Green Supply Chain Practices:
An Examination of Their Antecedents and Performance Outcomes

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by

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ABSTRACT

As manufacturing organizations move toward environmental sustainability, managers need to extend their environmental practices outside the organization, in the supply chain. A conceptual model—called the *supply chain environmental management model*—that established the influence of green supply chain practices on environmental technology selection and operational performance is developed and hypothesized using the natural resource-based view of the firm. The model also includes the linkage from supply chain integration to green supply chain practices, suggesting that general supply chain management is an antecedent to environment-related activities in the supply chain.

A survey in the package printing industry was conducted to collect data, which was used to validate the model and the new constructs that pertain to green supply chain practices, defined as the level of *environmental cooperation* and *environmental monitoring* with primary suppliers and major customers. Supply chain integration, comprising logistical integration and technological integration, is also validated with the survey data. A total sample of 84 North American plants participated, yielding a response rate of 23%.

Results suggest that green supply chain practices are positively linked to operational performance. In particular, environmental cooperation with suppliers was significantly and positively linked to all manufacturing performance metrics, while environmental cooperation with customers was only positively related to quality and environmental performance. Hence, managers can leverage environmental cooperation in the supply chain to yield better performance.

Results also indicate that green supply chain practices were affecting the allocation of resources among three types of environmental technologies, namely pollution prevention, pollution control, and management systems. Specifically, environmental cooperation with suppliers was associated with a shift of resources toward pollution prevention at the expense of infrastructural investments in management systems.

Finally, a strong link between technological integration and environmental cooperation was found, suggesting that supply chain managers must combine environmental collaborative initiative with broader strategic supply chain activities. Green supply chain practice constructs can be leveraged in studies pertaining to other industries, such as the service sector, where suppliers can be key to significant waste reduction and structural changes to achieve sustainability.

Keywords:

supply chain management

environmental management

environmental technologies

natural resource-based view of the firm.

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1. INTRODUCTION

With the planet population expected to grow from 6 billion today to 8 billion in 2020 (NCR 1998), consumption will inherently increase, creating pressure on all industries to supply more goods and services and, therefore, creating strain on the natural environment. Over the last decade, an increasing awareness regarding climate changes and natural resource depletion has been evident across several industries and in the population. International agencies and national governments met twice in the 1990s (the Earth Summit of Rio in 1992 and the Kyoto meeting of 1997) to establish goals regarding ozone depletion, gas emissions, and waste reduction. Meeting these goals will require significant changes in the production and consumption habits of the industrialized world. Given the current manufacturing processes and the different competitive pressures, it is generally accepted that both processes and products must be changed in order to maintain the pace of consumption in an environmentally sound and sustainable way. The current rate of consumption of non-renewable resources and the production of undesired output (i.e., pollution) amplify the urgency for organizations to select and/or develop technologies to reduce the environmental impact of their production activities and their products. In fact, over the next twenty years, environmental compliance and sustainability will be one of the critical challenges faced by all manufacturing industries (NRC 1998).

One consequence of this general awareness regarding the natural environment is the greater scrutiny of manufacturing organizations' operations and supply chain practices by a number of stakeholders groups including:

(i) immediate industrial and commercial customers that include environmental criteria in the selection and evaluation of their suppliers (Drumwright 1994; Walton et al. 1998);

(ii) immediate suppliers, particularly large corporations, that are concerned with the management of their products by the customers and other downstream organizations (Snir 2001);

(iii) segments of end consumers that are influenced by product properties (e.g., phosphate-free detergent, recycled content) or production processes (e.g., fair-trade coffee, save-the-dolphins tuna) and willing to pay a premium for such products (Cason and Gangadharan 2002; Teisl et al. 2002);

(iv) advocacy groups such as Greenpeace and the Sierra Club, which increase the exposure of organizations' environmental practices; and

(v) the financial sector, which devotes an increasing attention to organizations' environmental practices (Pearce and Ganzi 2002).

These diverse stakeholders, with their particular interests, pressure manufacturing organizations to adopt environmental practices that are in compliance with the existing regulations and, in some instances, to surpass these minimal requirements.

Some organizations, without necessarily being pressured, decide to go beyond existing regulations and different stakeholders' requirements and seek ways to reduce pollution at the source and to be proactive when faced by environmental challenges. Such initiatives can take the form of specific practices in conjunction with other members of the supply chain. For example, in recent years, many manufacturing organizations have increased their interest in green purchasing (Min and Galle 1997; Zsidisin and Siferd 2001), reverse logistics (Stock 1998), product stewardship (Snir 2001), and/or design-for-the-environment (Chen 2001). All these activities related to supply chain management occur across multiple organizations whether in the supply network or in the distribution channel and influence the way manufacturing organizations address environmental-related issues. Thus, rather than considering an organization's approach toward environmental management from the isolated perspective of a single manufacturer, explicit recognition of upstream and downstream interactions in the supply chain is needed.

1.1. Supply Chain Management

As manufacturing has globalized and competition has intensified over the last decade, supply chain management has received greater attention (Lambert et al. 1998; Mabert and Venkataramanan 1998; Mentzer et al. 2001). Supply chain management has stimulated a broad and rich field of research that has been disseminated through operations management (e.g., Gilbert and Ballou 1999), marketing (e.g., Buvik and John 2000), and information systems management (e.g., Scott 2000), leading to a wide variety of definitions (Mentzer et al. 2001). One particular definition, which is starting to gain consensus in the literature, suggests that supply chain management includes all the activities associated with the flow and transformation of goods, from raw material suppliers to end consumers (Handfield and Nichols 1999). It also encompasses all information flows up and down the supply chain (Lambert et al. 1998).

While desirable, extensive management across several echelons of the supply chain is very difficult, if not impossible (Choi et al. 2001). Similarly, within the realm of survey and analytical modeling research, studying beyond the interaction between an organization and one of its immediate echelons has proven to be difficult. Hence, in this dissertation, a narrower perspective of the supply chain is adopted. It considers the set of activities pertaining to the flows of material and information taking place between a focal plant and its immediate primary suppliers and major customers (Figure 1.1).

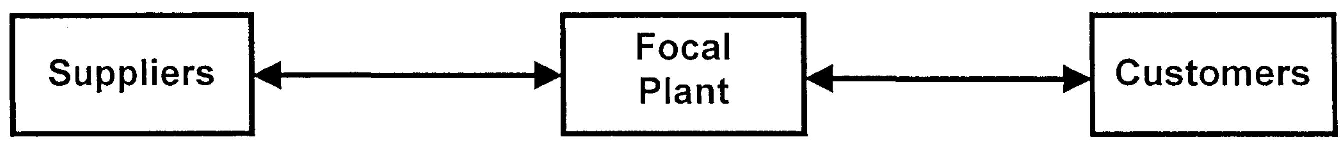

Figure 1.1 Simplified Supply Chain

Organizations increasingly rely on their supply network to handle more complex technologies and higher customer expectations. For instance, greater collaboration between organizations in the supply chain can lead to operational benefits including greater innovation (Dyer and Nobeoka 2000), faster time-to-market (Dyer 1996) and better financial performance (Carr and Pearson 1999), all critical for a firm's competitiveness. However, greater collaboration, taking the form of knowledge sharing or flexibility in logistical management, is not necessarily a panacea. For instance, activities such as supplier development, investment in information technologies, and inter-organizational product development teams can require significant deployment of resources by the buying and the supplying organizations. Hence, several authors advise against blind application of these supply chain practices throughout the entire supply network, as trade-offs exist and diminishing returns occur (Buvik and John 2000; Hartley and Choi 1996; Rigging and Mukhopadhyay 1994). For example, recent studies related to more collaborative supply chain management strategies suggested that such approaches did not systematically improve flexibility and cost performance in the buying organization (Dong et al. 2001; Shin et al. 2000). Because supply chain management can have an impact on a plant's managerial practices and organizational performance, investigating specific environmental-related activities in the supply chain can provide insights on plants' adoption of different types of environment management practices and their performance.

1.2. *Plant Environmental Management and Performance*

1.2.1. Environment Management Practices Within the Plant

One way to characterize a manufacturing organization's environmental management is through its selection of environmental technologies (Klassen and Whybark 1999a), often referred to by the dichotomy of pollution control vs. pollution prevention technologies (Sarkis and Cordeiro 2001). The former mostly takes the form of "end-of-pipe" technologies and remediation projects, while the latter seeks to reduce or eliminate pollution at its source by modifying production processes or products.

Several organizations favor off-the-shelf, less disruptive solutions suggesting more investment in end-of-pipe technologies, which keep their production process and products unchanged. For instance, an extensive survey conducted by Statistics Canada in 1997 revealed that the environment-related *capital* expenditures of Canadian plants was divided fairly equally between end-of-pipe technologies and integrated process technologies—defined as process modification and material substitution leading to reuse of waste and water in order to reduce emissions of pollutants and the amount of waste (Statistics Canada 2000). Furthermore, the same survey reported that of environment-related *operating* expenditures (in contrast to capital expenditures), end-of-pipe technologies are favored three to one over integrated process technologies.

One explanation for such behavior may lie in the characteristics of supply chain management. Ashford (1993) proposed that customers' unwillingness to relax product specifications and lack of supplier resources and expertise can partly explain the bias toward end-of-pipe technologies. Other possible explanations can include resistance to change, incomplete understanding of the production process, and a lack of supply chain collaboration (Dieleman and De Hoo 1993; Kemp 1993; Vachon and Klassen 2002a). Therefore, activities taking place in the supply chain can have an influence on the selection of environmental technologies within a focal plant.

