

**The Use of Recycled Materials in Manufacturing:
Implications for Supply Chain Management and Operations Strategy**

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Abstract

In this study we explore the implications of using recycled versus virgin materials for the supply chain structure and supplier relationships as well as the broader effects on operations strategy. We focus our study 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 the ideal environment to observe changes in the supply chain with the use of recycled materials. Based on the findings from an in-depth case study of a containerboard mini-mill and supplementary interviews with three other mini-mill managers, we posit several hypotheses 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, the ratio of non-integrated to integrated firms will increase. Further, we expect smaller non-integrated firms to access the market for recycled materials differently from the 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 systematically 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. We then generalize these hypotheses to other industries that use recycled materials.

(RECYCLING; GREEN MANUFACTURING; SUPPLY CHAIN MANAGEMENT;
OPERATIONS STRATEGY)

1. Introduction

In recent years research in the area of green manufacturing has extended into green supply chain management. Most of this research addresses issues related to evaluating current or potential suppliers' environmental practices, the environmental/economic benefits and drawbacks of establishing a green supply chain, and reverse logistics. Adding to the latter stream of research, in this study we focus on the upstream portion of the supply chain and the changes in the entire supply chain and operations strategy that result from using recycled versus virgin materials. Although this issue is relevant to any company for which the use of recycled materials is a viable option, these changes are especially pronounced in the corrugated cardboard industry, which is the primary context for this study, because of the prevalence of vertical integration and multiple supplier/customer/competitor relationships in 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. 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 (Ackerman, 1997; Denison and Ruston, 1997; Kharbanda and Stallworthy, 1990) with some exceptions (Bloemhof-Ruwaard, Van Wassenhove, Gabel, and Weaver, 1996). While the profitability of the recycling programs themselves (usually run by municipalities) may be marginal,

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 to create new products, which is the final step in a reverse logistics system. Our purpose is to examine how the use of recycled material affects the pre-existing forward logistics 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). 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. The case study was supplemented with interviews of managers at three other mini-mills.

There are several reasons for examining a mini-mill to see how the use of recycled materials affects the supply chain structure, supplier relationships, and operations strategy. First, mini-mills use recycled fiber (i.e., old corrugated containers or OCC) as raw material, in contrast to conventional containerboard mills that primarily use virgin fiber (i.e., 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* their competitors in corrugated cardboard markets. Thus, when an independent adds a mini-mill, changes in the supply chain structure and supplier relationships are easily observed. 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 well-defined and

understood. The third and fourth reasons suggest that insights from a case study of one mini-mill should be representative of the industry as a whole, especially when complemented with interviews of managers at mini-mills of both integrated and independent firms. In addition, because both integrated and independent firms have built mini-mills for containerboard production, the integrated firms provide a control sample of firms in which the addition of a mini-mill does not change their supply chain structure. Further, because markets for and industries that use recycled materials have many similarities, we will argue that our insights from the case are generalizable to any industry in which the use of recycled materials is a viable option.

The paper is organized as follows. Section 2 is a review of the literature on green supply chain management, focusing on the implications of using recycled materials. We discuss the placement of our study within the existing literature and the gaps it fills. 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 present the PaperCo case study and supplemental interviews of managers at three other mini-mills, concentrating on changes in the structure of the supply chain and supplier relationships following the addition of a mini-mill. Based on the case study findings, in Section 5 we then posit a number of hypotheses about how the use of recycled materials affects the supply chain structure, supplier relationships, and operations strategy. In Section 6 we state our conclusions, limitations, and directions for future research.

2. Literature review

Recent research has taken the concept of green manufacturing and expanded it to include the entire supply chain. Research into the green supply chain generally falls into three main categories: 1) evaluating current or potential suppliers' environmental practices (e.g. Bowen, Cousins, Lamming, and Faruk, 2001; Handfield, Walton, Seegers, and Melnyk, 1997; Johansson, 1994), 2) environmental risks, economic benefits, and economic drawbacks of establishing a green supply

chain (e.g. Allenby, 1993; Bowen, Cousins, Laming, and Faruk, 2001; Min and Galle, 1997; Narasimhan and Carter, 1998; Wu and Dunn, 1994), and 3) reverse logistics. Our study falls in the third category and is discussed in more detail in the following sections.

