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The use of recycled materials in manufacturing: implications for supply chain management and operations strategy

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In this study we explore the implications of using recycled versus virgin materials for supply chain structure and supplier relationships, as well as the broader effects on operations strategy in an evolving sustainable environment. We focus on the corrugated cardboard industry, where vertical integration is common, and non-integrated firms are both customers and competitors of integrated firms. These multiple supplier/customer/competitor relationships provide a complex environment to observe changes in the supply chain with the addition of a reverse supply chain system using recycled materials. Based on the findings from an in-depth case study we posit several propositions related to the use of recycled materials, supply chain structure, supplier relationships, and operations strategy. In summary, because the benefits of the changes in the supply chain and supplier relationships accrue primarily to non-integrated firms, we expect the use of recycled material inputs to be dominated by non-integrated firms, and with decreasing capital costs over time, and the ratio of non-integrated to integrated firms using recycled materials will increase. Further, we expect smaller non-integrated firms to access the market for recycled materials differently from larger integrated firms, with the smaller firms more likely to employ non-price-based means for securing their supply of recycled material inputs. Finally, since non-integrated firms are likely to have different operations strategies than integrated firms, we expect the use of recycled materials to indirectly lead to greater use of non-cost-based operations strategies and facilitate the emergence of new operations strategies in the industry.

Keywords: Case study; Paper industry; Reverse supply chain; Recycling; Supply chain management

1. Introduction

Concerns with the environmental effects of production and product disposal have prompted an increasing interest in management practices and the recovery of used products through reverse supply chain systems. Fleischmann *et al.* (2000) have identified the interaction between forward and reverse supply chain systems, in particular, as an area that requires further attention. Thus, in this study we focus on

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changes in the entire supply chain and operations strategy that result from using recycled versus virgin materials. Although this topic is relevant to any firm for which the use of recycled materials is a viable option, we have chosen the corrugated cardboard industry as the primary context for this study because changes in the supply chain are complex due to the prevalence of vertical integration and multiple supplier/customer/competitor relationships within the supply chain.

The source of recycled material is post-consumer waste (PCW), of which paper, metals, glass, and plastics are the largest categories (Kharbanda and Stallworthy 1990). Prior to the actual recycling process, this material is usually referred to as "used". However, because "used" can also refer to material or products intended for repair or remanufacture, we use the term "recycled" for clarity. More specifically, "recycling denotes material recovery without conserving any product structures" (Fleischmann *et al.* 1997: 3). As the demand for environmentally friendly products has grown, the technology for converting PCW into new products has improved, and more recycling programs have been put in place. As a result, the demand for recycled material and the availability and variety of products with recycled content continues to increase.

The discussion of the benefits and drawbacks of recycling has generally been framed in terms of the recycling program economics and environmental impact. Although recycling programs are often run at breakeven or a loss, it has been argued that the net environmental and societal effects are generally positive (Kharbanda and Stallworthy 1990, Ackerman 1997, Denison and Ruston 1997) with some exceptions (Bloemhof-Ruwaard *et al.* 1996). While the profitability of the recycling programs themselves (usually run by municipalities) may be marginal or negative, companies that convert the recycled material into products benefit economically because their manufacturing costs tend to be lower than if they used virgin materials (Kharbanda and Stallworthy 1990). However, in this study we look beyond the direct economic and environmental effects of using recycled materials. Our purpose is to examine how the use of recycled material affects the pre-existing forward supply chain system and the operations strategy of these manufacturers.

To explore these supply chain management and operations strategy issues, we conducted interviews of managers at a Midwestern containerboard paper mini-mill (henceforth, referred to as PaperCo) and managers at three other mini-mills. Containerboard is used in the production of corrugated cardboard boxes. It includes both linerboard that is used for the outside layer of the box and corrugating medium that is used for the inside fluting.

There are several reasons for examining a mini-mill to see how the addition of a reverse supply chain system using recycled materials affects the overall supply chain structure, supplier relationships, and operations strategy. First, mini-mills use recycled fiber [i.e. old corrugated cardboard or (OCC) as raw material, in contrast to conventional containerboard mills that primarily use virgin fiber from lumber]. Second, containerboard manufacturing is an intermediate link in the corrugated cardboard industry value chain that includes vertically integrated (i.e. lumber, containerboard manufacturing, and corrugated cardboard manufacturing) and non-integrated (i.e. corrugated cardboard manufacturing only) firms. The vertically integrated firms ("integrateds") are suppliers of containerboard to non-integrated corrugated cardboard manufacturers ("independents") *and* are their competitors in corrugated cardboard markets. Thus, when an independent adds a mini-mill, the supply chain structure and supplier relationships become more complex. Third, the technology and economics of mini-mills are relatively uniform across the firms. Fourth, because OCC and lumber are both commodities and the two main sources of fiber to the corrugated cardboard industry, their markets are better understood. The third and fourth reasons suggest that a case study, with interviews of managers and other personnel at mini-mills of both integrated and independent firms, will bring out key issues to help examine the factors that influence business managers and their decisions. Further, because markets for and industries that use recycled materials have many similarities, we will argue that our insights from the case may be relevant to other recycling industries.

The significance of this research involves not only the insight gained from an in-depth case study, but an improved understanding of typically complex relationships within forward and reverse supply chains. To date, there is a dearth of information regarding how forward supply chains are affected or change due to the introduction of a reverse supply chain. Further contributions of this study can be found in identifying and explaining relationships between key constructs through the application of qualitative data collection and analysis, and the development of testable propositions as an early foundation for later empirical work in the field of environmental management and reverse supply chain systems.

The paper is organized as follows. Section 2 is a review of the literature on reverse supply chains, focusing on the implications of using recycled materials. We discuss the placement of our study within the existing literature and how our research attempts to fill a gap in the literature. Section 3 provides the study context with descriptions of the mini-mill concept and structure of the corrugated cardboard industry supply chain. In section 4 we discuss our research methods. Section 5 presents the PaperCo case study and interviews of managers at three other mini-mills, concentrating on changes in the structure of the overall supply chain and supplier relationships following the addition of a mini-mill. Based on the case study findings, in section 6 we then posit a number of propositions about how the use of recycled materials affects the supply chain structure, supplier relationships, and operations strategy. In section 7 we state our conclusions, limitations, and directions for future research.

2. Literature review

Research on sustainable supply chain management includes general categories such as: (1) evaluating current or potential suppliers' environmental practices (e.g. Johannson 1994, Handfield *et al.* 1997, Bowen *et al.* 2001, Klassen and Vachon 2003); (2) environmental risks, economic benefits, and economic drawbacks of establishing a green supply chain (e.g. Allenby 1993, Wu and Dunn 1994, Min and Galle 1997, Narasimhan and Carter 1998, Bowen *et al.* 2001, Flowers and Linderman 2003); and (3) reverse supply chains (e.g. Fleischmann *et al.* 2000, 2001, Vachon *et al.* 2001, Guide and Van Wassenhove 2002, Prahinski and Kocabasoglu 2006). While the literature cited is not all-inclusive for the domain of sustainable supply chain management, it does help to demonstrate a diverse set of environmental management issues in this growing field of research. Our study falls in the third category and is more narrowly focused on examining the affects of recycled materials on existing supply chain systems. Next, we present a more detailed discussion of reverse supply chains, and the use of recycled materials in manufacturing, supply chain management, and operations.