1.2.2. Environmental Management and Organizational Performance

Proactive environmental practices can lead to *win-win* opportunities in terms of environmental and manufacturing performance (Porter and Van Der Linde 1995; Sarkis and Rasheed 1995). Other studies even proposed that organizations can develop some capabilities through their environmental effort, which translate into competitive advantage (Bonifant et al., 1995; Hart 1995) leading to greater profitability. This last perspective is often referred to as the natural resource-based view of the firm (Hart 1995; Russo and Fouts 1997) and was used in studies linking environmental management and manufacturing performance (Christmann 2000; Klassen and Whybark 1999b).

Despite some compelling evidence to support the natural resource-based view, the academic literature has reported a broad range of results, going from the expected positive link between environmental management and organizational performance (Aragon-Correa 1998; Russo and Fouts 1997), to mixed results (Boyd and McClelland 1999), to neutral impact (McWilliams and Siegel 2000), and even to adverse effect (Sarkis and Cordeiro 2001). To date, very little attention has been devoted to the potential influence of environmental management in the supply chain on plant-level performance.

1.3. Research Objectives and Expected Contribution

Four primary research objectives motivate this dissertation. Given the current literature on environmental management in supply chains, the first objective is to develop a typology defining environmental practices in the supply chain. Such a typology will allow the examination of the linkages existing between environmental activities in the supply chain and other supply chain activities more related to the material and informational flows between organizations.

The second objective is to study the influence of managerial practices in the supply chain on the way that a focal plant addresses environmental issues. The relationship between supply chain management and environmental management within a plant will be substantiated using the resource-based view of the firm literature specifically the segments associated with knowledge integration (Grant 1996a; Schroeder et al. 2002) and the relational view of inter-organizational activities (Dyer and Singh 1998).

Grounded in the natural resource-based view of the firm (Hart 1995; Russo and Fouts 1997; Sharma and Vredenburg 1998), the third objective of this dissertation is to develop a theoretical model that offers insights regarding the influence of environmental management within the supply chain on a plant's operational performance. It will be argued that a number of environmental practices in the supply chain can lead to the development of capabilities difficult to replicate, which can establish a competitive advantage.

The fourth objective is to provide empirical evidence to support a model that links environmental practices in the supply chain and environmental management within the plant to operational performance. A single industry survey is used to provide a vehicle for constructing and validating the measurements of the theoretical constructs in the model. Once they are empirically measured, the importance of individual variables for determining outcomes will be assessed.

The fulfillment of these research objectives will provide a greater theoretical, empirical, and managerial appreciation of environmental issues within supply chain management, and a scientific contribution to operations management research. Theoretically, this study will provide a test of the natural resource-based view of the firm. In addition, this research on the linkage between environmental practices in the supply chain and within the plant aims to fill a gap in the literature (Handfield et al. 1997; Carter and Carter 1998; Vachon and Klassen 2002a).

From an empirical perspective, developing measurements for environmental practices in the supply chain and evaluating the relationships with plant level variables enlarge the understanding of managerial challenges pertaining to both the supply chain and the environment.

This dissertation can also have managerial implications. Considering that managers have limited discretionary time and often have to work within a constrained set of physical, intellectual and financial assets, a clearer indication on the potential outcome from different type of interactions in the supply chain is needed. The literature provides little guidance for managers about how limited resources should be allocated between upstream (suppliers) and downstream (customers) supply chain members. Furthermore, very few studies have examined the operational impact of adopting environment-related interaction with suppliers and customers.

1.4. Overview of this Dissertation

This dissertation contains six additional chapters. Chapter 2 presents and defines the concepts used throughout this dissertation. It reviews the relevant literature to develop the theoretical constructs needed for the development of a conceptual model linking environmental practices in the supply chain, environmental management in the plant, and operational performance. The constructs are further specified in Chapter 3, where the hypothesized relationships between these constructs are stated and discussed. Hence, Chapter 3 is a more detailed and refined development informed by the literature and with linkages among the constructs grounded in theory. The methodology and research design are presented in Chapter 4. Also in that chapter, the survey instrument is presented in detail with relevant references to the literature. In Chapter 5, the constructs are validated through field research findings and factor assessment leading to the empirical analysis of the theoretical model in the Chapter 6. Concluding remarks and future research avenues are presented in the final chapter.

2. Literature Review

The goal of this chapter is to synthesize the relevant literature into an integrated conceptual model linking the different interactions in the supply chain to environmental management in the focal plant and to the plant's operational performance. At this point, only broad associations between the major constructs are made, a more detailed theoretical development is presented in Chapter 3.

Segments of three large bodies of literature are reviewed in this chapter. The first section reviews the segment of the supply chain management literature pertaining to the integration between buying and supplying organizations, which is termed *supply chain integration*. In the second section of this chapter, environmental management studies, which are mainly associated with manufacturing and operations management, are surveyed, with particular attention devoted to environmental technologies and environmental practices in the supply chain. The third section presents the literature referring to the resource-based view of the firm[1] with an emphasis on its application to supply chain management and environmental management. Finally, the last section synthesizes and incorporates the literature reviewed to form an integrated model entitled *Supply Chain Environmental Management*.

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[1] In this literature, the term *resource* refers to tangible and intangible assets owned by an organization: it should not be confused with the term natural resources commonly used to refer to the natural environment.

2.1. Supply Chain Management: Buyer-Supplier Integration

Integration between a buying organization and its suppliers usually aims to improve the operations in the buying organization and/or in the supply network. This integration can be related to tactical or strategic activities. Buyer-supplier integration affecting tactical activities is usually related to logistical management. It has been widely studied under the label of vertical coordination (Buvik and John 2000), buyer-supplier relationship (Carr and Pearson 1999), or supply management (Shin et al. 2000) and is termed here *logistical integration*. Buyer-supplier integration also takes place for strategic activities associated with technological changes. This type of integration has been examined in supplier development (Hartley and Choi 1996) and interfirm collaboration studies (Kaufman et al. 2000). These literature streams generally suggest that buyer-supplier integration can be an integral part of product development (Eisenhardt and Tabrizi 1995), process reengineering projects (Hammer and Champy 1993), and/or best management practices transfer (MacDuffie and Helper 1997); the integration of these types of activities is termed here *technological integration*. Both types of integration can take place upstream with the suppliers and downstream with the customers (Figure 2.1).

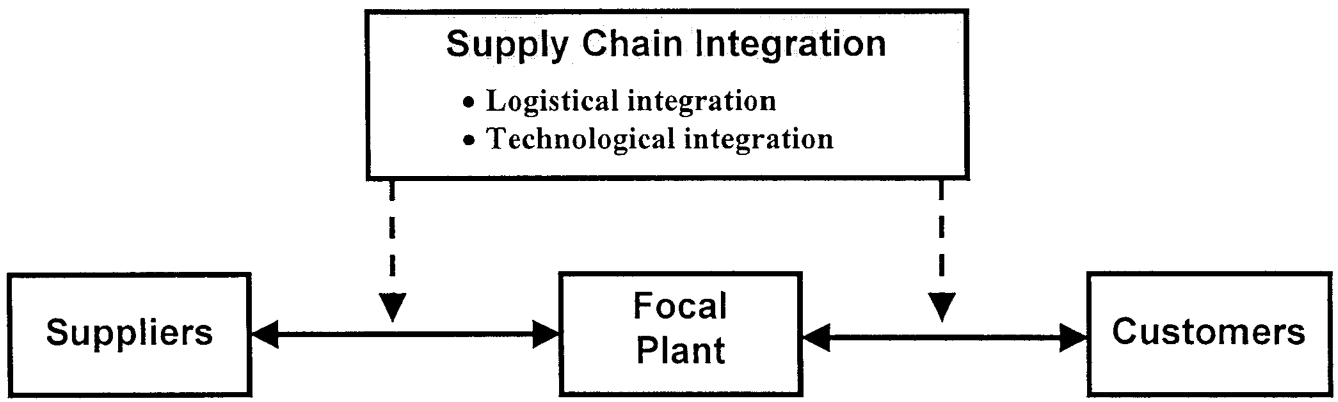

Figure 2.1 Simplified Supply Chain—With Supply Chain Integration

A major distinction between logistical and technological integration can be found in the type of knowledge that is shared or transferred between the buyer and the supplier. Two types of knowledge — tacit and explicit — are recognized in the literature (Dyer and Nobeoka 2000; Nonaka and Takeushi 1995). Tacit knowledge refers to unstructured information and context-specific skills that are difficult to articulate, communicate, and encode, whereas explicit knowledge refers to easily transferable information (Kaufman et al. 2000; Scott 2000) such as information enclosed in technical manuals or in a user guide. To be consistent with the literature, technological integration includes tacit knowledge sharing and transfers (Germain et al. 2001; Grant and Baden-Fuller 1995; Ahuja 2000) while logistical integration includes explicit knowledge sharing and transfers.

2.1.1. Logistical Integration

Frohlich and Westbrook (2001) proposed that the concept of logistical integration includes the degree of cooperation in managing information and material flows along the supply chain. The focus of their model is information sharing pertaining to planning systems, production plan, inventory levels, and computer linkages (e.g., EDI). Most of the studies in the field considered greater information exchange between supply chain members as the essence of logistical integration (Chen et al. 2001; Gavirneni et al. 1999). It is known to evolve with repeated transactions and, therefore, through time. As the interaction between the buyer and the supplier matures, trust builds, and information sharing becomes the norm (Dwyer et al. 1987; MacNeil 1978), moving the degree of logistical integration higher.