2.1. Reverse Logistics Systems

Green supply chain management includes the use of a reverse logistics system for the recovery of used materials and products. 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, Beullens, Bloemhof-Ruwaard, and Van Wassenhove, 2001: 158). If these two markets coincide, the network is referred to as “closed-loop”; if the markets diverge, the network is referred to as “open loop”. When products are recovered by an OEM, forward and reverse logistics networks are often intertwined (Fleischmann, et al., 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 remanufacturers (Majumder and Groenevelt, 2001). In general, Fleischmann, et al. (2001) find that coordinated design of the forward and reverse logistics 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. More broadly, reverse logistics models typically graft the reverse logistics system onto an existing forward logistics supply chain assuming that the pre-existing supply chain structure is basically unaltered (e.g. Carter and Ellram, 1998; Krumwiede and Sheu, 2002; Rogers and Tibben-Lembke, 1998). In this study we examine how the original forward logistics system is affected and changed due to the addition of a reverse logistics system.

2.2. The Use of Recycled Materials in Manufacturing

In this study we focus on firms in the reuse market of the reverse logistics system and first address 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 (Ackerman, 1997, Butler and Hooper, 2000; Kharbanda and Stallworthy, 1990). For example, 27 percent of 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 significantly reduce all 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 (Crandall, 1996; Kharbanda and Stallworthy, 1990).

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). 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 (Cavinato, 1992; Magretta, 1998; Narasimhan and Jayaram, 1998). However, this literature does not typically address the issues of market power and concentration of resources, which are two issues of particular importance for the choice of recycled versus virgin material inputs and have significant implications for the make/buy decision. These issues are specifically addressed in the literature on vertical integration, a discussion of which follows.

The use of recycled materials is especially interesting in the context of 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 supply chain structure and the nature of the supplier relationships.

According to Porter (1980) and Harrigan (1985), imbalances in market power 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 are as follows. First, the virgin materials are often controlled by a few companies. Second, prior to the introduction of technology to cost-effectively convert PCW to new products, substitute (i.e., recycled) materials were not economically viable. Third, much of the production of materials or intermediate products made from the material is for the integrated firm's own use, and, thus, the non-integrated companies are relatively unimportant to their suppliers. Fourth, the supplier's product is critical to the buyer'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 it should often be done even if there are no other direct 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 (Mahoney, 1992; Porter, 1980).

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. Further, the resulting reduction in the bargaining power by the integrated supplier/competitor firms has implications for 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 the use of recycled materials

is a viable option. This concentration of virgin material resources and subsequent introduction of recycled materials into the supply chain would be expected to have analogous effects on supply chain management, thereby generalizing the implications of using recycled materials beyond the corrugated cardboard industry.

2.4. The Use of Recycled Materials and Operations Strategy

Research on the strategic implications of green manufacturing are typically framed in terms of a producer marketing its product(s) as environmentally friendly (e.g. Chen, 2001; Preston, 2001). For example, Reinhardt (1998, 1999) concludes that it pays to be green if a company can gain a strategic advantage either through increased value, greater market penetration, or both. He states three necessary conditions for strategic advantage – willingness of customers to pay a premium (or at least enough to cover incremental costs) for “green” products, credible information about the environmentally friendly aspects of the product, and barriers to imitation. To the best of our knowledge, no studies have addressed the strategic implications of green manufacturing for firms that do not seek any direct strategic benefit from having environmentally friendly products.

One of the strategic benefits of backward integration (in this case, facilitated by the use of recycled materials) is that it increases the ability of backward-integrating firm to differentiate (Harrigan, 1983; Porter, 1980). In the PaperCo case study that follows, we examine the implications of the use of recycled materials on operations strategies in terms of non-environmentally-driven differentiation.

In summary, we can deduce from the literature that the use of recycled materials will have an impact on 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, we also expect the root causes of these changes, such as the concentration of virgin material resources, to have analogous effects in other industries that use recycled materials.