2.1 *Reverse supply chain systems*

Reverse supply chain systems enable the recovery of used materials and products and have both environmental and non-environmental implications for operations management. Recovery networks link a "disposer market" of used products available for repair, remanufacturing, or recycling with a "reuse market" which reflects the demand for these products (Fleischmann *et al.* 2000, 2001). When products are recovered by an Original Equipment Manufacturer (OEM), forward and reverse supply chain networks are often intertwined (Purohit 1992, Graedel and Allendby 1998, Fleischmann *et al.* 2000, 2001). Recent research involving OEM remanufacturing has examined the strategic and economic issues involved with the decision of whether or not to even establish a recovery network (Guide and Van Wassenhove 2001), or how to manage the recovery network when faced with competition from independent re-manufacturers (Majumder and Groenevelt 2001). In general, Fleischmann *et al.* (2001) find that coordinated design of the forward and reverse supply chain networks is advisable when there is a large geographical separation between the disposer and reuse markets, significant differences in their cost structures, and high return volumes.

In reverse supply chain systems for recycled material, material does not necessarily flow backwards through the same forward supply chain members, because the sources of the recyclable material (e.g. consumer, industrial user) or intermediaries often perform the initial sorting, storing, and transporting functions (Pohlen and Farris 1992). More broadly, reverse supply chain systems are often designed after and separately from existing forward supply chains (i.e. outbound logistics from manufacturer to customer) with the pre-existing supply chain structure assumed to be basically unaltered (e.g. Pohlen and Farris 1992, Carter and Ellram 1998, Rogers and Tibben-Lembke 1998, Krumwiede and Sheu 2002). This is typically the case with reverse supply chain systems for recycled material because the actors often differ in the forward and reverse systems (Fleischmann *et al.* 1997). In general, greater uncertainty in the timing, quantity, and quality of product returns often drives the decoupling of the forward and reverse supply chain systems (Thierry *et al.* 1995, Guide 2000, Tibben-Lembke and Rogers 2002). In other cases, the reverse supply chain system may be integrated with the existing system or designed concurrently, often to leverage existing processes and minimize incremental costs (e.g. Fleischmann *et al.* 2001, van Hillegersberg *et al.* 2001, Guide *et al.* 2003, Ketzenberg *et al.* 2003, Krikke *et al.* 2004, Seitz and Peattie 2004). This is more frequently the case for remanufacturing and re-usable item networks than recycling networks, with each type of network having its own characteristics (Fleischmann *et al.* 2000). While integrating a reverse supply chain system with a forward system results in changes to the existing supply chain structure (Fleischmann *et al.* 2001), in this study we examine *how* the existing forward supply chain system is affected and changed due to the addition of a reverse supply chain system.

2.2 *The use of recycled materials in manufacturing*

In this study we focus on firms in a reverse supply chain system and start by discussing the use of recycled materials as inputs to their manufacturing processes. One key factor affecting the use of recycled materials is the availability of PCW. The primary sources of recyclable materials are municipal and industrial recycling collection programs, which have been growing steadily over time (Kharbanda and Stallworthy 1990, Ackerman 1997, Butler and Hooper 2000). For example, 27 percent of US municipal waste was recycled or composted in 1995 versus only 9.6 percent in 1980 (Denison and Ruston 1997).

Another factor affecting the use of recycled materials is that the cost to convert them to new products is often less than the conversion cost using virgin materials (Butler and Hooper 2000, Fleischmann *et al*. 2001). For example, energy costs for producing metals using scrap material are much lower, with the savings in energy costs for manufacturing aluminum at 94 percent (Kharbanda and Stallworthy 1990). Steel mini-mills that melt scrap iron do not require the same level of investment – coke ovens, iron ore sintering facilities, blast furnaces – as conventional steel mills, greatly reducing capital and operating costs (Crandall 1996). Similarly, paper mini-mills have lower capital and operating costs than conventional mills because the separation of cellulose fibers from wood has already occurred (Denison and Ruston 1997). Because much of the negative environmental consequences of aluminum, steel, paper, and glass production stem from the initial processing of the virgin materials, environmental regulations and their associated costs are very high for manufacturers using virgin materials. On the other hand, manufacturers using recycled materials can significantly reduce forms of pollution and are subject to a fraction of the environmental regulations and costs of their virgin material counterparts (Kharbanda and Stallworthy 1990). The cost and environmental advantages of using recycled materials help explain the rapid introduction and growth of mini-mills in several industries (Kharbanda and Stallworthy 1990, Crandall 1996).

It is worth noting that some research has shown that the use of recycled versus virgin materials is not always optimal from a life cycle perspective (see Bloemhof-Ruwaard *et al*. 1996, for a discussion of the European paper and pulp industry and implications of recycled materials not lasting as long as virgin materials). However, this study focuses on firms that do realize lower capital and operating costs from using recycled versus virgin materials and explores the subsequent changes in the supply chain structure and supplier relationships with their use.

2.3 *The use of recycled materials and supply chain management*

"Make or buy" is one of the most basic decisions in supply chain management. Supply chain researchers and practitioners have found that strategic outsourcing (i.e. the decision to buy rather than make) may be driven by the potential for lower costs, higher quality, shorter lead times, and greater flexibility (Harrigan 1985, Cavinato 1992, Magretta 1998, Narasimhan and Jayaram 1998). However, this literature does not typically address the issues of market power and concentration regarding the choice of recycled versus virgin material inputs. The choice of using recycled materials has a significant implication for the make/buy decision.

These issues are specifically addressed in the literature on vertical integration, a discussion of which follows.

The impact of adding a reverse supply chain system using recycled materials is complex in an industry in which competitors at one level of the value chain may also be suppliers of virgin materials at another level. For example, non-vertically integrated corrugated cardboard manufacturers purchase containerboard primarily from vertically integrated firms that produce both containerboard and corrugated cardboard products. These supplier/competitor relationships create imbalances in market power, often to the detriment of non-integrated firms operating within the industry. Moreover, opportunities for non-integrated firms to backward integrate into containerboard manufacturing using recycled materials reduce the dependency of these firms on their competitors for their source of raw material, changing both the overall supply chain structure and the nature of the supplier relationships.

According to Porter (1980) and Harrigan (1985), imbalances in market power can result from conditions that give suppliers more bargaining power than their customers. Applying Porter's reasoning to the case of vertically integrated suppliers of virgin materials (or an intermediate product made from the virgin materials – e.g. containerboard made from lumber) selling to non-vertically integrated buyers within the same final goods (e.g. corrugated cardboard) industry, the explanations for this imbalance include: first, the virgin materials are often controlled by a few companies. Second, prior to the introduction of new technology to convert PCW to new products in a cost-effective manner, substitute (i.e. recycled) materials were not economically viable. Third, much of the production of PCW or intermediate products made from the material is for the integrated firm's own use, and non-integrated companies are relatively unimportant to their suppliers. Fourth, the integrated's product is critical to the independent's business.