A high degree of logistical integration is also characterized by flexibility in logistics management, particularly when facing unforeseen events (Noordewier et al. 1990; Webster 1992). Such logistical flexibility is often the result of incomplete contracts that allow for transactions between parties to be neither constraining nor highly formalized but more organic (Ring and Van de Ven 1992).

Based on the literature, a high degree of logistical integration can be defined as extensive information sharing taking place between a buying organization and its supply network in order to improve logistical management. Information pertaining to inventory levels, production planning, and production scheduling, is shared within an organic (i.e., not mechanistic) framework within which logistical transactions between the buying and the supplying organizations are characterized by incomplete contracts. The degree of logistical integration can vary from low to high depending on these two attributes (i.e., information sharing and logistical context). Hence, the mix of all these interorganizational activities for an individual organization can be positioned on a continuous spectrum as depicted in Figure 2.2 (Gardner et al. 1994; Hennart 1993; Webster 1992).

Low logistical integration is usually characterized by complete, detailed contracts with little latitude in the transaction parameters, where information sharing is limited to monitoring performance and minimizing risk (MacNeil 1978). Low logistical integration is consistent with the transactional approach found in the economic literature (Williamson 1979; 1981), also known as arm's-length transactions.

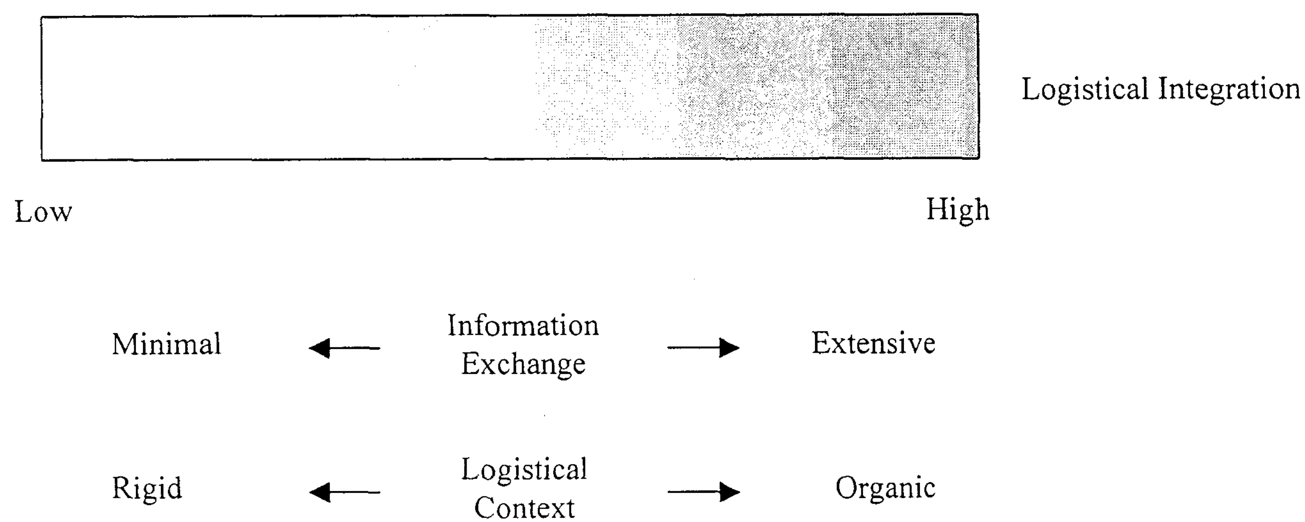

Figure 2.2 Logistical Integration Spectrum
(Adapted from Gardner et al. 1994)

Because supply chains have inherent and varying degrees of uncertainty (Davis 1993; Levy 1994), organizations adopt different mechanism to reduce uncertainty including better-coordinated activities within their supply chain. Increased coordination is made possible through increased information sharing (Buvik and John 2000; Chen et al. 2001), hence with greater logistical integration. One explanation of the beneficial role of information sharing in logistical management is demonstrated by the study of the bullwhip effect (Lee et al. 1997), which perspective is often analytically modeled.

A summary of papers using analytical models to study logistical integration is provided in Table 2.1. They suggest that, while in general a higher degree of integration can be beneficial, these benefits can vary depending on the operating context (Cachon and Fisher 2000; Lee et al. 2000; Cachon and Zipkin 1999). For example, information sharing can only have second order benefits if the demand by the buying organization is stable and long lead-time is permissible (Lee et al. 2000). Because logistical integration benefits can be contingent on the operating context (Cannon and Perreault 1999; Gavirneni et al. 1999; Dwyer et al. 1987) and can exhibit diminishing returns (Buvik and John 2000; Cachon and Zipkin 1999), a high degree of logistical integration is not pursued with all suppliers of the supplier base (Kaufman et al. 2000).

Table 2.1 Illustrative Papers on Information Sharing in Supply Chain Using Analytical Modeling

Study	Overview	Main Conclusions
Gavirneni et al. (1999)	• Two-echelon model (retailer and suppliers) with limited capacity at the supplier level. • (S,s) inventory management model with different degree of information sharing • There is asymmetry of information between buyers and suppliers.	• More information is always beneficial • When the variance of the end-demand is high or the differential "S-s" is extreme (low or high), information is not as beneficial.
Cachon and Zipkin (1999)	• Two-stage supply chain: one supplier and one retailer. • Model three different scenarios: two non-cooperative games with different sets of information and a cooperative game with information disclosure. • Performance variable: inventory-related costs.	• With the presence of backorder cost, the Nash equilibrium never leads to the optimal solution (First Best) in a non-cooperative game. • When firms decide to cooperate, inventory levels tend to be higher than the Second Best solution. • The difference between the second best and the first best equilibrium can be only marginal depending on the context.
Lee et al. (2000)	• Two-echelon supply chain (retailers and manufacturers) • Model optimal ordering decisions for the retailer and the manufacturer with information sharing and without it.	• If the manufacturer bears the responsibility to provide reliable supply to the retailer, the latter has no direct benefits from information sharing. • For the manufacturer, information sharing leads to inventory reduction, and overall production cost reduction. • The savings are more important in cases where the demand is highly variable, there is long lead-time and the demand is strongly auto correlated.
Cachon and Fisher (2000)	• Supply chain inventory management between two echelons: one supplier and multiple retailers. • Model the supply chain expected costs: holding cost, backorder cost and in transit cost	• On average, information sharing leads to a 2.2% saving. • Information sharing allowed a reduction in the lead-time (21%). • Information sharing suggests that information technology aiming to speed up information transfer or to smooth physical flows is more appropriate than information technology aiming to increase the information.

Despite these caveats, operational performance is generally positively linked to increased information sharing. Linkages taking the form of real-time electronic data interchange, shared planning/scheduling, and access to inventory data can yield greater supply chain effectiveness if they are established within a flexible framework (Bowersox 1990; Fisher 1997). For example, advanced commitment in quantities ordered from major customers allows suppliers to have more stable production scheduling, reduced inventory, and greater capacity utilization (Gilbert and Ballou 1999).

2.1.2. Technological Integration

Technological integration can be defined as tacit knowledge sharing and transfers taking place between a buying and a supplying organization regarding activities such as product development, process reengineering, and technical training. The term *technological* is defined broadly to include not only structural aspects such as product- and process-related changes but also to include managerial techniques and expertise. As such, two things can determine the degree of technological integration: the extent of technical and tacit knowledge sharing and the interaction between organizations regarding the product and process design (Figure 2.3).

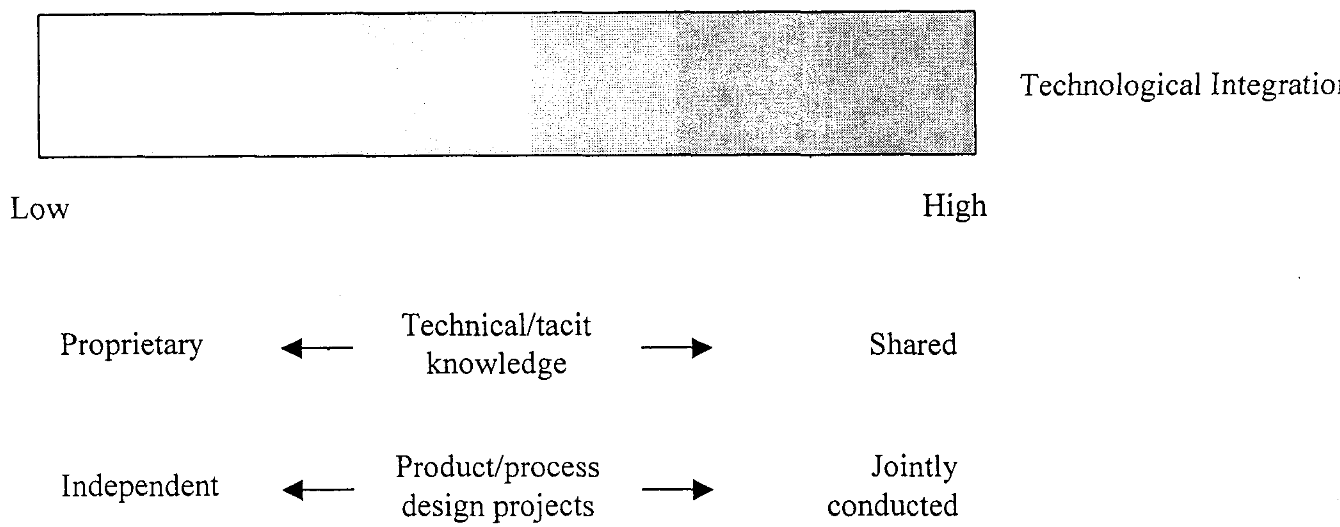

Figure 2.3 Technological Integration Spectrum

Technological integration provides opportunities and potential benefits for both parties. For example, a supplier can assist its customer's product development effort or process reengineering by providing its expertise; this can decrease a new product's time-to-market and increase the effectiveness of new processes (Kaufman et al. 2000). A buying company can seek to develop the competencies and capabilities of its suppliers by providing its own expertise (Leenders and Fearon 1997; Watts and Hahn 1993). For example, a buying company can assist its suppliers in the implementation of a quality management system (Trent and Monczka 1999) or lean production principles (MacDuffie and Helper 1997), thereby assuring a more reliable and cheaper source of material or components. This last possibility is often referred to as supplier development activities (Krause 1999; Krause et al. 2000).

