the market. You need a critical mass to be a viable supplier in this market.

• Two important characteristics of this industry:
  • The decision makers on the buyer side are risk adverse. The administrators and procurement leaders would be personally embarrassed if the purchased equipment does not work, if scanners are down.
  • This is the only industry in which 'plumbers and carpenters run the house' - the doctors are the workers but they make the decisions, they are in charge, indirectly.

• Question:
  • What do customers want?
  • How do they perceive OEM refurbishment, when compared to refurbishment by brokers?
  • What are they willing to pay and how much risk are they willing to take?

Executive #2 3-12
Monday, March 12, 2012
3:30 PM
Topic of the call was 'an OEM's decisions regarding new and refurbished product sales and service contracts'.
  • OEMs should view the 4 transactions (new and refurbished product sales and service contract sales) as 4 integrated transactions!
    ○ In reality, OEMs often do not have the tools to do this and business entities might not be correctly incentivized
  • Service contracts:
    ○ As complexity of the product goes up, so does the complexity of the contract
    ○ Contract is completely customizable! Anything from complete responsibility for all maintenance to only some training etc. in house mechanics who would do service and trouble shooting. The solutions are creative.
    ○ Service is big business!
Sophistication goes down as products are easier, less sophisticated. Some might have no contract at all in these cases.

In summary: both pricing and content of the contracts is completely customized

Good management of service requires world class management in terms of training, material and parts etc

As units get more complex, almost all customers buy service contracts

Costs do not vary geographically so much as they do between urban and rural areas. Urban will require quicker response times etc. than rural.

OEM2

OEM2

Tuesday, August 02, 2011
1:00 PM

- OEM2 refurbishes most capital equipment, primarily digital imaging equipment. It does depend on the modality. For example, some cheaper ultra sound equipment is refurbished which only sells for $10,000. Of course it depends on cost of refurbishing and how much it can be sold for in the market
- The percentage of business (revenue) that is refurbished is less than 10%.
- According to sales executive, OEM2 will sell refurbished when the customer asks for it. OEM2 will be part of needs definition and if refurbished is what fits in the budget, OEM2 will suggest refurbished.
- Of refurbished equipment, only a small percentage (~2%) is being sold through GPOs. it is mostly hospitals buying direct, or imaging centers, that focus on volume and efficiency, rather than on the current and new technology, or physician offices. Academic hospitals generally want the newest and latest technology.
- OEM2 gets cores primarily through trade ins, but will also buy from brokers (who get them from competitors)
- Some brokers and refurbishers will refurbish OEM2 product themselves, which can cause problems. Their operation is usually not that sophisticated.
- OEM2 will at times sell older equipment, for which part supply is perhaps limited, "as is".
- OEM2 performs refurbishing in house. Only some minor (ie non-core) tasks might at times be outsourced, like painting. The main driver appears to be concern for quality.
  - Some 3rd party service maintenance providers will attempt to buy the cores in the market, but only for parts. These firms have no intention of selling the
cores or refurbishing them, but are interested in the parts only, to use them to service equipment in the field, or to sell the (OEM) parts to other service firms.

- The barriers of entry for these types of firms are of course much lower than for an equipment manufacturer. A firm would need 5-6 people and some parts and can become a service maintenance firm. Risk is lower.
- This can cause issues on a number of levels for the OEMs, for example systems do not come back to the OEM so cores supply is impacted.

- GPO support for refurbished equipment varies
- Relationship with the GPO varies. With some it's difficult, easier with others. In general they represent the hospital. It's not negative, but still it's a negotiation each time.
- Refurbished business has grown at OEM2 over the last 10 years
- Refurbished equipment goes overseas and stays domestic
- It takes a couple of weeks, about a month, to refurbish an average piece of equipment (digital imaging)
- Primary concern, challenge, is likely the availability of cores along with parts availability
  - In addition, OEM sometimes wants to end a product, from a strategic perspective, but it could still be refurbished and sold as there still is demand for the refurbished version of this equipment
- OEM2 Strategy is to increase refurbishing
- Question: the 3rd party market: what is their financial structure? How do they get the systems from the customers etc. OEM2 sees the 3rd party refurbishers as tough competition.
- the market is in a state of flux. There is a transformation in the market. It is the question what the future involvement of GPOs is in capital equipment purchasing. Group facilities might decrease the need for GPOs involvement, in capital equipment purchasing and perhaps in general

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**OEM2 visit**

Monday, September 26, 2011
11:00 AM

**Source of cores**
- Trade-ins
- Leases (from OEM2 financial services)
- Open market buying
○ OEM2 prefers to buy from end users (hospitals), does not buy much from brokers/dealers, due to additional mark-up
  • US is biggest source; most other countries do not have the install base
  • OEM2 is not actively attempting to optimize all 4 components of revenue (new and refurbished sales and service revenue for both new and refurbished).