From the perspective of the non-integrated firm, the opportunity to offset the bargaining power of the integrated suppliers is a motivation to backward integrate. In fact, Porter (1980) argues that offsetting the bargaining power of the integrated suppliers can be so beneficial to the non-integrated firm that vertical integration should often be done even if there are no other direct cost savings from integration. Benefits of offsetting the bargaining power of integrated suppliers through backward integration can include lower costs or higher profits through greater efficiencies and/or by adjusting prices of the intermediate and final products. Another benefit of vertical integration, of particular importance to non-integrated companies in the corrugated cardboard industry where shortages of containerboard occur with some frequency, is that firms can integrate backward to ensure supply of high demand materials in order to avoid rationing of those materials (Porter 1980, Mahoney 1992).

The preceding discussion suggests that the relationship between integrated and non-integrated firms in this industry provides the motivation for backward integration into containerboard manufacturing by the non-integrated firms. To the extent that this backward integration occurs, the supply chain structure is altered. The resulting reduction in the bargaining power by the integrated supplier/competitor firms has implications for buyer-supplier relationships. More specifically, the motivation for backward integration is rooted in the concentration of virgin material resources by the integrated firms. However, similar concentration of virgin material resources exists in other industries, such as the steel industry, in which recycled materials are used. Although not explicitly addressed in this study, the concentration of virgin material resources and subsequent introduction of recycled materials into the supply chain may merit examination for analogous effects on supply chain management in other industries that share this characteristic.

One of the strategic benefits of backward integration is the ability to differentiate (in this case, facilitated by the use of recycled materials) (Porter 1980, Harrigan 1983). In the PaperCo case study that follows, we examine the implications of the use of recycled materials on operations strategies.

In summary, we deduce from the literature that the addition of a reverse supply chain system using recycled materials is likely to impact overall supply chain structure, supplier relationships, and operations strategy. In the PaperCo case study, we examine these issues in the context of an industry that is highly vertically integrated because we expect the changes to be marked, for reasons discussed earlier. However, to the extent that the root causes of these changes, such as the concentration of virgin material resources, are found in other industries that use recycled materials, these potential impacts may be worth investigating there as well.

3. Study context

3.1 *Containerboard mini-mills*

At the turn of the century, US total containerboard production was approximately 35 million tons, of which over four million tons were made from recycled materials, primarily OCC (Shaw 2000). Even as 2.2 million tons of containerboard capacity was lost in 1999 through the shutdown of conventional mills, recycled linerboard production produced in minimills rose 10.5%, reflecting the tremendous growth in the use of recycled materials in the corrugated cardboard industry. Consumers of containerboard include 15 integrated firms operating in the US with a total of 524 plants producing corrugated cardboard products and 647 independent firms with 832 plants (source: Fiber Box Association, June 10, 2004).

Using recycled materials, mini-mills usually produce only one type of containerboard (either linerboard or corrugating medium), which greatly simplifies facilities and process design and reduces capital and operating costs. This allows mini-mills to operate profitably at relatively small volumes, typically about 400 tons per day (tpd). As of 1993 the average cost to build a mini-mill was $60 million versus over $1 billion for an economically viable conventional mill (Kinstrey 1993, Young *et al.* 1993, Patrick 1994).

The economic benefits and capital structure of mini-mills have allowed typically smaller, independent corrugated cardboard manufacturers to backward integrate into containerboard manufacturing (Kinstrey 1993, Young *et al.* 1993). Additional environmental concerns make it virtually impossible to get a permit to add containerboard capacity using virgin materials, and new capacity is primarily based on the mini-mill concept (Shaw 2000). Unlike conventional mills, mini-mills can be brought on-line in a short period of time (often less than a year), and investors can realize a quick return on their investment, which is especially important to the smaller, less well-capitalized independents. The option of backward integration into containerboard manufacturing is attractive to many independent corrugated cardboard manufacturers who want more control of their reverse supply chain and prices because the markets for containerboard are cyclical. In this industry, shortages and price increases occur every five years on average (Shaw 2000).

Although independent corrugated cardboard manufacturers can increase their degree of vertical integration by adding a mini-mill, we will refer to them as independents to distinguish them from integrateds that own conventional mills and lumber. While most early mini-mills were owned by independents, integrateds soon followed. Although the economic benefits of mini-mills accrue in the same way to integrateds as to independents, there are at least two additional considerations unique to integrateds. First, a mini-mill may be a defensive response to maintain market share in the local area (Young *et al.* 1993). Second, integrateds may also use the mini-mill concept to add additional capacity.

The previous discussion suggests that the benefits of building and operating a mini-mill are similar for independents and integrateds. In the next section we discuss the availability of recycled materials and the different implications for independents and integrateds.

3.2 *Corrugated cardboard industry supply chain structure*

Based on the observations of the authors, the availability of recycled materials has affected the supply chain structure in the corrugated cardboard industry in two ways. First, the much lower capital costs of mini-mills have allowed independents to backward integrate into containerboard manufacturing, which means that formerly independent corrugated cardboard manufacturers are no longer dependent (or *as* dependent, depending on the degree of vertical integration) on the integrateds to supply their containerboard. Second, the sources of OCC (e.g. municipalities, grocery store chains) are outside the corrugated cardboard industry, which further diminishes the previous supplier/competitor power relationship between integrateds and independents.

We next discuss the research methods before presenting information from several firms in our study and the resulting propositions to help position further research in this area.

4. Research methods

The purpose of this study is to examine a reverse supply chain issue that has not been previously addressed in the literature, namely, how the use of recycled versus virgin materials affects the supply chain structure, supplier relationships, and operations strategy. While much has been done in the general area of reverse supply chain systems design (e.g. Thierry *et al.* 1995, Fleischmann *et al.* 1997, 2001, Dowlatshahi 2000, Guide 2000, Ferrer and Whybark 2001), little research exists regarding the more narrowly focused implications of using recycled raw materials – which typically involves a separate reverse supply chain system – on the forward supply chain and operations strategy.

Because we were unable to find a well-developed set of theories regarding this particular branch of knowledge, Eisenhardt (1989) and McCutcheon and Meredith (1993) suggest that theory-building can best be done through case study research.

Consistent with this, much of the research in "reverse logistics and reverse supply chains" has been case-based (e.g. Thierry *et al*. 1995, Fleischman *et al*. 2000, Guide *et al*. 2003, Blackburn *et al*. 2004, Seitz and Peattie 2004), although Fleischmann *et al*. (2000) have suggested additional case study research in product recovery supply chains. The method followed in this study was similar to the grounded theory development methodology suggested by Glaser and Strauss (1967), Miles and Huberman (1994), and Yin (2003). While causality cannot be shown in case studies, analysis of data collected from field research can help support the development of theory and the generalizability of results.