Technological integration across the supply chain has been the trademark of major Japanese automakers, namely Toyota and Honda (Leenders and Fearon 1997; Dyer and Nobeoka 2000). Liker and Wu (2000) investigated the difference between American first tier automotive suppliers dealing with both the Japanese automakers and the American "Big 3." They found that, in general, Japanese automakers' suppliers had higher inventory turnover, higher productivity, and better quality than their American counterparts. Their conclusion was that the differences disclosed in the study were explained, among other things, by the effective supplier development program put in place by the Japanese automakers. Similar results in terms of the quality of design and development speed were found when suppliers shared tacit knowledge with the buying organization (Dyer 1996).

2.1.3. Synthesis: Supply Chain Integration

Logistical and technological integration have been rarely studied together in the literature. Figure 2.4 proposes a two-dimensional matrix representing different combinations of logistical and technological integration. As suggested by Figure 2.4, logistical and technological integration can be considered as orthogonal – i.e., both dimensions are independent from each other. Together, these two dimensions compose what is termed here *supply chain integration.*

Low logistical integration/low technological integration – This is the case where virtually no integration takes place between a plant and its suppliers or its customers. An example of such a situation would be a plant that is selling its product through a spot market. It is also the case of the supply of energy and other utilities. There is no involvement between the parties to improve the logistical flow of goods or to change the technology in respective organizations.

High logistical integration/low technological integration – This is also known as integrated logistics where organizations involved in material exchanges have invested in information technologies to improve the information sharing pertaining to logistical management. It takes the form of electronic linkages with suppliers/customers in order to optimize logistical activities. It can also include a transfer of responsibilities allowing more effective and efficient logistics systems. An example of this would be a plant that manages the inventory of its goods within the buying organization (often referred to as JIT II or vendor managed inventory).

Technological Integration	**High**	• Joint product development team • Knowledge sharing in process reengineering	• Mutual development of systems and capabilities • Joint logistical resources and equipment
	Low	• Energy supply • Raw material commodity purchase	• JIT II / Vendor-managed inventory • ERP / EDI linkages
		Low	**High**
		Logistical Integration	

Figure 2.4 Supply Chain Integration

Low logistical integration/high technological integration – This is a situation where the organizations are integrated for the purpose of a particular project but do not integrate on a day-to-day or tactical level. Examples include the involvement of suppliers in product development or process reengineering tied to material substitutions, equipment changes, or new product design.

High logistical integration/high technological integration – this is the greatest form of supply chain integration, where in organizations get involved through investments and direct action in the development of suppliers or in joint process reengineering and product development projects, coupled with extensive information exchange in logistical integration. One important aspect of supply chain integration is that it aims to improve supply chain efficiency and effectiveness, which in turn should influence different dimensions of a plant's manufacturing performance along the supply chain.

2.1.4. Operational Performance

Supply chain management literature develops some performance metrics mainly based on cost, customer responsiveness, and financial indicators (Beamon 1999; Brewer and Speh 2000; Cachon and Fisher 2000; Fawcett and Cooper 1998). However, as is the case with buyer-supplier integration, most of the studies did not consider multi-echelon costs and responsiveness, concentrating instead on two consecutive echelons. It is noteworthy that most of the performance metrics are closely related to those widely accepted in the operations strategy literature. For example, Van Hoek (1998) proposed measuring suppliers' contribution to the buying organization's operational performance as an indicator of supply chain performance. Therefore, in this section, the different dimensions of performance associated with manufacturing operations are reviewed.

There are four widely accepted manufacturing performance indicators: cost, quality, delivery, and flexibility (Skinner 1969; Ward et al. 1998; Wheelwright 1984). While cost is not an uncontested order-winner, it remains important for manufacturing firms. Costs are reflected through direct material costs, labor and overall productivity, capacity utilization, and inventory level (Ward et al. 1998). The links between supply chain management and cost performance are numerous. Several studies examined the implication of information sharing and collaboration among supply chain members for inventory costs. These costs are usually modeled to include measurements of holding, backorder, and obsolescence costs (Cachon and Fisher 2000; Kohli and Park 1994; Lee et al. 2000).

Quality, including the supplier's involvement in continuous improvement and TQM systems (Ahire et al. 1996; MacDuffie and Helper 1997), has also been an important metric in supply chain management. For example, Kekre et al. (1995) argue that the number of suppliers is inversely correlated with product quality. Product reliability, conformance, and durability are the dimensions of quality (Garvin 1987) examined in this dissertation.

Delivery performance is generally divided into two subdimensions: speed and reliability (Flynn and Flynn 1999; Salvatore et al. 2001). Speed refers to the degree of customer responsiveness including the order cycle time (i.e., the time from the placement of an order by a customer to its shipment or receipt) and manufacturing throughput time (i.e., from the start of the first manufacturing operation to the completion of the last operation) (Rigging and Mukhopadhyay 1994). The notion of speed also refers to time-to-market and product development (Scott 2000). Reliability relates to the ability of a plant to follow through on its commitment to a particular delivery date. It is measured by the percentage of orders delivered late and, for those delivered late, average tardiness. Supply chain activities have been shown to be associated with delivery performance (Vachon and Klassen 2002).

Beamon (1999) proposes that flexibility should be considered in supply chain performance. Supply chain flexibility is defined as the system's ability to accommodate volume and schedule fluctuation from suppliers, manufacturers, and customers. This definition is consistent with the manufacturing literature that advocates mix flexibility, new product flexibility, and volume flexibility as a means of reacting to operating context fluctuations (Suarez et al. 1995; Vickery et al. 1999).

Manufacturing organizations have a direct impact on the natural environment through its process design and management (e.g., pollutant, energy consumption) and product design (e.g., hazardous material). Historically, the reporting of environmental performance has not been given a great deal of attention (EPA 2000b) as the operations management literature traditionally emphasized the performance metrics related to cost, quality, delivery and flexibility. Recent international environmental meetings and trends for more environmentally sound operations, require considering environmental performance to be added to that list. Besides the Toxic Release Inventory in the US (TRI) or its Canadian equivalent the National Pollutant Release Inventory (NPRI) filed by individual facilities as required by law, only a few generally recognized measurements can be found in the literature.

Klassen (1995) provided an excellent review of environmental performance measurement used in the literature prior to 1995. Since 1995, the measurement used for plant and firm level environmental performance was the TRI computed by the EPA in the United States (Geffen and Rothenberg 2000; Hamilton 1995). It has been widely used in events studies and has been linked with financial performance (Dowell et al. 2000; Konar and Cohen 2001). The Canadian equivalent, the National Pollutant Release Inventory (NPRI) has not been used as extensively in academic research because it is more difficult to create sizeable sample to conduct meaningful empirical statistical analysis.

2.2. Green Operations Management

Two main perspectives in environmental management were researched. The first perspective focuses on environmental strategy and practices within one organization and investigates their antecedents in the organization and performance outcomes. Several studies in that stream were conducted characterizing environmental strategy by the extent of proactive behavior in an organization, as opposed to reactive (Hunt and Auster 1990; Porter and Van Der Linde 1995), and assessing the influence of environmental strategy on different performance metrics (Aragon-Correa 1998; Cordeiro and Sarkis 1997; Khanna and Damon 1999; Sharma and Vredenburg 1998). However, most of the studies regarding environmental strategy are difficult to link within a manufacturing and operations management framework because they are mostly conducted at the firm or corporate level.

Using the same internal perspective, other studies concentrated on the implementation and the impact of an environmental management system such as ISO 14001 at the business unit or plant level (e.g., Corbett and Russo 2001; Darnall et al. 2001; Montabon et al. 2000). This type of analysis builds on earlier work that had initiated the integration of different operations management principles with environmental management (Angell and Klassen 1999; Corbett and Van Wassenhove 1993; Klassen 1993). For example, linkages of environmental management with process-based strategy such as lean production (King and Lenox 2001; Rothenberg et al. 2001) and quality management (Curkovic et al. 2000) have been conceptualized in the literature. In this dissertation, a similar manufacturing perspective is examined. This perspective, based on environmental technologies, is elaborated in sub-section 2.2.1.

A growing interest on the influence of different stakeholders, including members of the supply chain, on corporate and operations environmental strategy is evident in the literature (Delmas 2001; Henriques and Sadorsky 1999). Hence, another perspective in environmental management is considering boundary spanning activities and the organization's interaction with its external context. The interaction with other members of the supply chain – customers and suppliers – regarding environmental issues has generated a stream of research concentrating on reverse logistics, remanufacturing, design for the environment and green purchasing. Several analytical studies have examined the interaction among supply chain members in regards to product recovery (Fleischmann et al. 1997; Guide 2000) and shared-saving contracts (Bierma and Waterstraat 1996; Corbett 2001). In this dissertation, another segment of the literature, focusing on the environmental interaction between organizations in a supply chain, also referred to as green supply chain, is reviewed. *Green supply chain practices* are discussed in detail in sub-section 2.2.2.