Customers
  • Government does not buy refurbished!
  • Universities for the most part do not buy refurbished, they want cutting edge
  • Imaging centers
  • Smaller doctors offices, businesses, starting physicians. A refurbished system may be their second/back up system.

Refurbishing
  • OEM2 always takes ownership of the equipment
  • OEM2 Service will move systems in the field for hospitals, but seemingly this often times gets done by 3rd parties.
  • The service organization does ‘field refurbishing’ to a small degree.

GPO
  • Imaging centers generally do not buy through GPOs.
  • If physician offices are part of hospitals (ie part of an Integrated Delivery Network), they will buy through the GPO, else they will buy directly from the OEM

Brokers/dealers
  • Some brokers are good, but especially outside the US more of them are not as good.
  • In a number of countries governments have shut brokers down.

Incoming trade-ins:
  • One of three things will happen:
    ○ Harvested for parts: they work with the service organization on this initiative
    ○ Disposed of in an environmentally acceptable manner
    ○ Refurbished
  • This decision is made based on age and condition of the equipment and how long it has been since the model has been out of forward production
  • They do not refuse trade-ins.

Production volumes
• The volume in the refurbishing operation follows trends and promotions in the forward channel:
  ○ End of year for hospitals and for OEM2 can drive promotions or can lead to end of year purchases, which generates trade-ins.
  ○ Similarly, trade shows or launches of new products can provide a boost of incoming trade-ins/cores

Process
• For refurbished MRI and CT, OEM2 carries a backlog. Each unit that is being refurbished has been allocated to an order.
• It takes 2-3 wks to refurbish an MRI or CT scanner
• In the ultrasound facility:
  ○ Units arrive at testing. From testing they go to repair or straight to 'inventory of cores waiting to be refurbished'.
  ○ Units will be fully or partially refurbished, depending on the order
  ○ Refurbishing is build to order
  ○ Inventory turns ~ 4 times per year. # of units on the floor in inventory was surprisingly high
    • Note: For MRI/CT scanners there is no inventory. There is an order for each unit that comes in

Competition
• OEM2's equipment is relatively 'open'. (ultrasound equipment). Others can relatively easy copy the refurbishing task

Market:
• ~15% of the total ultrasound market is refurbished
• ~20-25% of MRI/CT market is refurbished

Challenges & Questions:
• How does a hospital decide to sell their equipment? What are the criteria? Is it price only? Is appropriate environmental disposal a concern for the hospitals? When do they simply go with the OEM and when do they prefer a 3rd party?
• When do hospitals decide to finance (lease) the system versus buy it (and capitalize it).
• How quickly do they depreciate it?
• It is difficult to determine how refurbished fits in with changing portfolios
• what drives hospitals in both buying and selling decisions - what are the criteria.
OEM3

Executive #3 8-26 and 8-28
Friday, August 26, 2011
11:00 PM

- Refurbishing
  - OEM3 started only ~2 years ago, with CT systems
  - They have a dedicated facility, right near the headquarters
  - Volume: 50-60 CT scanners per year
  - Highly successful
  - They get cores primarily from customers trading in, when buying new, but they also buy from brokers (like the other OEMs)
  - Process:
    - 'full refurbishing', using a 100-point list/process, which leads to an 'as good as new' product
    - It takes ~1wk to refurbish a CT scanner
    - Their facility has multiple bays and they do 'true refurbishing'. It takes ~2 people per bay
    - OEM3 has been doing MRI for about 3 months
      - Takes ~2 wks to refurbish
      - A new MRI costs ~$1MM, a refurbished one ~750-900k
    - They also very recently started with ultrasound refurbishing

- Sales & marketing:
  - Same channel that sells new also sells refurbished. OEM3 sees it as just another product in the portfolio.
  - Does not feel that new and refurbished equipment are competing with each other. "it's all about fulfilling the customers' requirements. You always ask them about their budget."
  - Margins are less on refurbished equipment, but generally comparable. For low CT scanners, there can be no margin at all at times. It's all about 'getting the socket' there, in that case the revenue comes from service agreements.
  - There has been a trend towards more refurbished demand in the market. About 10% or more growth in this segment annually, depending on the modality.
  - Believes that more of the refurbishing is shifting towards the OEM, since the OEMs are getting more serious about refurbishing