Klassen (1995) and Logsdon (1985) determined that industries subjected to environmental regulation for many years, such as the steel, paper, pulp, or petroleum industries tend to have very standardized environmental practices through contact with industry associations. Environmental practices may include not only internal environmental practices, (e.g. Design for Environment, Environmental Management Systems, or Environmentally Responsible Manufacturing) but also external environmental practices (e.g. Sustainable Supply Chain Management, Reverse Logistics, or Closed Loop Supply Chains). Thus, the use of an in-depth case study, along with interviews with other mini-mill executives, is likely to raise the major issues associated with mini-mills and their effect on the supply chain.

The researchers in this project relied primarily on the methods of qualitative data analysis developed by Miles and Huberman (1994), which consists of anticipatory conceptual model development and simultaneous data collection, reduction, display, and conclusions testing. After taking the above steps, the authors went back to the literature to look for similar frameworks upon which to build. Multiple interviews were used in order to provide a broader taxonomy of supply chain implications.

The interview protocol was developed based on the researchers' understanding of environmental and supply chain issues facing the industry, in general, and the corrugated cardboard industry specifically. In this study we focus on the supply chain issues raised during the interviews. The protocol was pre-tested with a general manager, V.P. of operations, and a CEO in the industry. The pretest consisted of first mailing the protocol and then interviewing these individuals by phone and face-to-face regarding the appropriateness and clarity of the questions. They provided both written and verbal comments that helped to validate the appropriateness of the protocol. Where necessary, a few structural changes were made to the protocol after the pre-test.

Next, travel arrangements were made and schedules set at multiple facilities. A single industry and firm context was chosen for several reasons. While validity is easier to achieve in a cross-industry study, much of the work in a growing field of research involves a single industry. A single industry/firm fit well with qualitative research as the researchers wanted to work with small samples of people within a specific context and study both the people and the business in-depth. This approach to our sample was both convenient, as one of the researchers was very familiar with both the industry and the firm studied, and purposeful in that it is also theory-based (Miles and Huberman 1994), with the opportunity to expand on a growing body of knowledge. Interviews were conducted in the respondents' facilities during the summer of 2002, and discussions focused on: the consideration of recycled raw material factors as an important part of processes, the factors affecting supply chain projects, tools used, metrics, perceived environmental opportunities, and changes in supply chain structure and supplier relationships following the opening of the mini-mill. Sample questions from the interview protocol most relevant to this study are included in the appendix.

When conducting the interviews, two researchers were present so that both could collect data and cross-check notes after interviews were done. Different managers were questioned individually at several sessions scheduled over three days. The same structured interview protocol was used at each session. Follow-up questions to clarify and elaborate on the responses were added when necessary. After the interviews were finished, any additional follow-up questions were conducted over the phone. When the sessions involved multiple respondents, all comments or views of the managers were recorded separately. Subsequent coding of the notes and summarizing in a meta-matrix was done to highlight any differing views of the managers.

Following each interview, the field notes were typed. To facilitate data coding and reduction, a meta-matrix display was constructed to summarize the major findings at each site (Miles and Huberman 1994). The researchers reviewed the transcribed field notes for all interviews at least three times.

5. Case study

Figures 1 and 2 show the supply chain structure and relationships between an integrated and independent firm prior to and following the adoption of mini-mills. In both figures a border denotes the boundary of the firm. In figure 1, prior to the introduction of mini-mills, the independent corrugated cardboard manufacturer (CorrugatedInc, in our study) was completely dependent on the integrated firm for its supply of containerboard, yet at the same time was a competitor with the integrated firm in the corrugated cardboard market. In figure 2, following the adoption of a containerboard mini-mill, the independent firm backward integrates and is a supplier of containerboard, not only to itself, but also possibly to other integrated or independent firms in the industry. Moreover, because the materials (primarily OCC) for the containerboard mini-mills come from outside the firms' boundaries, neither firm is completely dependent on the other for their raw materials. These changes in supply chain structure and relationships may be in contradiction to models in the literature that assume the pre-existing forward supply chain is basically unaltered following the addition of a separate reverse supply chain system (Pohlen and Farris 1992, Carter and Ellram 1998, Krumwiede and Sheu 2002).

For the rest of this section we present a case study of PaperCo, a mini-mill owned by an independent corrugated cardboard manufacturer, to explore the implications of these changes in the overall supply chain. In addition, the strategic impacts of using recycled material through the addition of the PaperCo mini-mill are examined.

PaperCo is a business unit of a privately held firm (henceforth referred to as CorrugatedInc) that produces corrugated cardboard boxes and sheets in a large Midwestern city. The mini-mill is located in a small town about 40 miles from CorrugatedInc's corrugated cardboard manufacturing facilities and near concentrated sources of OCC. PaperCo has a daily production of about 400 tons of linerboard.

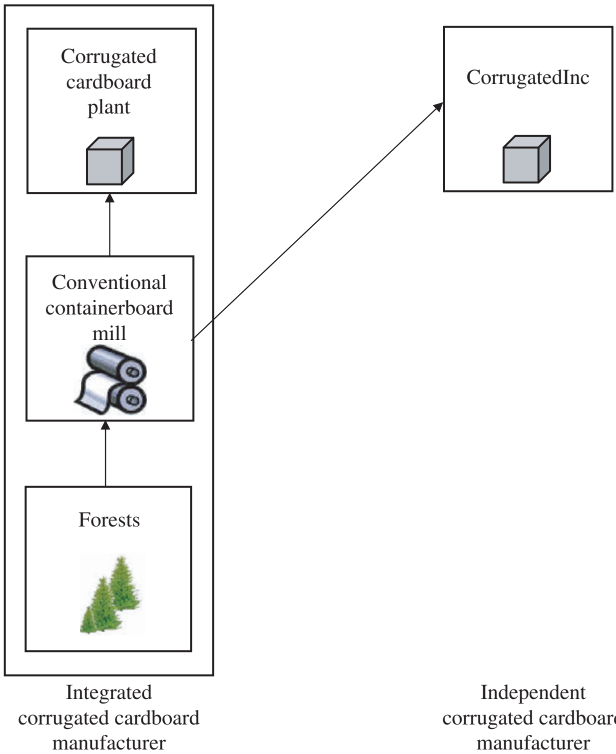
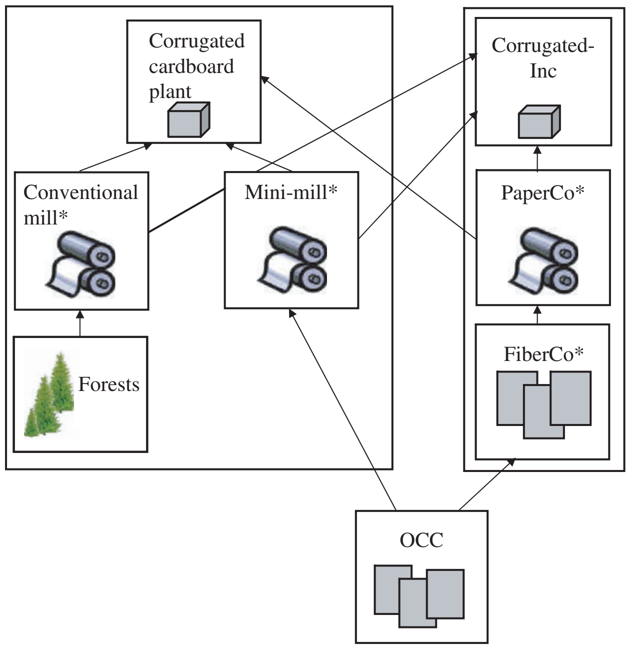


Figure 1. Supply chain relationships without containerboard mini-mills.