Research Methods

The purpose of this study is to examine a reverse logistics 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. Because a well-developed set of theories regarding this particular branch of knowledge does not exist, Eisenhardt (1989) and McCutcheon & Meredith (1993) suggest that theory-building can best be done through case study research. While causality can not 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. 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 interview protocol was developed based on the researchers' understanding of environmental and supply chain issues facing 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 two managers and one CEO in the industry. Minor changes were made to the protocol after the pre-test. Interviews were conducted in the respondents' facilities, and discussions focused on: the consideration of environmental factors as an important part of processes, the factors affecting environmental 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, different managers were questioned at each of the several sessions scheduled over three days. The same structured interview protocol was used at all of the

sessions, and the researchers often asked additional follow-up questions to clarify and elaborate on the responses. When the sessions involved multiple respondents, all comments or views of the managers were recorded separately. Subsequent coding of the notes was done to highlight any differing views of the managers.

3. Study Context

Containerboard Mini-Mills

Total containerboard production in 1999 was approximately 35 million tons, of which over 4 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 mini-mills rose 10.5%, reflecting the tremendous growth in the use of recycled materials in the corrugated cardboard industry.

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; Patrick, 1994; Young, Ferguson, Harrison, and Glowacki, 1993). The economic benefits and capital structure of mini-mills have allowed independent corrugated cardboard manufacturers to backward integrate into containerboard manufacturing (Kinstrey, 1993; Young, et al., 1993). Unlike conventional mills, mini-mills can be brought on-line in a short period of time (often less than a year), meaning that investors 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 because the markets for containerboard are cyclical, with shortages and price increases occurring every 5 years,

on average (Shaw, 2000). Although independent corrugated cardboard manufacturers increase their degree of vertical integration by adding a mini-mill, we will continue to refer to them as independents to distinguish them from integrators that own conventional mills and lumber.

While most early mini-mills were owned by independents, integrators soon followed. Although the economic benefits of mini-mills accrue in the same way to integrators as to independents, there are at least two additional considerations unique to integrators. First, a mini-mill may be a defensive response to maintain market share in the local area (Young, et al., 1993). Second, integrators can also use the mini-mill concept to add additional capacity. Because of their greater access to capital and greater capacity needs, integrators typically build larger mini-mills than independents (Ferguson, 1995).

The previous discussion suggests that the direct economic effects of building and operating a mini-mill are similar for independents and integrators. In the next section we discuss an issue that has very different implications for independents and integrators.

Corrugated Cardboard Industry Supply Chain Structure

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 integrators to supply their containerboard. Second, the sources of OCC (e.g. municipalities, grocery store chains) are outside the corrugated cardboard industry, which further erodes the previous supplier/competitor relationship between integrators and independents.

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 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 are in contrast to models in the literature that assume the pre-existing forward logistics supply chain is basically unaltered following the addition of a reverse logistics supply chain.

Insert Figures 1 and 2 about here.

In the next 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 supply chain. In addition, the non-environmental strategic impacts of using recycled material through the addition of the PaperCo mini-mill are examined.

4. Case Study

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. It has a daily production of about 400 tons of linerboard.

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. The information from respondents outside of CorrugatedInc and PaperCo increase the reliability of the study.

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. Detailed information about the interview subjects and summaries of responses to representative questions can be found in Tables 1 and 2.

Insert Tables 1 and 2 about here.

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 product to satisfy most of its internal demand. However, PaperCo produces linerboard only, and both linerboard and corrugating medium are needed to make corrugated cardboard. The Sales Administrator explained that PaperCo trades 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 with linerboard producers in other parts of the country where CorrugatedInc has corrugated cardboard manufacturing facilities. In addition, PaperCo sells linerboard to other corrugated cardboard manufacturers, including both independents and integrators. While CorrugatedInc sources most of its containerboard from PaperCo or through PaperCo's trades, it also continues to buy containerboard from other suppliers. 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 integrators).