2.2.1. *Environmental Technology*

Both theoretical and empirical studies have sought to define and categorize environmental technologies. Some of these propose a dichotomy that separates the different technologies into pollution control and pollution prevention (often referred to as clean technology) (De Hoo 1997; Dieleman and De Hoo 1993; Lanjouw and Mody 1996; Sarkis and Cordeiro 2001). More elaborated categories have also been proposed in the literature. For example, Shrivastava (1995) developed a typology of environmental technologies that include five themes:

(i) design for disassembly;
(ii) manufacturing for the environment;
(iii) total quality environmental management;
(iv) industrial ecosystems;
(v) technology assessment.

These categories are not grounded in practical operations aspects and are difficult to operationalize in an empirical research design. Unfortunately, this typology cuts across different levels of the organization, and the categories are not mutually exclusive. A categorization grounded in a theoretical framework would be more useful and more appealing for studying the selection of environmental technologies in manufacturing. Using the operations strategy literature, Klassen and Whybark (1999b) proposed such a grounded typology by considering three forms of environmental technologies: pollution prevention, pollution control and management systems.

The groundbreaking work of Skinner (1969; 1978) helped to establish a paradigm that defines operations strategy as a set of decisions regarding manufacturing bricks-and-mortar and operational procedures. The classification of these different decision and investment areas into *infrastructural* and *structural* has emerged as an important, foundational feature of the operations strategy paradigm (Leong et al. 1990) (a rough analogy from information systems is hardware and software). Structural decisions are related to capacity, facilities, equipment, automation, and the degree of vertical integration: they usually require significant capital outlays and are difficult to alter or reverse (Hayes and Wheelwright 1984, p. 31). Infrastructural decisions affect the people and systems that make manufacturing work; these decisions are related to the workforce, quality management, production planning and control, and organizational issues such as reward systems, roles, and responsibilities. Both sets of decisions are equally important in operations strategy (Hayes et al. 1988; Leong et al. 1990), and can be linked to environmental management in manufacturing organizations (Angell and Klassen 1999; Corbett and Van Wassenhove 1993).

Pollution prevention technologies are *structural* investments in production that involve process- or product-based changes (Klassen and Whybark 1999a). The emphasis here is the physical product and/or process change. Investments in technologies that reduce or eliminate pollution sources (by using new equipment that consumes less energy or that reduces the scrap level) are investments in pollution prevention (Hart 1997). Material substitution (e.g., water- instead of solvent-based ink in printing) and source reduction (e.g., the use of recycled substrate in printing) are also examples of pollution prevention technologies. While better housekeeping, environmental management systems, and integration of environmental considerations in production planning and scheduling are considered by some to be preventive (e.g., Hart 1995), these activities are infrastructural investments. As such, this narrow definition reflects the structural/infrastructural distinction and operational implications made in operations strategy research (Wheelwright 1984).

In contrast, pollution *control* technologies are structural investments that treat or dispose of pollutants or harmful byproducts at the end of a manufacturing process. To accomplish this, additional operations or equipment must be added to the end of an existing manufacturing process, leaving the original product and manufacturing process virtually unaltered. Pollution control technologies include both end-of-pipe controls and remediation. End-of-pipe controls usually take the form of equipment that is added as a final step to capture pollutants and wastes prior to their discharge (e.g., air filtration systems). Remediation refers to cleaning up the environmental damage caused by crises or past practices and is often driven by regulation or a better scientific understanding of environmental damage (e.g., cleanup of leaking oil tanks). Managers often prefer these types of technologies because they are less disruptive than structural and integrated changes in products and processes. Therefore, despite the potential benefits of selecting pollution prevention technologies, managers have demonstrated resistance to such changes (Bonifant et al. 1995; Jones and Klassen 2001).

Management systems are *infrastructural* investments that affect the way manufacturing is managed. They include efforts to formalize procedures for evaluating environmental impacts during capital decision budgeting, to gain ISO 14001 certification, to increase outside stakeholder involvement in managing operations, to increase employee training for spill prevention and waste reduction, and to develop better housekeeping procedures. For example, a printing plant manager can schedule products with light-colored inks ahead of those requiring dark inks to reduce the use of cleaning solvents between print runs. Often these infrastructural systems include aspects that both control and prevent environmental degradation.

The observable pattern of investment can be thought of as a portfolio with a plant- or firm-specific mix of different types of environmental technologies selected. Based on a comparison of classification approaches, three broad and mutually exclusive categories of environmental technologies are identified: pollution prevention, pollution control, and management systems. The classification put forward by Klassen and Whybark (1999a) allows environmental technology selection to be assessed at the plant level. It is also consistent with the most recent developments in the field made by Statistics Canada (2000) in their bi-annual survey on environmental protection expenditures. Statistics Canada collects data on six categories of expenditures (Statistics Canada 2000):

(i) environmental monitoring;

(ii) assessment and audit;

(iii) reclamation and decommissioning;

(iv) wildlife protection;

(v) end-of-pipe processes; and

(vi) integrated processes.

The integrated process category corresponds to the pollution prevention as defined in Klassen and Whybark (1999a). End-of-pipe processes and reclamation/decommissioning together comprise pollution control technologies. Finally, environmental monitoring/assessment and auditing represent the management systems. Wildlife protection, the only category that is not included in Klassen and Whybark's classification, does not create a major bias since it accounts for less than 2% of the total capital expenditures in Canada and is mostly done by the primary sector of the economy (i.e., utilities, logging, pulp/paper).

A manufacturer's investment in environmental management is affected not just by the *form* (i.e., allocation) of that investment across different types of environmental technologies—pollution prevention, pollution control and management systems— but also by the *level* (i.e., extent) of resources invested in environmentally related projects (Klassen 2000; Klassen and Vachon, forthcoming). Hence, in this dissertation explicit recognition of the absolute value of the investment in environmental technologies is made.

2.2.2. Green Supply Chain Practices

The consideration of interorganizational activities related to environmental management is the primary characteristic of *Green Supply Chain Practices* (GSCP). They differ from environmental technologies, discussed in the last sub-section, as the latter is mainly internally focused. Unlike environmental technologies and partly due to the lack of consensus in the supply chain management literature, it is more difficult to conceptually develop GSCP in a solid theoretical framework. This absence of a theoretical framework can explain the broad range of definitions and conceptualizations found in the literature. For instance, environmental issues in the supply chain have been labeled and defined using a variety of terms including *green supply* (Bowen et al. 2001), *environmental purchasing* (Carter and Carter 1998; Zsidisin and Siferd 2001), *green purchasing* (Min and Galle 1997), and *green value chain* (Handfield et al. 1997). To this literature, one needs to add the numerous studies on product stewardship (e.g., Snir 2001), life-cycle-analysis (e.g., McIntyre et al. 1998), reverse logistics (e.g., Stock 1998), and product recovery (e.g., Thierry et al. 1995). However, from these several studies, it is possible to extract some generally accepted characteristics about GSCP; they include:

(i) interaction between a buying plant and its suppliers directed at achieving sustained improvements in environmental performance at the buying organization's plant (Handfield et al. 1997; Hines et al. 2000);

(ii) interaction between a buying plant and its suppliers directed at achieving sustained improvements in environmental performance at the suppliers' plant (Gavaghan et al. 1998; Lippmann 1999); and

(iii) information gathering and processing in order to evaluate or to control suppliers' behavior regarding the natural environment (Krut and Karasin 1999; Min and Galle 1997).

The recent application of the internalization/externalization framework (Buckley and Casson 1976) to supplier development (Krause et al. 2000) can help to establish a theoretical basis to GSCP. The internationalization/externalization framework suggests that organizations in a situation of imperfect market and uncertainty can opt to internalize some markets by committing internal resources to bypass such markets. However, an organization can practice both internalization and externalization, as they are not mutually exclusive (Krause 1999; Krause et al. 2000; MacDuffie and Helper 1997). Using a similar framework, an organization can approach environmental issues in the supply chain management by:

(i) internalizing such functions by conducting activities directly involving their own resources; or,

(ii) using external markets (arm's length) to evaluate suppliers' performance and to create pressure for them to comply and improve.

Based on these two possible approaches, and integrating the general characteristics pertaining to GSCP, two sets of supply chain practices are defined (Hall 2000; Lippmann 1999; Noci 1997):

(i) activities comprising a direct involvement of the buying organization with its suppliers to jointly develop environmental solutions, termed here as *environmental cooperation*; and,

(ii) activities using markets or arm's-length transactions conducted by the buying organization in order to evaluate and control its suppliers, termed here as *environmental monitoring*.

While similar to the Bowen et al. (2001) classification scheme of green supply, environmental cooperation in GSCP is more complete than what they proposed; as it includes the notion of collaborative planning and solution finding between organizations.

It is more inclusive than most of the green purchasing literature that suggests green purchasing is the degree of involvement of the purchasing function in environmental strategy development and planning (Carter and Carter 1998; Min and Galle 1997; Zsidisin and Siferd 2001). Environmental cooperation corresponds to the *internalization* component of the internalization/externalization framework.