To gather internal information for the case, we interviewed the CEO of CorrugatedInc (respondent A), the General Manager of the fiber procurement business unit, FiberCo (respondent B), and several PaperCo managers (respondents C through H). In addition to the interviews for the in-depth PaperCo case study, we also conducted phone interviews with managers at three other mini-mills to explore the main strategic and supply chain issues addressed in this case study. Respondent I is an executive from an independent firm; respondent J is an internal management consultant who works within an integrated firm; and respondent K is the director of supply chain management for containerboard products for an integrated firm. Detailed information about the interview subjects can be found in table 1.

Contrasting responses, clustering of responses, and general comparisons allowed for content-analytic summary tables (Miles and Huberman 1994). Our analysis of the field notes led to early conclusions about the data that has been verified (with follow-up phone calls) by respondents within PaperCo and within the industry. Checking our conclusions against the original field data, following up with respondents and clarifying the conceptual importance of the conclusions all help lead to more reliable insights from this study. This approach is similar to the procedures for exploratory case studies as outlined by Glaser and Strauss (1967) and is commonly cited as a part of hypothesis generation (Yin 2003). Our approach to data collection and analysis sets the stage for the following discussion of our findings and the case-based propositions generated in section 6 of this study.



Integrated corrugated manufacturer (conventional containerboard mill and mini-containerboard mill)

Independent corrugated cardboard manufacturer with containerboard mini-mill

*Conventional mills and mini-mills are also suppliers to other independents.

Figure 2. Supply chain relationships with containerboard mini-mills.

For each individual interviewed, we asked background information and standard questions (see Appendix). We also asked questions specific to the position of the interview subject. For example, the CEO spoke about his strategic vision for the mini-mill within CorrugatedInc. The other interview subjects were then asked about their understanding of the strategic vision for PaperCo. Finally, we ended the interview by asking if there were any other issues the interview subject would like to discuss. We were impressed by the consistency of responses across interview subjects, in particular with respect to the strategic vision and implementation.

5.1 *Company history*

Until the addition of the mini-mill, CorrugatedInc purchased all of its containerboard needs from other containerboard manufacturers, most of which were business units of integrated firms. In terms of tonnage, PaperCo produces enough linerboard to satisfy most of its internal demand. However, PaperCo produces linerboard only, and both linerboard and corrugating medium are needed to make corrugated

Table 1. Position and responsibilities of interview subjects.

Respondent	Position	Responsibilities
A	CEO of CorrugatedInc	
B	Vice President and General Manager of FiberCo	Overall responsibility for procurement of fiber for PaperCo
C	General Manager of PaperCo	Overall responsibility for PaperCo operations
D	Plant Manager of PaperCo	Engineering, maintenance, and production
E	Administration Manager of PaperCo	Accounting, MIS, and purchasing (except for fiber)
F	Sales Administrator of PaperCo	Production scheduling, customer service, sales support, and trading
G	Product Development Engineer of PaperCo	New product development, product support
H	Technical Manager of PaperCo	Process engineering, quality, environmental performance
	Interviews outside of PaperCo	
I	President and CEO of US operations for a Holding Company including an independent corrugated cardboard manufacturer and mini-mill	Overall responsibility for a group of business units including an independent corrugated cardboard manufacturer and mini-mill
J	Engineering Manager and Process Consultant for a mini-mill business unit of large integrated firm	Internal management and process consultant for paper-making processes at a mini-mill
K	Director of Containerboard Logistics for an additional large integrated firm	Overall responsibility for supply chain management and logistics for containerboard products

cardboard. The Sales Administrator explained that PaperCo trades linerboard with corrugating medium manufacturers to achieve the required balance of containerboard materials. Because freight charges are a significant portion of the delivered cost of containerboard, PaperCo will also trade linerboard with linerboard producers in other parts of the country where CorrugatedInc has corrugated cardboard manufacturing facilities. In addition, PaperCo both sells and trades their linerboard with other independents (or corrugated medium manufacturers), and integrateds. While CorrugatedInc sources most of its linerboard from PaperCo or through PaperCo's trades, it also continues to buy containerboard from other suppliers. FiberCo is involved in sourcing secondary materials such as OCC. Figure 2 shows the new supplier relationships between PaperCo's mini-mill and CorrugatedInc as well as between PaperCo and other corrugated cardboard manufacturers (both independents and integrateds).

According to the CEO of CorrugatedInc and respondents B and E, the decision to build a mini-mill was the result of a number of strategic and competitive factors. They cited the desire to be less dependent on their suppliers of containerboard to be the most important reason for building the mini-mill. Dependence on their suppliers of containerboard creates two key problem for CorrugatedInc that are addressed by the addition of a mini-mill. First, during periods of high demand and low supply, suppliers of containerboard institute rationing, satisfying their internal demand first. Thus, independents (including CorrugatedInc) were especially likely to have unsatisfied demand for containerboard, and adding a mini-mill would greatly reduce this problem.

Second, even during periods of sufficient supply, their suppliers were not adequately meeting their needs. As defined by the CEO, CorrugatedInc's corporate and operations strategy is ''outside-in'' (customer pull) rather than ''inside-out'' (production push). Relative to other corrugated cardboard manufacturers, CorrugatedInc stresses flexibility, high value-added services, and customer intimacy in their operations. According to several respondents from PaperCo (A, B, and C), the customer pull approach is in contrast with the dominant mode of operations in the industry (used by respondents J and K at different integrated firms), which is high-volume and low-cost oriented. As a result, CorrugatedInc's containerboard suppliers had more of a production push strategy or, as the CEO terms it, a ''make it and they'll buy it'' philosophy of long, single product production runs, which was not meeting the needs of CorrugatedInc in terms of product mix and delivery characteristics.

Thus, the CEO saw an opportunity to backward integrate into containerboard manufacturing to better meet its own needs. In addition, because independents tend to compete less on cost (due to their smaller size and fewer economies of scale) and more on other competitive dimensions, the CEO saw an opportunity to supply containerboard to other independents in a manner consistent with their needs. According to the Product Development Engineer, most new products introduced by PaperCo are customer-driven, and PaperCo's willingness to develop new value-added products for customers is a tremendous source of competitive advantage. Both the increase in profit potential and decrease in supplier dependence are reflected in the changes from figure 1 to figure 2 in the supply chain structure among the containerboard mills and corrugated cardboard manufacturers.