- GPOs
  - They have agreements with the top 4 GPOs
• Premier, Novation, Medical assets (who acquired broadlane and amerinet)
• does not see GPOs as a concern with regards to selling refurbished
• The agreement is done annually and according to the executive there is little involvement by the GPO beyond this. The exception is that there are group buys, or promos, where the GPO negotiates special deals with the OEMs, special pricing for a quarter for example. Nowadays it is ~40% of purchases that happen like this, it used to be more like 20%
• There are some 'internal' GPOs, or cooperations, maybe a dozen or a couple of dozen in the country, where a group of investor-owned hospitals does the purchasing as a group. This group operates as a GPO.
• About 1/3 of sales (new and refurbished items) are being sold outside of the GPO, 2/3 through the GPO
  ○ Cores:
    • Trade ins come from their own sales organization or through brokers, never directly from the competitor
  ○ Operational challenge:
    • Getting sufficient cores, they do not have enough inventory

• To be continued on Monday 8/29:
• Customers for refurbished:
  ○ The typical customer is a lower volume institution, looking for a 'bread and butter device', that is interested in turning patients, not cutting edge technology, an outpatient hospital, a small community hospital
  ○ Most equipment is about ~5 yr old technology
  ○ 0% of the refurbished items are going overseas. OEM3 does not have a global refurbishing program, like others do.
• Brokers
  ○ The brokers are causing serious problems for OEM3
  ○ They sell OEM3 systems and generally (9/10 times) these systems are not installed or serviced by OEM3. The systems are not refurbished according to OEM3 specs
  ○ OEM3 tries to prevent this as much as possible by buying the cores on the market where they can. If an existing customer buys new, they will take the trade-in.
  ○ OEM3 does not sell their own systems to brokers
  ○ They have no more than 2 dozen brokers, but not an approved list.
  ○ There are some brokers that are good refurbishers
- Warranty & service
  - About 80% come with a 1-yr warranty
  - Almost all units sold end up with a service agreement
    - OEM3 does ALL service in-house and does NOT service any non-OEM3 equipment.
- OEMs partly started getting into refurbishing to protect the brand and to protect customer satisfaction, since brand would be damaged by poorly refurbished equipment by 3rd-party refubishers ending up in customers' hands.
- Outsourcing
  - Only some painting is outsourced, all else is done in house
- Life cycle
  - Equipment is just recycled once then it is already 5-6 yrs old, which makes for a ~10-12yr total life cycle
- Question/ challenge for us:
  - What is the price difference that drives the customer to the OEM instead of the third-party broker. This would be interesting for both the broker and the OEM
    - What is the perception of price and quality when buying from broker and OEM?
  - The pricing issue:
    - To increase the refurbished volume, the install base needs to be increased. When selling new, service is often included and the OEM takes a 1yr hit in service revenue ($100k). The total picture needs to be analyzed:
    - Price of new can be decreased, so that the install base increases and increased service revenue associated with selling refurbished equipment makes up for the price loss and the loss in sales revenue (due to lower price).

**OEM4**

Executive #4 6-22  
Wednesday, June 22, 2011  
1:00 PM

What products are you refurbishing/ remanufacturing?
- All products he sells; cat scanners, MRI, ultrasounds. Products range from $150k to -$3-4M
Does the division outsource any refurbishment/remanufacturing?
- No. Everything done in house
- “OEM4 wants to control quality”

How much does refurbishment contribute/ what part of your business is refurb?
- ~10%, called RF program. OEMs each have their refurbished programs/ brands;

How are you planning to expand the operation? In house or acquisition of partner or outsourced?
- All in house, centrally organized, by product type. 1 type of product or just a few per location/ facility

Who are the customers for the refurbished products?
- Community hospitals, smaller hospitals. Sometimes larger hospitals, especially when they are privately owned

What are the constraints in growing the refurb business?
- Customers; often still feel that they are buying used inferior products

How are you organized operationally? Are the manufacturing and refurb/reman processes integrated or separated?
- Completely separate; separate facilities, organized centrally
- When products arrive, they are updated with new parts/ components like x-ray tubes and software.