Environmental monitoring involves activities of gathering and processing supplier information through publicly disclosed environmental records, questionnaires, and/or audits (Walton et al. 1998; Min and Galle 1997). Another set of practices consistent with environmental monitoring requires chain members to comply with specific environmental practice standard or codes. Usually, these standards are embedded in the selection and evaluation criteria of suppliers (Walton et al. 1998). ISO 14000 certification, as required by large American automotive companies, constitutes an example of a practice that imposes environmental process management on suppliers. In a similar way, a customer can impose specifications for parts, components, or materials on its suppliers to satisfy regulations or downstream requirements. For example, a commercial printer providing packaging to an environmentally-conscious consumer product manufacturer (e.g., The Body Shop) can be forced to conform to a minimum level of recycled fibers in the paperboard supplied by the paper mill.

The objective for plants practicing extensive environmental monitoring is to gain a certain level of assurance that their suppliers comply with the regulations and to reduce risks associated with environmental issues. These risks are not only legal and financial, but also operational. If a supplier is shut down because of a hazardous material accident or because it faces an EPA ordinance to clean up contaminated soil, the buying organization might face a sudden shortage of a critical part or material. Environmental monitoring corresponds to the *externalization* component of the internalization/externalization framework. Similar to supply chain integration, green supply chain practices can take place upstream with the suppliers as well as downstream with the customers (Figure 2.5). Note that environmental cooperation and environmental monitoring are conceptualized as being orthogonal.

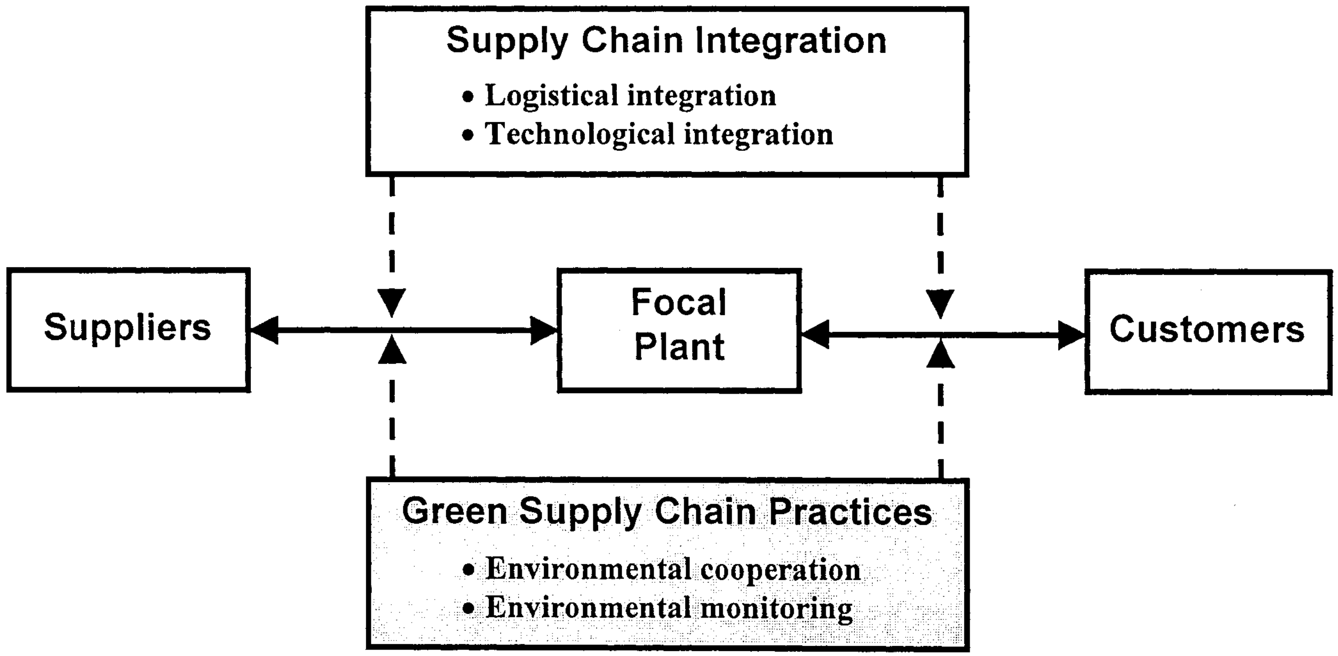

Figure 2.5 Simplified Supply Chain—With Green Supply Chain Practices

2.3. Resource Based View of the Firm

Environmental management, both internal to the plant and external, in the supply chain, can be analyzed through the resource-based view of the firm (RBV) (Barney 1991). The RBV suggests that a firm, through the set of resources it possesses, can develop capabilities providing competitive advantage. In order for a resource to provide sustainable competitive advantage it needs to be (i) valuable, (ii) rare, (iii) not substitutable, and (iv) imperfectly imitable. Hence, according to the RBV, resources that are valuable and costly to copy provide a source of sustained competitive advantage (Grant 1996b).

Research on the RBV in manufacturing is sparse but can provide important insights (Amundson 1998; St. John et al. 2001). For example, manufacturing synergy among business units of large corporations, measured by the number of common activities within their respective value chain, was argued to generate manufacturing competencies (St. John and Harrison 1999). More recently, resources generated through inter-organizational and internal learning were positively correlated with manufacturing performance (Schroeder et al. 2002). The RBV was also used as a theoretical lens in studying supply chain management and environmental management.

2.3.1. RBV and Supply Chain Management

Inter-organizational learning, which can occur through supply chain management, entails a problem solving routine involving suppliers and/or customers (Schroeder et al. 2002). As such, it is often recognized as providing additional capabilities to organizations (Dyer and Singh 1998; Grant and Baden-Fuller 1995; Lorenzoni and Lipparini 1999; Teece et al. 1997). This process of capability development through the supply chain is often referred to as the relational view of supply chain management and is a complementary perspective to the RBV (Dyer and Singh 1998). The relational view suggests that organizational capabilities can be developed by the combination of resources existing in different organizations in the supply chain (Dyer and Nobeoka 2000; Dyer 1996; Kaufman et al. 2000; Lorenzoni and Lipparini 1999; Schroeder et al. 2002; St. John and Harrison 1999; Takeishi 2001). Therefore it is possible to establish a theoretical link between different supply chain activities – supply chain integration or GSCP – and organizational performance.

2.3.2. RBV and the Natural Environment

The natural-resource-based view of the firm (NRBV) offers a similar perspective for environmental management (Hart 1995). An environmental management strategy founded on resources that exhibit the properties proposed by the RBV will theoretically create a sustained competitive advantage (Russo and Fouts 1997; Hart 1995). Resources developed through environmental management can generate operational capabilities such as the ability to more easily manage technological change (Russo and Fouts 1997), increased stakeholder integration (Sharma and Vredenburg 1998), and continuous improvement routine (Hart 1995).

The NBRV was the theoretical grounds for two survey-based studies involving manufacturing organizations. Klassen and Whybark (1999b) argued that the selection of pollution prevention technologies enable manufacturing organizations to develop capabilities difficult for competitors to replicate. They tested this proposition with a survey in the American furniture industry and found that a greater emphasis on environmental investment in pollution prevention technologies was positively linked to cost, delivery, flexibility, and environmental performance. Christmann (2000) used the concept asset complementarity to argue that manufacturing organizations can develop capabilities through the combination of process-related skills such as the use of, innovation in, and early application of pollution prevention technologies (within the industry). Her primary finding was that the combination of innovation and implementation skills related to pollution prevention technologies led to a cost advantage when compared to major competitors.

2.4. Integrative Model

Before providing an integrative model, an important distinction between supply chain integration and GSCP needs to be made. Supply chain integration emphasizes the sharing of knowledge – tacit or explicit – on general aspects related to tactical or strategic activities. Green supply chain practices are characterized by the type and degree of interactions between the members of a supply chain regarding, specifically, environmental issues. For instance, environmental monitoring relies heavily on explicit knowledge transfer through evaluative and control activities, but specific to environmental regulation compliance and sounded environmental practices. Hence, the major contrast is the higher degree of specificity of the activities included in GSCP.

The goal of this literature review was to develop a model linking four major constructs: supply chain integration, GSCP, environmental technology selection, and operational performance. Within the first construct, a distinction was made between logistical and technological integration within supply chains. The importance of these two dimensions is further developed in the next chapter.

Pooling know-how and providing cooperative solutions to environmental issues are more likely to cause a different set of environmental technologies to be selected by plant managers than without pooling. Similarly, the procedural content of environmental monitoring activities is more likely to lead to management systems or pollution control (Noci 1997). The integrative conceptual model presented in Figure 2.6 provides a sound theoretical basis for deriving testable hypotheses linked to the research objectives presented in section 1.4.