We now discuss the use of 100% recycled fiber. PaperCo requires 150 000 tons of fiber each year to meet its production needs. However, PaperCo does not directly procure fiber. Instead, CorrugatedInc added a separate business unit, FiberCo, to provide recycled cardboard to PaperCo. In other words, the forward and reverse supply chains are decoupled.

At the time the mini-mill was being built, OCC was priced at \$170–\$200 per ton, which was and is historically very high. Subsequently, the price of OCC fell below \$50 per ton. As with standard grades of containerboard, OCC is considered a commodity, with significant fluctuations in prices that are set in the open market. Because OCC is a significant portion of the product cost, it's price variability contributes to wide swings in the profitability of the mini-mill.

At first, FiberCo would obtain OCC from as far away as 500 miles. However, similar to containerboard, because OCC costs are set in the open market (although OCC purchasers can and do deviate from the market prices), differences in the delivered cost of OCC are primarily associated with freight charges. Thus, FiberCo tries to obtain OCC from suppliers within a 150-mile radius of the mini-mill.

To meet the needs of PaperCo, FiberCo must obtain 200 000 tons of OCC per year out of the approximately 1 million tons available in its target area. However, other mini-mills in the area compete for OCC, including a larger mini-mill located about 100 miles from PaperCo that is owned by an integrated firm. Thus, FiberCo has instituted a number of procurement policies that allow it to compete effectively for the available OCC. First, generators of OCC consider it to be a waste product, and they typically want it taken off their hands as soon as possible. According to the General Manager of FiberCo., unlike many larger publicly traded companies that do not want to hold the OCC on their balance sheet (arguably, because it depresses return on assets), FiberCo is willing to obtain the OCC as soon as it is available. In fact, some generators will accept a lower price for this "guaranteed take." In addition, FiberCo will accept unbaled OCC, which costs less, while larger mini-mills require the OCC to be baled. Overall, FiberCo obtains one-third of its OCC from waste haulers, one-third from processors and brokers, and one-third from industrial, commercial and institutional generators. Although FiberCo has a storage facility about 50 miles from the mini-mill, approximately 75% of the OCC used by PaperCo is shipped directly from the generators to the mini-mill, saving on transportation and holding costs.

Arguably the most important aspect of their procurement strategy is that FiberCo is willing to work with small generators of OCC and has instituted methods to do so in a cost-effective manner. FiberCo has over 500 suppliers of OCC, and a generator that supplies 40–50 tons per month is considered to be a good supplier. This is in contrast with larger firms that won't accept less than 200 tons per month per supplier. Thus, FiberCo focuses on smaller generators, where the competition for OCC is not as intense. FiberCo also realizes that dealing with OCC is not an important issue for most small generators. According to the General Manager of FiberCo, FiberCo tries to be "a mouse in the corner" and take care of the generators' OCC while involving the generator as little as possible. As such, FiberCo installs collection and compressing equipment at the generators' sites and contracts to have the OCC taken away. In some cases, small generators are happy to have their OCC taken away and will charge little or nothing for the OCC itself. FiberCo has not lost an OCC supplier since it began operations, which the General Manager attributes, at least in part, to their methods of working with suppliers.

Summaries of responses within a condensed example of our meta-matrix can be found in table 2. The number of respondents reported for a given protocol question is representative of those that commented on a given question. Any omissions are the result of not talking about a particular protocol item.

6. Case-based insights and propositions

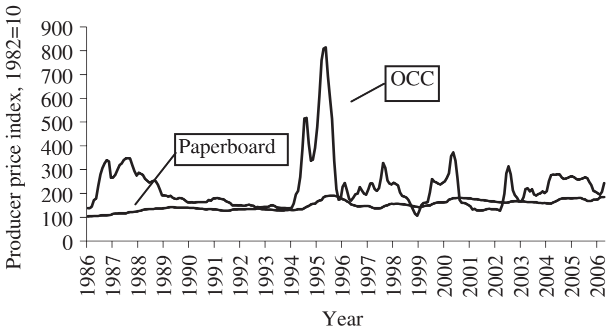
Based on a synthesis of the case study findings and associated literature, we offer a number of insights and propositions concerning implications of using recycled materials for the supply chain structure, supplier relationships, and operations strategy. We state the propositions in the context of the corrugated cardboard industry and then discuss commonalities with other industries that use recycled material.

All firms in the industry can realize lower capital and operating costs from using recycled versus virgin materials. However, the changes in supply chain structure decrease the bargaining power of the originally integrated firms as the opportunity for backward integration becomes available to independent firms (as shown in figures 1 and 2). In fact, as Porter (1980) suggests, even in the absence of any direct savings from integration, offsetting the bargaining power of the integrated suppliers

Table 2. Summary of responses to representative questions.

Protocol questions (respondents)	Responses
Competitive initiatives in this industry? (A, B, C, D, G, I, K)	Current: cost reduction, capacity, market share, reducing supply chain lead times Future: consolidation, providing value-added services for customers, and more vertical integration of industry
Key success factors? (A, B, C, D, G, I, K)	New applications, expanding value-added services such as warehousing and logistics. Respondent I stressed the importance of cycle time, better quality, and scheduling
Marketing strategy? (A, B, D, I)	Independents cannot be the low-cost providers because integrateds have better economies of scale. Instead, they need to be cost competitive while technologically savvy and maintain close relationships with their customers. Products are not marketed as environmentally friendly
Compare the paper industry markets for recycled materials with virgin materials. (B, C, I, K)	The trend has been to transition away from virgin to recycled materials with OCC becoming the primary recycled material
What are the issues associated with buying from integrated manufacturers? (B, C, I, K)	Very structured and tough to deal with, power is not always negotiable
What are the issues associated with buying from vendors of OCC? (B, C, K)	More flexibility, typically dealing with smaller volumes, purity of material
What issues are important for an independent firm to consider when deciding whether to add a mini-mill? (A, B, E, I)	Less dependence on raw material suppliers; become a full-service provider with the addition of this type of facility; better manage their supply chain; competitors successfully developed mini-mills; no competitors of the mini-mill are within 70 miles of the facility, yet waste haulers are only 30 miles away; relationship with energy providers and waste water treatment facility, simplifies environmental compliance issues
What issues are important for an integrated firm to consider when deciding whether to add a mini-mill? (A, E, F, J, K)	Cost, maintain low-cost-provider strategy, regional need for capacity, small-scale production, to use recycled materials
What are the benefits of using recycled boxes (OCC) as materials? (C, D, E, H, J, K)	Safer (no chemicals), less expensive, do not have to harvest trees, no odors, less EPA permitting

can result in a net benefit to the previously non-integrated firm. As discussed in the PaperCo case, the CEO and other interview subjects cited decreased supplier dependence as the primary reason for building the mini-mill. This is in contrast to respondents J and K from integrated firms who cited cost and capacity as the primary reasons for building a mini-mill. The inclusion of respondents J and K in the study provide ‘‘natural controls’’ that allows us to identify systematically different reasons for building mini-mills.