This is a growing opportunity; customers get the best bang for the buck, they get a technology that’s still viable.

OEM4 offers same warranty on refurb products as on new products (12 months)

OEM4 does not use specific incentives for their account executives to entice them to sell refurbished equipment. Sales representatives go off of the customer needs and offers refurbished when they see a fit.
Difference between durable capital equipment and supplies:
- Some third party service providers do refurbishing of supplies, OEMs do not
- OEMs refurbish capital equipment

OSU MC does some procurement of refurbished equipment
Since the heart hospital is a quad-level hospital (robotics etc for heart, lung and liver transplant type surgeries), newest equipment is often preferred
Problem: new models introduced by OEMs every 3-4 years, and depreciation is ~7 yrs minimum. Solution is to keep a range of equipment, for example in CT scanners
CT scanners range from $700k-$1.8M
Common practice by HCO1:
- “Recycling” the scanners within the healthcare organization, sending older ones to outpatient clinics and OEM will take the ones that were at the outpatient clinics
  - Take it out of service, OEM will take it and dispose of it
  - OEM will rebuild it and sell it in US
  - OEM will rebuild it and sell it or overseas
  - OEM will refurbish it (on site or at OEMs cite)
  - Old Equipment is donated to biomedical studies for study on animals or to vet hospital

Same ‘swapping out’ practice with magnetic Resonance (MR) devices.
MC recently bought refurbished ‘echo machine’:
- Looks new, most recent software etc
- Stigma attached to it internally
- Warranty from OEM1 is same
- Same maintenance contract
- Saved $50k, only spend ~$100,500

OEMs rebrand refurbished equipment
HCO1 MC bought refurbished radiological equipment and saved ~$250k
At some point OEM stops supporting these units
Equipment often upgraded as part of expansion
Executive #6 7-14
Thursday, July 14, 2011
2:00 PM

- Purchasing process:
  - GPO is typically involved, not only for supplies and commodities but also for
capital equipment
  - GPO (Novation) does the competitive bidding
  - 7 yr contract w/ Novation
  - HCO1 starts with Novation prices, then ends up with better after negotiating
with the vendors directly
  - Many of HCO1's purchases go though Novation
  - If MC wants to buy outside of the GPO, a bid waiver has to be signed by CEO
and they would have to show that the preferred vendor/ product is truly
different
- Small % is refurbished items
  - There needs to be a comfort level with the type of product
  - HCO1 will go through an OEM not a broker
- Purchasing Decision by clinical department/ purchasing/ clinical engineering
- Decision to switch vendors would be made as part of the purchasing process
- HCO1 looking for some form of standardization, but it has it's downsides
  - They have standardized towards one of the OEMs over the years
- Old machines/ equipment:
  - Rerouted to other remote facilities
  - OEM will offer trade-in rebate
  - Brokers are not involved in sell-off
- For some items (example: ~2500 monitors) the MC forms a buying committee of
~20 people, including nursing staff, clinical enginerring, purchasing, pharmacy, IT
  - 3 vendors part of GPO, but put it out for bid since other vendors might have
different technology
- They do not have the resources to do this process for all
- Basically, GPO produces the vendors

Executive #7 7-18
Monday, July 18, 2011
3:00 PM

- GPO
  - HCO1-MC uses the GPO for most of the purchases
  - Theoretically then can buy outside of the GPO, but would have to do a bid-
waiver and would have to show why the vendor is different / unique.
Is not good for certain groups of products, like implantables, physician preference items