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. This dependence takes two forms. 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 or 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 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 respondent J and K's 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. While PaperCo can and does produce commodity-type products, it also produces non-commodity value-added type papers such as colored papers. 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 focus on the heart of the mini-mill concept, which is 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. According to the Administration Manager, who is responsible for all procurement except for fiber, the sources of OCC, such as garbage haulers, do not typically "sell" their products, and require different procurement approaches. Because of this, fiber procurement was put into a separate business unit. More generally, consistent with the disposer and reuse markets being in the same geographic area, the forward and reverse logistics networks 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. As with standard grades of containerboard, OCC is considered a commodity, and prices are set in the open market. More recently, the price of OCC fell below \$50 per ton. Throughout this period, the price of containerboard remained fairly stable. Thus, because

OCC is a significant portion of the product cost, it contributes to wide variations 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. Unlike many larger publicly-traded companies that don't want to hold the OCC on their balance sheet, 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 1/3 of its OCC from waste haulers, 1/3 from processors and brokers, and 1/3 from generators such as grocery stores. 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 (out of FiberCo's total requirements of over 15,000 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 corrugated cardboard waste 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.

5. Case-Based Hypotheses

Based on a synthesis of the case study findings and associated literature, we offer a number of hypotheses concerning implications of using recycled materials for the supply chain structure, supplier relationships, and operations strategy. We state the hypotheses in the context of the corrugated cardboard industry and then discuss how they can be generalized to other industries that used 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 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.

Although the case study demonstrates direct economic benefits from adding a mini-mill, and the existing literature supports 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 containerboard), rather than containerboard prices. Under such circumstances, the profitability and cost advantage of all mini-mills decrease considerably. Yet, even with the decreased profitability and higher costs, the independent firms would still benefit from the changes in the supply chain structure, with the concomitant increased bargaining power, decreased supplier dependence, and other lower transactions costs. Thus, it follows that the rationale independents will use to justify building mini-mills is likely to focus on the potential benefits from the changes in the supply chain structure. This is stated in Hypothesis 1.

H1: 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 unique opportunity to examine whether, in fact, this is the case. First, because of environmental concerns, it is 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). Second, because independents face the same costs for adding a mini-mill as integrators and have the option to continue to purchase containerboard rather than produce it themselves, 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 Hypothesis 2. In essence, this will move the industry more toward the structure shown in Figure 2.

H2: Non-integrated firms will be more likely to add mini-mills and use recycled material inputs than integrated firms.

Hypothesis 3 extends this line of reasoning longitudinally. As the capital cost for building a mini-mill decreases, more independents can afford to add mini-mills and realize the supply chain benefits. As a result, we expect the ratio of independents to integrators will increase over time.

H3: With decreasing capital costs over time, the ratio of independents to integrators 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 generalize H2, 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 (H3). While H1 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 U.S. steel production to lower labor and capital costs and improvements in electric furnace and rolling technology, a more complete explanation of this phenomenon that follows from this study stems from the 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 logistics systems, in which the original manufacturer can exert some control over the remanufacturing of its own products (by limiting or encouraging independent remanufacturers 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. Hypothesis 4 follows from this.

H4: Markets for recyclable materials are accessible to both independent and integrated firms.

Hypothesis 4 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 integrators. 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 Hypotheses 5a and 5b. Further, we expect these hypotheses to apply to all industries that use recycled material.

H5a: Firm and mini-mill size will be positively associated with the average size of their recycled material suppliers.

H5b: Firm and mini-mill size will be positively 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 Hypothesis 5b, 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 integrations 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.

Because independents are likely to have systematically different operations strategies from the low cost strategy typical of integrations, 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 reduce strategic constraints, allowing new strategies to emerge, as stated in Hypothesis 6. This is also consistent with the vertical integration literature that suggests that backward integration allows the backward-integrating firm to strategically differentiate.

H6: 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.

Generalizing this hypothesis, we expect the same strategic outcomes to be characteristic of analogous new entrants using recycled materials in other industries.

6. Conclusions

In this study we look beyond the existing green supply chain literature that primarily addresses the direct economic and environmental effects of establishing a green supply chain. Rather, we focus on the non-environmental implications of using recycled versus virgin materials for the supply chain structure, supplier relationships, and operations strategy. We focused our study 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.