Source: Bureau of Labor Statistics, www.bls.gov, as of May 31, 2006.

Figure 3. Producer price index for OCC and paperboard.

Although the case study demonstrates direct economic benefits from adding a mini-mill, and the existing literature supports potential cost benefits from using recycled versus virgin materials, backward integration using recycled materials is not without financial risk. For example, wide fluctuations in the cost of OCC create conditions under which OCC costs increase dramatically while containerboard prices remain stable or even fall (as described by the General Manager of FiberCo). This is illustrated in figure 3, which is a comparison of OCC and paperboard prices relative to their respective 1982 baseline prices. Our comparison uses paperboard prices because the Bureau of Labor Statistics tracks paperboard (which includes both containerboard and boxboard, the latter of which is used to produce cereal boxes, for example), rather than containerboard prices. Under such circumstances, the profitability and cost advantage of mini-mills decrease considerably. Yet, even with the decreased profitability and higher costs, the independent firms would still benefit from the changes in the overall supply chain structure, with the concomitant increased bargaining power, decreased supplier dependence, and other lower transactions costs. Thus, independents will justify building mini-mills by focusing on the potential benefits from changes in the supply chain structure. This is stated in Proposition 1.

P1: Non-integrated firms using recycled materials to backward integrate will be most likely to justify their actions based on potential benefits from the changes in the supply chain structure and supplier relationships.

Further, because independent firms have reasons other than capital and operating costs for adding mini-mills, we posit that independent firms are more likely to add mini-mills than integrated firms. The corrugated cardboard industry provides a valuable opportunity to examine whether, in fact, this is the case. First, because of environmental concerns, it is virtually impossible to obtain a permit to add containerboard capacity using virgin materials, and new capacity is primarily based on the mini-mill concept (Shaw 2000). Second, independents face the same costs for adding a mini-mill as integrateds and have the option to continue to purchase containerboard rather than produce it themselves. In addition, as discussed previously, a reverse supply chain system for recycled materials is typically designed separately from the forward supply chain system. Potential synergies of designing both a forward and reverse supply chain that may disproportionately benefit either independents or integrateds are lacking. Thus, both independents and integrateds are limited to adding containerboard capacity through mini-mills, and there are few synergies with their existing forward supply chain system. However, differences in the incentive to add a mini-mill are related to the supply chain benefits that accrue primarily to the independents. Thus, we expect these supply chain benefits to result in a disproportionate amount of total mini-mill capacity being added by independent corrugated cardboard manufacturers, as stated in Proposition 2. In essence, this will move the industry more toward the structure shown in figure 2.

P2: Non-integrated firms will be more likely to add mini-mills and use recycled material inputs than integrated firms.

Proposition 3 follows from Proposition 2 and extends this line of reasoning longitudinally. As previously discussed, the relatively low cost of adding a containerboard mini-mill has allowed independent corrugated cardboard manufacturers to backward integrate into containerboard manufacturing. If the capital cost for building a mini-mill continues to decrease, more independents can afford to add mini-mills and realize the supply chain benefits. As a result, we expect the ratio of independents to integrateds using recycled material inputs will increase over time.

P3: With decreasing capital costs over time, the ratio of independents to integrateds using recycled material inputs will increase.

Other industries, such as the steel industry, experience the same lower capital costs by building mini-mills that use recycled materials. However, unlike the corrugated cardboard industry, the steel produced at these mini-mills is an end-product rather than an intermediate product. Thus, to restate P3 for this industry, we would expect the use of recycled raw materials to be dominated by new entrants into an industry, with increasing dominance by new entrants as capital costs decrease over time (P3). While P1 is not directly relevant to new entrants because they are not backward integrating, new entrants have analogous benefits of a supply chain structure that does not require them to rely on a potential competitor for their source of raw materials. While Crandall (1996) attributes the rise of mini-mills and their increasing share of the US steel production to lower labor and capital costs and improvements in electric furnace and rolling technology, an additional explanation of this phenomenon that may follow from our study stems from the potential change in the supply chain structure that allows new entrants into the market because they do not need to rely on the coke and iron ore inputs controlled by integrated steel manufacturers.

Unlike many remanufacturing reverse supply chain systems, in which the original manufacturer can exert some control over the remanufacturing of its own products (by limiting or encouraging independent re-manufacturers and/or engaging in remanufacturing themselves), corrugated cardboard manufacturers have little, if any, control over the recycling of its products. One reason for this difference is that the sources of recyclable materials such as OCC include municipal and industrial recycling programs that effectively decouple the original producers and recyclers of these products. In addition to procuring OCC from these recycling programs, FiberCo also contracts directly with generators, who consider OCC to be waste.

While FiberCo would technically be a "customer" to the generators, the supplier/customer relationship is unusual in the sense that the "supplier" of OCC is selling their by-products rather than their products. Consequently, the generator does not consider itself a producer in the traditional sense and is, therefore, unconcerned with developing a marketing strategy for this "product" (Zikmund and Stanton 1971). Further, as the term "post-consumer waste" implies and the case study confirms, the sources of recyclable materials are highly diffuse. Taken together, this suggests that recycling programs and other generators of recyclable materials are unlikely to have an *a priori* or strong allegiance to any particular OCC consumer firm, and markets for recyclable materials are accessible to both independent and integrated firms.

The availability of recyclable materials for both independent and integrated firms is important as a precursor to the supply chain structure shown in figure 2. Without access to the markets for recyclable materials, opportunities for independents to operate mini-mills would be severely limited, resulting in the status quo as shown in figure 1. The same would be true for potential new entrants into other industries using recycled materials. Moreover, the case study suggests that smaller independents may be accessing the markets for OCC differently than integrateds. In particular, FiberCo focuses on smaller generators of OCC and employs flexible and relationship-centric means to secure their supply of OCC rather than competing entirely on price – as is more characteristic of the larger integrated firms. Differences in the nature of the access to recyclable materials are stated in Propositions 4a and 4b. To the extent that other industries that use recycled materials also have diffuse sources of recycled materials and large differences in the size of the firms within the industry, these propositions may also be applicable.

P4a: Firm and mini-mill size will be positively associated with the average size of their recycled material suppliers.

P4b: Firm and mini-mill size will be negatively associated with the use of non-price-related strategies for securing their supply of recycled material inputs.

In addition to the implications for procurement strategy, as stated in Proposition 4b, the use of recycled materials has broader implications for operations strategy. As discussed in the PaperCo case, one of the reasons CorrugatedInc chose to add a mini-mill was because existing mills were not meeting its needs. Unlike integrateds that focus on high volume and low cost, CorrugatedInc and other independents do not compete primarily on cost, due to their smaller size and fewer economies of scale. Thus, CorrugatedInc's suppliers of containerboard, with a preference for long standard grade production runs, were out of sync with CorrugatedInc's competitive priorities of flexibility, high value-added services, and customer intimacy. By adding a mini-mill CorrugatedInc is now able to supply its corrugated cardboard operations in a manner consistent with its competitive priorities and also be a linerboard supplier to other independents with non-cost based strategies. While previous research has indicated that the primary strategic benefits of green manufacturing are related to marketing products as environmentally friendly or through lower costs, we are suggesting that there are other strategic implications as well.