- Since the last 5 years, HCO1-MC has been acting more like a business
- Purchasing:
  - Digital imaging: CT scanners are ~$1-2MM and they buy 1-2 per year
  - Rarely buy refurbished
  - They have their own equipment refurbished, as part of a relocation to a different location
  - Capital equipment and implantables forms the largest portion of the purchasing budget
  - They do a performance analysis of the GPO's performance, which is really just based on price - compare them to benchmarks
- Purchasing process flow:
  1. Requests from anywhere, like clinical dept, go to:
     1. Clinical engineers
        - Check standards and ensure requested equipment fits with equipment already in place
     2. Finance
        - Does it fit in the budget?
     3. Departmental approvals
        - By business units, like CT unit, MRI unit. Budgets are at this level
     4. Administration level approval
        - For aggregate department budget sign off
     5. CEO
        - For large purchases
  - After these steps, purchasing gets involved
    - Sometimes they get involved earlier, to do needs specification
    - Purchasing comes up with suppliers with the clinical engineering group
    - OEMs do not just interact with purchasing, also with clinical engineering and especially higher level administration
- Challenge:
  - How to distinguish the need from the want
    - How useful is equipment that is desired by physicians?
    - Buyers do not always have the expertise to make this distinction
  - Along with this:
    - Buying refurbished only works if the physician is interested in saving money
- Random items:
  - Buying refurbished digital imaging equipment is rare at HCO1
  - GPOs do well with commodities - it is reasonable and feasible to buy more standard commodity type items through the GPO
- They have looked at leasing but rarely do it. It adds more cost to the acquisition.
- OEM will offer rebates for trade-ins, both their own and competitor products
- OEMs are NOT driving refurbished items
- **Purchasing environment compared to conventional setting:**
  - Purchasing in the medical industry is different
  - OEMs dictate in healthcare
  - In automotive for example, the car makers (buyers) have the power, dictate
  - In healthcare, each hospital buys just a very small portion of the OEM’s revenue
  - There seems to be an oligopoly
  - The GPOs have organized the buyers and the suppliers

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**Executive #6, 9-2**
Friday, September 02, 2011
3:00 PM

- **Brokers/ dealers**
  - HCO1 does sell trade ins to brokers occasionally. In the past they used a leasing firm that also refurbished. This firm since then sold off the medical equipment refurbishing business

- **MD buyline**
  - Subscription based service. Shows how much each member paid for each piece of equipment, close to real time. The market is thus efficient.
  - Since this feature is available to all the OEMs' customers, it is helpful for them to disguise the discounts they give on new equipment in the trade-in. This is just another reason why OEMs are always interested in getting back their equipment, or even the competitor’s equipment. The trade in price can be used to show a high(er) new equipment price.

- **GPOs**
  - GPOs are used for among others these reasons:
    - To access the discount
    - To be compliant with the state mandated bidding process (competitive bidding needed for purchases >25k)
    - No need to develop RFQ/ RFPs in house; "it's hard to do a good RFP. If you set the specs too high, no one will meet them. If you set them too low, you might end up with someone you do not want." Thus it saves labor and it is easier.
    - Reduces time it takes to be able to place an order. It would take 3 extra months to place an order without the GPO, if specs had to be written.
• Buying refurbished:
  ○ Want the very best for the ER, than perhaps one level down for main hospital, than further down to the remote facilities.
  ○ Executive takes grieve from docs when he buys refurbished.
  ○ Current state of the art is important for HCO1. Often times refurbished equipment is one generation (3-4 years) older.
Appendix B: Questionnaire
Appendix B: Questionnaire

<table>
<thead>
<tr>
<th>Item</th>
<th>Abbreviated question</th>
<th>Mean</th>
<th>Standard Deviation</th>
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<tr>
<td><strong>Cooperation with OEM</strong></td>
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<tr>
<td>oemcoop1</td>
<td>Our relationship with the OEM is better described as &quot;cooperative&quot;.</td>
<td>5.47</td>
<td>1.03</td>
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<td>oemcoop2</td>
<td>We perform well together.</td>
<td>5.56</td>
<td>0.86</td>
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<td>We share detailed and timely information with the OEM to enable them to improve their planning and operations.</td>
<td>4.93</td>
<td>1.12</td>
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<td>oemcoop5</td>
<td>Joint continuous improvement efforts (in purchasing or service for example) are conducted.</td>
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<td>Dispute resolution is open and constructive.</td>
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<td>1.06</td>
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<td><strong>Commitment to OEM</strong></td>
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<td>oemcomm1</td>
<td>Our HCO is loyal to the OEM.</td>
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<td>oemcomm2</td>
<td>Our HCO sees this relationship as a partnership.</td>
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<td>Our HCO is committed to the preservation of a good relationship with the OEM.</td>
<td>5.23</td>
<td>1.03</td>
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<td><strong>Cooperation with GPO</strong></td>
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<td>We perform well together.</td>
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<td>We share detailed and timely information with the GPO to enable them to improve their planning and operations.</td>
<td>5.25</td>
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<td>Dispute resolution is open and constructive.</td>
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<td>Our HCO is committed to the preservation of a good relationship with the GPO.</td>
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<td><strong>OEM Performance</strong></td>
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<tr>
<td>oemperf1</td>
<td>Rate OEM on equipment quality</td>
<td>6.20</td>
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<td>oemperf2</td>
<td>Rate OEM on equipment value</td>
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<td>Rate OEM on responsiveness to requests for changes</td>
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<td>oemperf4</td>
<td>Rate OEM on service quality</td>
<td>5.94</td>
<td>0.81</td>
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</table>
oemperf5  Rate OEM on overall performance  5.96  0.66