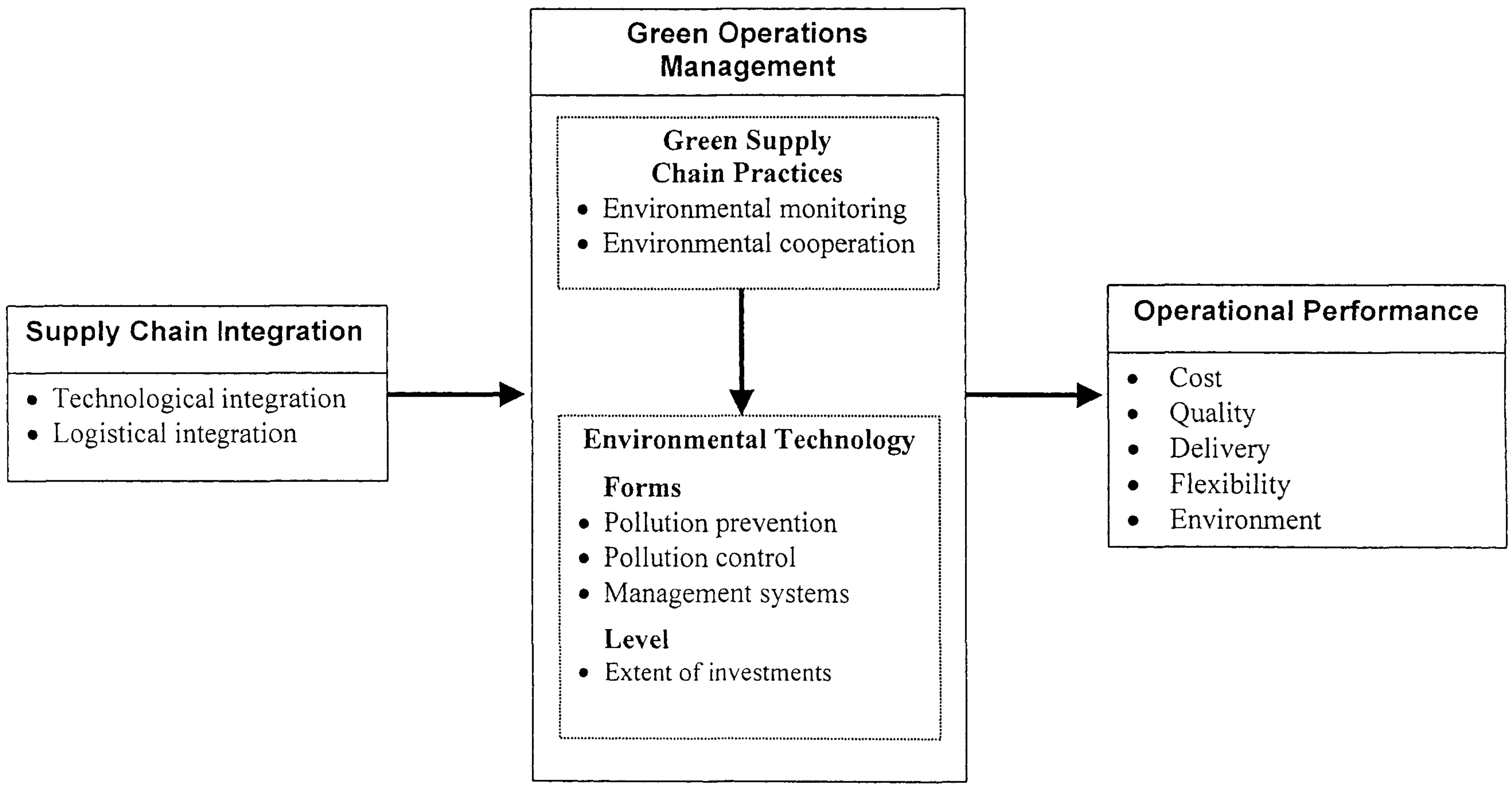

Figure 2.6 Supply Chain Environmental Management Model

3. RESEARCH HYPOTHESES

The conceptual model developed and presented in Figure 2.6 serves as the basis for deriving the research hypotheses that will be tested in this dissertation. This chapter begins by further developing the endogenous constructs (i.e., GSCP, environmental technology, operational performance) and exploring the linkages among them. After discussing these linkages, supply chain integration is further developed and other contextual variables related to the focal plant and its supply chain are introduced. Their potential impact on GSCP and environmental technology selection is then examined. The chapter ends with a synthesis of all the hypotheses put forward.

3.1. Green Supply Chain Practices

Green supply chain practices (GSCP) include environmental cooperation and environmental monitoring activities. Environmental cooperation occurs when a plant shares its know-how and experience with its suppliers and/or customers for environmental management and planning purposes and to find solutions to environmental challenges (Florida 1996; Gavaghan et al. 1998; Rao 2002). Environmental monitoring includes the imposition of standards and environmental requirements such as the respect of existing regulations or industry standards, and it is usually conducted through audits or questionnaires (Goldsby and Stank 2000; Krut and Karasin 1999; Walton et al. 1998). Both of these sets of activities have a potential influence on environmental management practices and thereby operational performance.

3.1.1. Environmental Cooperation to Operational Performance

Environmental cooperation activities include the exchange of technical information and require a mutual willingness to learn about each other's operations in order to improve environmental practices (Canning and Hanmer-Lloyd 2001; Geffen and Rothenberg 2000). They also include collaboration to reduce the environmental impact associated with material flows in the supply chain (Bowen et al. 2001; Carter and Carter 1998). These practices take the form of joint planning and decision-making regarding environmental issues, which is consistent with examples and cases presented in the green supply chain literature (Geffen and Rothenberg 2000; Handfield et al. 1997; Krut and Karasin 1999; Walton et al. 1998).

Several cases in the literature illustrate the linkage between environmental cooperation and operational performance. For example, Xerox, a leading firm in the photocopier industry, leveraged its Asset Recycle Management program to generate an annual savings of $300 to $400 million (Hart 1997). These savings were the end result of a broad array of managerial practices that have reshaped the Xerox supply chain. In particular, Xerox favored partnerships with its suppliers as one critical approach to fostering the design of more environmentally friendly products (Xerox 1999). By interacting with its key suppliers to design products that are easier to remanufacture, Xerox developed a capability difficult for the competition to replicate, which lead to improved environmental and operational performance (Reinhardt 1999).

Another example of environmental cooperation is Castrol, a lubricant producer supplying the automotive industry. Castrol worked with one of its customer's plants to insure a proper use of its chemical. This interaction resulted in process modifications leading to significant savings through less chemical use at the customer's plant, hence helping the environment (Reiskin et al. 2000). Similar anecdotal evidence has been reported for the automotive industry (Geffen and Rothenberg 2000). Specifically, a paint and coating supplier worked on-site in the paint shop of an automaker to develop a better product-based solution to the ever-increasing pressure faced by the automakers to reduce VOC (volatile organic compound) emissions.

The competitive advantage generated by environmental cooperation is twofold. First, it includes knowledge integration and collaboration between organizations, which are recognized to be resources having the properties required to generate competitive advantage (Grant 1996a; Simonin 1997). As such, manufacturing organizations adopting cooperative activities with their suppliers and customers can develop organizational capabilities (Lorenzoni and Lipparini 1999), which will be reflected not only in environmental performance but also in other performance dimensions such as cost and quality (Hart 1997; Porter and Van Der Linde 1995). In fact, environmental cooperation can also lead to improved productivity (Geffen and Rothenberg 2000), improved financial performance (Carter et al. 2000), and greater product quality (Gavaghan et al. 1998).

Second, environmental cooperation is directly associated with a proactive environmental management orientation (Noci 1997), as the ability to respond efficiently and effectively to new environmental challenges and regulations (Bonifant et al. 1995; Klassen and Whybark 1999b). Because cooperative GSCP are linked to proactive management orientation (Noci 1997; Bowen et al. 2001), it is expected to influence positively operational performance (Aragon-Correa 1998; Porter and Van Der Linde 1995).

> *H1a: As cooperative GSCP increases, cost performance improves.*
>
> *H1b: As cooperative GSCP increases, quality performance improves.*
>
> *H1c: As cooperative GSCP increases, delivery performance improves.*
>
> *H1d: As cooperative GSCP increases, flexibility performance improves.*
>
> *H1e: As cooperative GSCP increases, environmental performance improves.*

Note that these hypotheses, as all those following in this chapter, assume *ceteris paribus*.

3.1.2. Environmental Monitoring to Operational Performance

Environmental monitoring is common practice in several industries in North America (Min and Galle 1997; Walton et al. 1998) and around the world (Gascoigne 2002; Krut and Karasin 1999). For example, the U.S. electronic industry developed a standardized questionnaire, used by major companies such Hewlett-Packard, Compaq, and IBM to evaluate the environmental practices of their suppliers around the world. As noted by an HP procurement representative: "We can't constantly be in charge of making sure that they comply… and the suppliers are accepting responsibility for their own environmental practices" (Krut and Karasin 1999). This last statement reflects two important points. First, it demonstrates that environmental monitoring is an arm's-length activity using external procedures to address environmental issues in the supply chain. Second, it shows that competitive advantage can hardly be developed through practices such as questionnaires, audits or any other data gathering approaches that can be easily replicated by the competitors. Therefore, the theoretical foundation based on the NBRV is not applicable to environmental monitoring; other perspectives are needed.

Environmental monitoring aims to minimize managerial and environmental risk and assure a continuous supply (Drumwright 1994; Krut and Karasin 1999; Vachon and Klassen 2001). A critical supplier's operations being paralyzed or disrupted because of an environmental agency citation can have major consequences for the buying organization. However, such monitoring activities are expensive and require the deployment of financial and human resources providing very little value-added in the operations besides reducing the risk of disruption (Krut and Karasin 1999; Lippmann 1999). Hence, while increasing the reliability of deliveries, such practices hamper cost performance.

Note that environmental monitoring generates more formalization through the implementation of operational procedures in the supply chain (Krut and Karasin 1999; Wycherley 1999). A certain level of formalization is a fundamental premise of quality management systems (e.g., ISO 9000) and environmental management systems (e.g., ISO 14000), which seek respectively to improve quality and environmental performance (Corbett and Kirsch 2001; King and Lenox 2001). Such formalization can be important to impose structure and procedures in interorganizational activities. Environmental monitoring, through such procedures, also entails activities essential to the clear communication of environmental expectations and requirements to the suppliers (Gascoigne 2002; Lippmann 1999). Clearer information on specifications and other product features increases the degree of conformance, impacting positively on quality. However, those kind of formalized procedures can constrain suppliers from reacting effectively to unforeseen events, reducing the degree of flexibility (Choi et al. 2001; Segars et al. 1998). Building on this last section, the following set of hypotheses are proposed:

H2a: As environmental monitoring increases, cost performance worsens.