In contrast with the reverse logistics literature that typically assumes that the pre-existing supply chain is basically unaltered, 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 one-way supplier relationship has been replaced by two-way relationships, changing 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 logistics, recycling, supply chain management, and operations management, we posited several hypotheses related to the use of recycled materials, supply chain structure, supplier relationships, and operations strategy. In review, 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, the ratio of independents to integrations will increase. Further, we expect smaller non-integrated firms to 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, we expect the use of recycled materials to indirectly lead to greater use of non-cost based operations strategies in the industry. We then generalized the hypotheses beyond the corrugated cardboard industry to other industries that use recycled materials.

One limitation of this research is that it is based on a single in-depth case study supplemented by interviews with managers at other mini-mills. 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 hypotheses (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, this should increase the generalizability of the study. Future research on different industries and larger sample sizes will be needed to further substantiate the grounded theory developed in this study.

In summary, in addition to the environmental and direct economic effects of green manufacturing and green supply chain management addressed in the existing literature, we believe that a better understanding of the non-environmental benefits of green manufacturing for supply chain management and operations strategy will further increase the attractiveness and use of environmentally friendly practices. This study and the resulting grounded theory are a step toward addressing this important issue.

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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	Engineering, maintenance, and production
E	Administration Manager	Accounting, MIS, and purchasing (except for fiber)
F	Sales Administrator	Production scheduling, customer service, sales support, and trading
G	Product Development Engineer	New product development, product support
H	Technical Manager	Process engineering, quality, environmental performance

Interviews outside of PaperCo

I	President and CEO of U.S. 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 a large integrated firm	Overall responsibility for supply chain management and logistics for containerboard products

Table 2: Summary of Responses to Representative Questions

Protocol questions/(Respondents)	Responses
Competitive initiatives in this industry? (A, B, C, D, I, K)	Current: cost reduction, capacity, market share, taking time out of the supply chain. Future: consolidation, providing value-added services for customers, and more vertical integration of industry.
Key success factors? (A, B, C, D, 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 can not be the low cost providers because integrators 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 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, cleanliness 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, lack of infrastructure, small scale production, to use recycled materials.
What are the benefits of using recycled boxes as materials? (C, D, E, H, J, K)	Safer (no chemicals), less expensive, do not have to harvest trees, no odors, less permitting.