*Healthcare Organization Performance*

h_perf1  Compared to our competitor(s), our HCO:-is better at holding patient costs down  5.43  1.23
h_perf2  Compared to our competitor(s), our HCO:-is better at attaining high clinical labor productivity  5.18  1.24
h_perf3  Compared to our competitor(s), our HCO:-is better at maintaining high capacity utilization  5.15  1.14

*GPO Performance*

gpoperf1  Rate GPO on performance regarding the competitive bidding process with the OEMs  5.18  1.04
gpoperf2  Rate GPO on service quality  5.20  1.02
gpoperf3  Rate GPO on overall performance  5.24  1.03

*OEM Referent Power*

oem_ref1  We admire the way that the OEM runs their business.  4.28  0.97
oem_ref2  We often do what the OEM suggests because we are proud to be affiliated with them.  3.99  1.10
oem_ref3  We talk up the OEM to our colleagues as a great business with which to be associated.  4.09  1.13

*OEM Expert Power*

oem_exp1  We see the OEM as an expert in the digital imaging equipment market.  5.27  0.98
oem_exp2  We respect the judgment of the OEM's representatives.  4.89  1.01
oem_exp3  Our HCO believes the OEM retains expertise that makes them likely to suggest the proper things to do.  4.91  1.05

*GPO Reward Power*

gpo Rew1  The GPO offers incentives to our HCO when we are initially reluctant to cooperate with a new program.  3.91  1.38

gpo Rew2  The GPO will favor us on other occasions if we go along with their suggestions.  3.67  1.30

gpo Rew3  The GPO offers us rewards so we will go along with their suggestions.  3.39  1.40

*GPO Coercive Power*

gpo_coe1  If we do not do as they ask, we will not receive very good treatment from the GPO.  3.03  1.67

gpo_coe2  If we do not agree with the GPO's suggestions, they could make things difficult for us.  2.73  1.46

gpo_coe3  The GPO makes it clear that failing to comply with their requests will result in penalties against us.  2.67  1.47

*GPO Legal Legitimate Power*

gpo_leg1  The GPO often refers to the terms of our contract to gain compliance on particular suggestions.  3.16  1.60

gpo_leg2  The GPO makes a point to refer to our legal agreement when attempting to influence us.  2.77  1.44
<table>
<thead>
<tr>
<th>ID</th>
<th>Question</th>
<th>Value</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>gpo_leg3</td>
<td>The GPO uses sections of our formal agreement as a tool to get us to follow their suggestions.</td>
<td>2.87</td>
<td>1.47</td>
</tr>
<tr>
<td><strong>GPO Referent Power</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gpo_ref1</td>
<td>We admire the way that the GPO runs their business.</td>
<td>4.69</td>
<td>1.27</td>
</tr>
<tr>
<td>gpo_ref2</td>
<td>We often do what the GPO suggests because we are proud to be affiliated with them.</td>
<td>4.38</td>
<td>1.22</td>
</tr>
<tr>
<td>gpo_ref3</td>
<td>We talk up the GPO to our colleagues as a great business with which to be associated.</td>
<td>4.54</td>
<td>1.42</td>
</tr>
<tr>
<td><strong>GPO Expert Power</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gpo_exp1</td>
<td>We see the GPO as an expert in the digital imaging equipment market.</td>
<td>4.08</td>
<td>1.30</td>
</tr>
<tr>
<td>gpo_exp2</td>
<td>We respect the judgment of the GPO's representatives.</td>
<td>4.74</td>
<td>1.22</td>
</tr>
<tr>
<td>gpo_exp3</td>
<td>Our HCO believes the GPO retains expertise that makes them likely to suggest the proper things to do.</td>
<td>4.72</td>
<td>1.14</td>
</tr>
<tr>
<td><strong>Dependence on GPO</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gpo_dep1</td>
<td>We use multiple GPO's for the procurement of digital imaging equipment. (reverse coded)</td>
<td>4.75</td>
<td>1.72</td>
</tr>
<tr>
<td>gpo_dep2</td>
<td>We use multiple GPO's for services not related to procurement. (reverse coded)</td>
<td>4.78</td>
<td>1.67</td>
</tr>
<tr>
<td>gpo_dep3</td>
<td>How difficult would it be to switch GPOs for procurement of future digital imaging equipment?</td>
<td>4.59</td>
<td>1.61</td>
</tr>
<tr>
<td>gpo_dep4</td>
<td>How difficult would it be to switch providers for services not related to procurement, currently performed by the GPO?</td>
<td>4.36</td>
<td>1.46</td>
</tr>
<tr>
<td>gpo_dep5</td>
<td>% of annual purchasing volume of Digital imaging equipment mediated through GPO</td>
<td>3.52</td>
<td>1.24</td>
</tr>
<tr>
<td><strong>Dependence on OEM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>oem_dep1</td>
<td>We buy digital imaging equipment from multiple sources/vendors. (reverse coded)</td>
<td>2.92</td>
<td>1.39</td>
</tr>
<tr>
<td>oem_dep2</td>
<td>How difficult would it be to switch OEMs for purchasing future digital imaging equipment?</td>
<td>4.20</td>
<td>1.46</td>
</tr>
<tr>
<td>oem_dep3</td>
<td>How difficult would it be to switch providers for the service and maintenance of your digital imaging equipment?</td>
<td>4.24</td>
<td>1.40</td>
</tr>
</tbody>
</table>
Appendix C Profit calculations and analysis
Appendix C Profit calculations and analysis