Because independents are likely to have systematically different operations strategies from the low-cost strategy typical of integrateds, we expect to observe changes in the strategic mix of the industry as more independent firms add mini-mills. In addition to facilitating the expansion of existing non-cost-based strategies, the use of recycled materials and the resulting backward integration by non-integrated firms should allow new strategies to emerge, as stated in Proposition 5. This is also consistent with the vertical integration literature that suggests that backward integration by a particular firm allows it to differentiate its strategy from that of other firms in the industry (Porter 1980, Harrigan 1983).

P5: The use of recycled materials (through the addition of mini-mills) by independent firms will increase the use of non-cost-based operations strategies in the industry.

To the extent that these strategic constraints exist in other industries that use recycled materials, similar strategic outcomes may be expected to result as well.

Based on the summary of information from this case study, some general observations can be made and empirically tested at a later time through data collection, construct development, and testing of the propositions in this study. The researchers' knowledge of the paper industry, a literature review, and the qualitative data collected during this study lead to some of the following insights: (1) the use of recycled materials can change the power relationships among integrated firms' supply chain through the introduction of smaller independent entities that each take a specialized role in the use of recycled materials; (2) integrated firms benefit from economies of scale using virgin materials, but are burdened with a process that cannot utilize recycled raw materials; (3) integrated firms will have more difficulty competing with independent firms specializing in the use of recycled materials when performance is measured by the dimensions of quality, lead time, and flexibility; and (4) these same integrated firms, if they want to utilize recycled raw materials, will have to look at further development of their own infrastructure (introduction of a mini-mill), and/or work with independents as an alternative to the costs of developing their own capacity for utilizing recycled materials.

When managers face supply chain decisions such as those discussed in this study, it is important for both researchers and managers to identify and try to explain relationships between key entities in an industry. In this study, we strive to identify important relationships in supply chains that utilize recycled materials while simultaneously examining how existing forward supply chains are affected and changed due to the addition of a reverse supply chain.

7. Conclusions

Unlike supply chains in which the forward and reverse supply chain systems are integrated, this study addresses the case in which the two systems are designed separately and not solely for environmental benefits. We also examine the implications of using recycled materials on operations strategy with a focus on the corrugated cardboard industry, where vertical integration is common, and non-integrated firms are both customers and competitors of integrated firms. These supplier/customer/competitor relationships provide the ideal environment to observe changes in the supply chain with the use of recycled materials and the complimentary benefits to both firms and the environment.

In contrast with the reverse supply chain literature that typically assumes that the existing supply chain is basically unaltered when the reverse supply chain is designed separately from the forward supply chain system, figures 1 and 2 show the supplier relationships before and after the adoption of containerboard paper mini-mills and how they change as a result of the availability and use of recycled material. In figure 1 the independent corrugated cardboard manufacturer is dependent on integrated firms for their supply of containerboard while also being competitors in the corrugated cardboard market. Figure 2 illustrates the situation where both independent and integrated firms add mini-mills. The backward integration by the independent firm results in important changes in the supply chain structure and supplier relationships. The buyer and supplier relationship has been replaced by a system in which both entities are able to switch roles and also change the balance of bargaining power. Moreover, the use of recycled materials at the mini-mills further decreases the independent firm's dependence on the integrated firm because the source of raw materials is outside the boundaries of either firm. To better understand the implications of these changes we conducted an in-depth case study of PaperCo, a containerboard mini-mill business unit of CorrugatedInc, which is an independent corrugated cardboard manufacturer. The case study was supplemented with interviews of managers at three other mini-mills, one associated with an independent corrugated cardboard manufacturer and two associated with large integrated firms.

Based on the findings from the PaperCo case study, the supplementary interviews, and the literature on reverse supply chains, recycling, supply chain management, and operations strategy, we posited several propositions related to the use of recycled materials, supply chain structure, supplier relationships, and operations strategy. Because the benefits of the changes in the supply chain and supplier relationships accrue primarily to non-integrated firms, managers should expect the use of recycled material inputs to be dominated by non-integrated firms, and with decreasing capital costs over time, the ratio of independents to integrateds will increase. Further, management should expect to see smaller non-integrated firms access the market for recycled materials differently from the larger integrated firms, with the smaller firms being more likely to employ non-price-based means for securing their supply of recycled material inputs. Finally, since non-integrated firms are likely to have systematically different operations strategies than integrated firms, practitioners should expect the use of recycled materials to indirectly lead to greater use of non-cost-based operations strategies in the industry. We then discuss possible implications of these propositions for other process-related industries that use recycled materials.

Because this research is based on an in-depth case study, with additional interviews with managers at other mini-mills, limitations include concerns with generalizability, causality, and lack of larger-scale empirical testing. However, the technology and economics of mini-mills are relatively uniform across the firms, and the information across interview subjects was consistent both within PaperCo and among the different mini-mill managers. Further, because many underlying factors that drive our propositions (e.g. concentration of virgin material resources and general characteristics of the markets for recycled materials) are found in other industries that use recycled materials, we believe these propositions may be applicable and testable in such industries as well. The results of this study should help explain similar, current, and emerging, process-related industries where recycled materials can be used for raw material inputs. In addition, the limited sample size and industries involved restrict the generalizability of our findings. Further, while case study research does not support causality, the research presented in this study does provide the opportunity for the application and further empirical testing of the models and posited relationships regarding vertically integrated industries that use recycled materials. Future research in different industries and larger sample sizes will be needed to quantitatively assess the relationships identified from this research and further substantiate the grounded theory developed in this study.

In summary, we believe that a better understanding of the non-environmental as well as the environmental implications of using recycled materials for supply chain management and operations strategy will further increase the attractiveness and use of environmental management practices and sustainable production. The results of this study help to examine and explain supply chain relationships that are an incremental step toward addressing this important issue.

Appendix

Selected interview protocol

Name and Title of Respondent:

Primary Job Responsibilities:

Primary Product(s) and Customer(s):

What are the major competitive initiatives in your industry (current, and near future)?

What are the key success factors for your firm?

What is your marketing strategy?

Compare and contrast the markets for recycled boxes (OCC) with the markets for virgin material. Are the markets concentrated or diffused for:

- OCC?
- Virgin?

What are the issues associated with buying from:

- Integrated manufacturers? Vendors of OCC?

I want to hear the story of how your firm developed the mini-mill:

- How was this decision arrived at?
- What factors influenced this decision?
- Under what conditions would management change this decision?
- Costs?
- Risks?

Why would an integrated manufacturer build a mini-mill when it has virgin material available? How does capacity management factor in?

What are the benefits/drawbacks of being an integrated manufacturer?

What are the benefits/drawbacks of being an independent manufacturer?

What are the strategic and tactical benefits of using recycled boxes as inputs?

- From an economic standpoint? Environmental? Production? Customer-side? Supply-side?

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