Figure 1: Supply Chain Relationships without Containerboard Mini-Mills

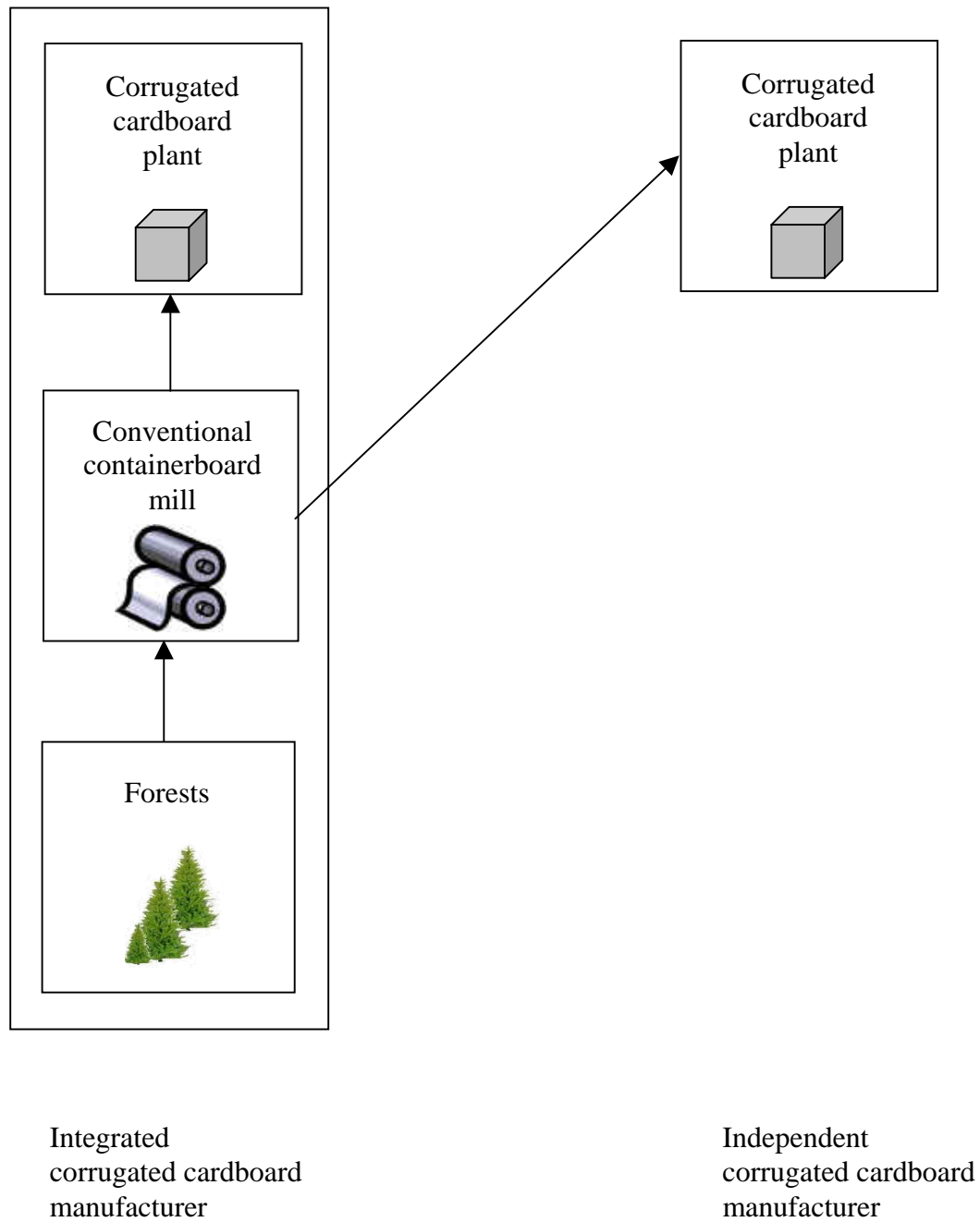
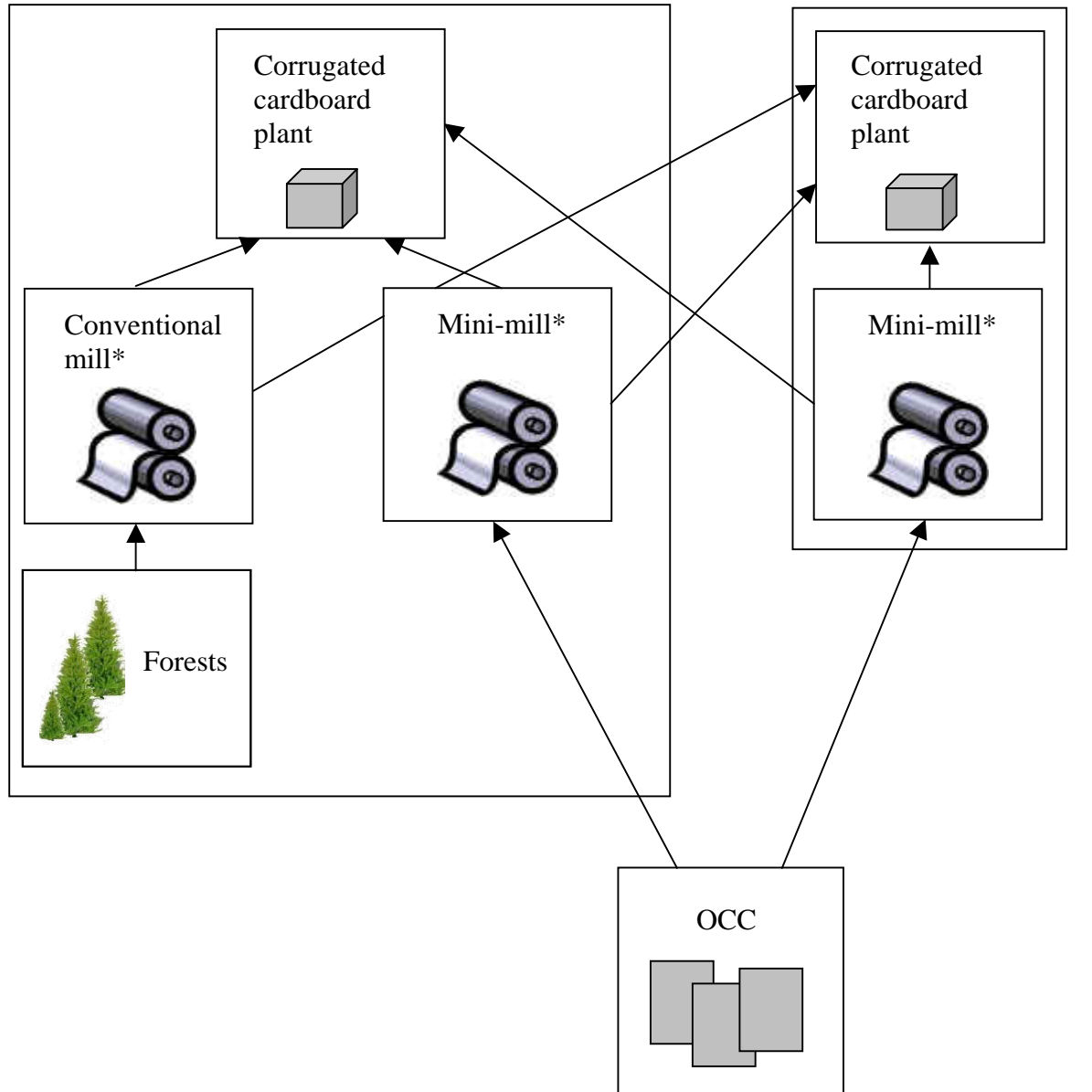