Profit from refurbished products and service contracts for refurbished products in scenario 1, where all demand is fulfilled from carry-over inventory plus refurbished cores is expressed below. The total profit is the sum of the revenue from the demand for refurbished products and service, minus cost to provide service, collection cost, disposal cost, cores-acquisition cost, refurbishing cost and inventory cost of the remaining inventory after demand is fulfilled.

\[
P_{R_t}(1) = R_{R_t} + R_{Sr_t} - C_{Sr_t} - C_{c_t} - C_{D_t} - C_{A_t} - C_{R_t} - C_{I_t}
\]

\[
= D_t \left[ p_{rt} + \gamma_t \left( \sum_{i=0}^{L_R} (p_{Sr_{t+i}} - c_{Sr_{t+i}}) \right) \right] - \sum_{k=1}^{t-1} c_{c_{t-k}} (\beta_k n_{t-k} + \epsilon_t)
\]

\[
- \sum_{k=1}^{t-1} \delta_{t-k} (\beta_k n_{t-k} + \epsilon_t) c_{d_{t-k}} - \sum_{k=1}^{t-1} A_{t-k} c_{a_{t-k}}
\]

\[
- c_{r_t} \left( \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \epsilon_t) + A_{t-k} \right)
\]

\[
- c_l \left[ I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \epsilon_t) + A_{t-k} \right] - D_t
\]

\[
= D_t \left[ p_{rt} + c_l + \gamma_t \left( \sum_{i=0}^{L_R} (p_{Sr_{t+i}} - c_{Sr_{t+i}}) \right) \right]
\]

\[
- \sum_{k=1}^{t-1} \left[ (c_{c_{t-k}} + c_{r_t} + c_l) + \delta_{t-k} (c_{d_{t-k}} - c_{r_t} - c_l) (\beta_k n_{t-k} + \epsilon_t)
\]