Figure 2: Supply Chain Relationships with Containerboard Mini-Mills

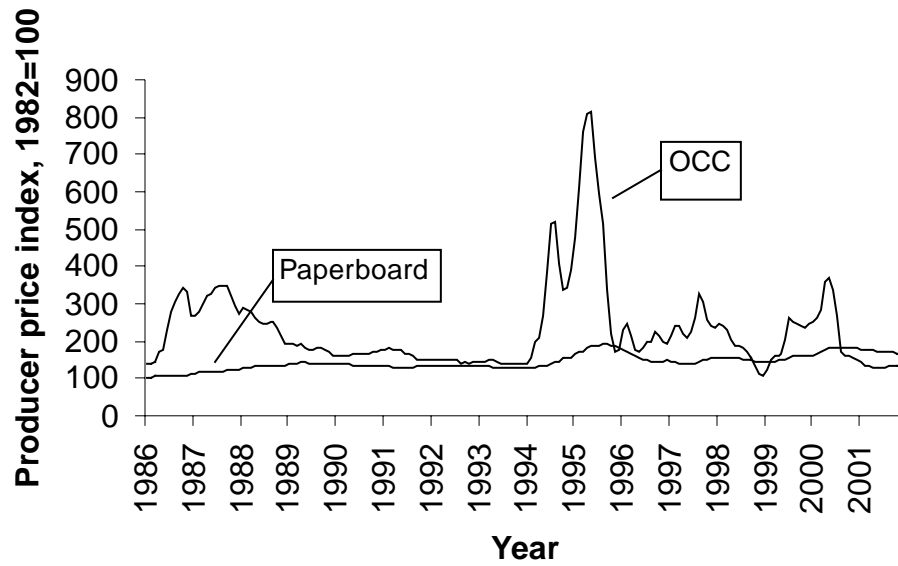


Integrated corrugated manufacturer (conventional containerboard mill and containerboard mini-mill)

Independent cardboard corrugated cardboard manufacturer with containerboard mini-mill

*conventional mills and mini-mills are also suppliers to other independents

Figure 3: Producer Price Index for OCC and Paperboard*



*Source: Bureau of Labor Statistics

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?