\[
+ A_{t-k} (c_{a_{t-k}} + c_{r_t} + c_l) \right] - c_l I_{t-1}; \text{ for } t = 2,3,\ldots,T; \text{ for } k = 1,2,\ldots,t-1
\]
Profit from scenario 2, where carry-over inventory of refurbished products plus the quantity of refurbished products is not sufficient to fulfill all demand for refurbished products is expressed below. The total profit is the sum of the revenue from the sold refurbished products and service, minus cost to provide service, collection cost, disposal cost, cores-acquisition cost, refurbishing cost and inventory cost of the carry-over inventory. In this scenario, the quantity of sold refurbished product equals the carry-over inventory from period t-1, plus the number of products refurbished in period t.
\[ P_{R_t}(2) = R_{R_t} - C_{R_t} + R_{S_{t-1}} - C_{S_{t-1}} - C_{C_t} - C_{D_{t-1}} - C_{A_t} - C_{I_{t-1}} \]
\[ = p_{R_t} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \]
\[ - c_{R_t} \left( \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \]
\[ + \sum_{i=0}^{L_R} \gamma_t p_{S_{t+1}} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \]
\[ - \sum_{i=0}^{L_R} \gamma_t c_{S_{t+1}} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \]
\[ - \sum_{k=1}^{t-1} c_{c_{t-k}} (\beta_k n_{t-k} + \varepsilon_t) - \sum_{k=1}^{t-1} \delta_{t-k} (\beta_k n_{t-k} + \varepsilon_t) c_{d_{t-k}} - \sum_{k=1}^{t-1} A_{t-k} c_{a_{t-k}} \]
\[ - c_t I_{t-1} \]
\[ = \left( p_{R_t} - c_{R_t} \right) \]
\[ + \gamma_t \left( \sum_{i=0}^{L_R} p_{S_{t+1}} - c_{S_{t+1}} \right) \left( \sum_{k=1}^{t-1} ((1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k}) \right) \]
\[ + \left( p_{R_t} - c_t + \gamma_t \left( \sum_{i=0}^{L_R} p_{S_{t+1}} - c_{S_{t+1}} \right) \right) I_{t-1} \]
\[ - \sum_{k=1}^{t-1} \left( (c_{c_{t-k}} + \delta_{t-k} c_{d_{t-k}})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} c_{a_{t-k}} \right) \quad \text{for } t = 2, 3, \ldots, T; \quad k = 1, 2, \ldots, t - 1 \]
Determining the break-even point between the two scenarios $I_{t-1} + Q_t \geq D_t$ and $I_{t-1} + Q_t < D_t$ provides insight in the importance of the parameters and decision variables in the digital equipment OEM’s refurbishing environment.

$$
D_t \left[ p_{r_t} + \gamma_t \left( \sum_{i=0}^{L_R} (p_{SRT_{t+i}} - c_{SRT_{t+i}}) \right) \right] - \sum_{k=1}^{t-1} c_{ct-k} (\beta_k n_{t-k} + \varepsilon_t)
- \sum_{k=1}^{t-1} \delta_{t-k} (\beta_k n_{t-k} + \varepsilon_t) c_{d_{t-k}}
- \sum_{k=1}^{t-1} A_{t-k} c_{a_{t-k}}
- c_{r_t} \left( \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right)
- c_t \left[ (I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k}) - D_t \right] = p_{r_t} (I_{t-1}
+ \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k})
- c_{r_t} \left( \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right)
+ \sum_{i=0}^{L_R} \gamma_t p_{SRT_{t+i}} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right)
- \sum_{i=0}^{L_R} \gamma_t c_{SRT_{t+i}} \left( I_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k}) (\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right)
- \sum_{k=1}^{t-1} c_{ct-k} (\beta_k n_{t-k} + \varepsilon_t)
+ \sum_{k=1}^{t-1} \delta_{t-k} (\beta_k n_{t-k} + \varepsilon_t) c_{d_{t-k}}
- \sum_{k=1}^{t-1} A_{t-k} c_{a_{t-k}}
$$
Which can be restated as:

\[
D_t \left[ p_{rt} + c_t + \gamma_t \left( \sum_{i=0}^{L_R} (p_{sr_{t+i}} - c_{sr_{t+i}}) \right) \right] - c_t \left[ \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right] \\
= p_{rt} \left( l_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \\
+ \sum_{i=0}^{L_R} \gamma_t p_{sr_{t+i}} \left( l_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \\
- \sum_{i=0}^{L_R} \gamma_t c_{sr_{t+i}} \left( l_{t-1} + \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right)
\]

Which can be reduced to:

\[
D_t \left[ p_{rt} + c_t + \gamma_t \left( \sum_{i=0}^{L_R} (p_{sr_{t+i}} - c_{sr_{t+i}}) \right) \right] \\
= \left[ p_{rt} + c_t + \gamma_t \left( \sum_{i=0}^{L_R} (p_{sr_{t+i}} - c_{sr_{t+i}}) \right) \right] l_{t-1} \\
+ \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k}
\]

Which can be restated as:

\[
p_{rt} \left( D_t - l_{t-1} - \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) \\
+ c_t \left( D_t - l_{t-1} - \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) + \gamma_t \left( \sum_{i=0}^{L_R} (p_{sr_{t+i}} - c_{sr_{t+i}}) \right) \left( D_t - l_{t-1} - \sum_{k=1}^{t-1} (1 - \delta_{t-k})(\beta_k n_{t-k} + \varepsilon_t) + A_{t-k} \right) = 0 \text{ for } t = 2,3,\ldots,T; k = 1,2,\ldots,t-1
\]