H2b: As environmental monitoring increases, quality performance improves.

H2c: As environmental monitoring increases, delivery performance improves.

H2d: As environmental monitoring increases, flexibility performance worsens.

H2e: As environmental monitoring increases, environmental performance improves.

3.1.3. Environmental Cooperation to Environmental Technology

Hart (1995) proposed that cooperation among the members of a supply chain leads to more advance environmental management including product stewardship. On the other hand, Ashford (1993) and Kemp (1993) argued that a lack of cooperation from the customers and lack of knowledge transfer from the suppliers are major impediments to a prevention technological response to environmental issues. It is also suggested that suppliers can be primary drivers in pollution prevention technology development (Bonifant et al. 1995; Green et al. 1998). Noci (1997) proposed that the cooperative activities should be considered as being proactive, leading to less pollution control and more pollution preventation technologies. Hence, through a supplier's knowledge and the willingness of customers to participate in strategic features of the focal plant's operations, environmental cooperation leads to more systemic environmental solutions (Florida 1996; Geffen and Rothenberg 2000).

Cooperative GSCP also facilitate the implementation of product- or process-based modifications and therefore reduce the reluctance of managers to implement systemic solutions, which might be disruptive (Jones and Klassen 2001). In fact, environmental cooperation activities with suppliers and customers usually leads to structural changes in the focal plant's products (Cramer and Schot 1993; Noci 1997) or processes (Geffen and Rothenberg 2000). For example, Phillips' eco-design initiative includes a roadmap for improving product design and environmental performance by working closely with its suppliers (Young and Kielkiewicz-Young 2001).

Suppliers can react to a customer's needs by developing and introducing technologies that reduce emissions. An example of such a supplier-driven environmental technology is the recent development of hybrid inks in the printing industry. Hybrid inks allow applying an UV (ultra-violet) coating within a press run instead of waiting for the ink to dry before applying the coating, saving emissions during the usual drying period. Because this ink dries instantaneously, the coating can be immediately applied (Adams 2001). As a result, the print runs produce less volatile organic compound (VOC) emissions. An example of a customer-driven environmental technology is the incorporation of the package printers into the new package design in order to reduce waste and, therefore, reduce environmental harm from the printing process (O'Brien

1999). Such a transfer of knowledge can only take place in a cooperative context where joint environmental planning and solution finding are possible.

H3a: As environmental cooperation increases, a greater proportion of environmental investment is made toward pollution prevention.

The literature does not provide indication on the influence of environmental cooperation on the level of investment in environmental technology. It can be argued, however, that environmental cooperation, through better planning and problem solving activities with other supply chain members, allows the focal plant to assess more environment-related projects with positive outcomes. This is linked to notion of complementary assets Christmann (2000), which suggests that the combination of resources provides opportunities that were not possible using the resources individually. Such opportunities, can translate into greater total investment across all environment-related projects.

H3b: As environmental cooperation increases, the level of investment in environmental technology increases.

3.1.4. Environmental Monitoring to Environmental Technology

Environmental monitoring is linked to an arm's-length approach to GSCP where the buying organization does not get involved in the suppliers' operations (Vachon and Klassen 2001). This type of activity is generally not associated with design-for-environment and concurrent engineering efforts (Florida 1996). As such, monitoring activities within GSCP are less likely to trigger process modification or product adaptation, which are fundamentally linked to pollution prevention.

Environmental monitoring through its procedural and formalized approach in GSCP requires a greater emphasis on management systems (Florida and Davison 2001; Walton et al. 1998). By aiming to control and evaluate managerial and environmental risks, environmental monitoring does not reduce or eliminate pollution sources; these activities push the environmental technology selection toward more pollution control and management systems (Vachon and Klassen 2001). Furthermore, increasing the degree of formalization in the supply chain can inhibit innovative behavior in an organizational system (Choi et al. 2001).

Given that monitoring activities tend to focus on easily verified measures, these activities also can be expected to affect the selection of environmental technologies. First, rather than encourage systemic changes, which often require long term planning and joint implementation, suppliers might instead favor "quick fixes" such as those offered by end-of-pipe pollution control equipment (Noci 1997). Second, as the objective of evaluative activities is primarily to monitor and control, thereby forcing improvement, these activities are in many ways similar to environmental regulations that prescribe compliance (and specific paperwork) for particular emissions. Focusing on compliance can limit the set of technological options considered, which in turn leads to the adoption of end-of-pipe technologies being favored (Bonifant et al. 1995; Vachon and Klassen 2002a). Therefore, with more monitoring activities it is expected that the investments in both management systems and pollution control technologies will be higher.

> *H4a: As environmental monitoring increases, a greater proportion of environmental investment is made toward pollution control and management systems.*

Stakeholder analyses in the environmental management literature (e.g., Henrique and Sadorsky 1999) can help to establish a link between environmental monitoring and the level of investment in environmental technology. It can be argued, that environmental monitoring by customers, an important stakeholder, increase the managerial awareness related to environmental issues in a focal plant. As such, a focal plant invests more continually in order to comply with existing and coming regulations and different customers' requirements. On the other hand environmental monitoring of the suppliers conducted by a focal plant includes costly activities such as audits and information analyses from supplier evaluations.

H4b: As environmental monitoring increases, the level of investment in environmental technology increases.

3.2. Supply Chain Integration

Supply chain integration is defined as comprising logistical and technological integration. These two dimensions reflect, respectively, the tactical and strategic components of supply chain management. Logistical integration includes data sharing, and technological integration pertains more to product development, process reengineering, and resource commitment within the supply chain.

3.2.1. Supply Chain Integration to Green Supply Chain Practices

Logistical integration provides a basis for achieving cooperative solutions to reducing the environmental impact of the material flows among supply chain members. Studies show that supply chain coordination correlates positively with green purchasing actions (Carter and Carter 1998) and green logistical collaboration with suppliers (Bowen et al. 2001).

Also, with low logistical integration, more arm's-length transactions are conducted within the supply chain, which are an impediment to knowledge integration between organizations (Grant and Baden-Fuller 1995).

Similarly, prior technological integration experience is also important for effective collaborative activities involving tacit knowledge integration (Grant 1996a). Therefore, existing technological integration within a supply chain positively influences cooperative activities related to environmental issues. Evidence supporting the contention that supply chain integration is an antecedent to environmental cooperation is also found in Canning and Hanmer-Lloyd (2001), Roy et al. (2001), and Cramer and Schot (1993). While it could be argued that environmental cooperation can initiate integration in the supply chain (logistical or technological), it is unlikely that environment-related goals and objectives take precedent to more operational aspects that are related to cost, quality and delivery. Therefore, the relationship proposed here suggests that supply chain integration precedes environmental cooperation and not vice-versa.

> *H5: As the degree of supply chain integration increases (logistical and technological), environmental cooperation increases.*

3.2.2. Supply Chain Integration to Environmental Technologies

Technological integration is characterized primarily by tacit knowledge integration, which occurs through information exchange in a rich communication setting (Purdy and Safayeni 2000). These activities are also associated with the sharing of resources, such as equipment and personnel, among supply chain members in order to improve manufacturing or logistical performance along the chain. Cross-fertilization of resources can lead to systemic changes through new product development or process reengineering (Dyer and Nobeoka 2000; Lorenzoni and Lipparini 1999; Takeishi 2001). For example, technological integration can influence a plant's structural elements such as product quality design (Fynes and Voss 2002) and process reengineering pertaining to a lean production system (MacDuffie and Helper 1997). Hence, technological integration can lead to product adaptation and fundamental process modifications, which is the idea underlying pollution prevention technology.

H6a: As technological integration increases, a greater proportion of environmental investment is made toward pollution prevention.

Technological integration allows the focal plant to integrate its knowledge and capabilities with its suppliers and customers. Through knowledge sharing, collaborative activities reduce uncertainty, willingness to change, and other sources of resistance frequently associated with the lack of investment in environmental technologies (Ashford 1993; Kemp 1993).Collaboration along the supply chain also helps management to identify and evaluate a greater variety of options that might address particular environmental challenges (Bonifant et al. 1995).

H6b: As technological integration increases, the level of investment in environmental technologies increases.

The extensive low-level information sharing that occurs with logistical integration contributes to better inventory management, and improved scheduling and production planning. These improvements have implications for environmental management, as inventory management affects waste disposal, and production planning can reduce energy consumption and scrap generation. All of these are infrastructural in nature. Thus, it is expected that greater logistical integration would be consistent with greater allocation of environmental investment toward management systems.

> *H6c: As logistical integration increases, a greater proportion of environmental investment is made toward pollution control and management systems.*

3.3. Plant and Supply Chain Characteristics

Analysis of data on operational performance and the allocation of resources in different environmental technologies needs to be controlled for certain exogenous and contextual variables namely: organizational size, equipment age, the level of investment in new manufacturing equipment, and the size of supply network and customer base.

3.3.1. Organizational Size

Size is an important contextual variable that is widely used in operations strategy and environmental management literature (e.g., Grant et al. 2002; Klassen and Whybark 1999b). Organizational size is positively correlated to the ability to develop new products and processes (Damanpour 1996) while providing leverage in inter-organizational activities (Choi et al. 2001; Lambert et al. 1998). Because innovative capacity is linked to proactive management orientation (Aragon-Correa 1998; Florida 1996), there is a potential impact of organizational size on environmental technology selection and GSCP. Small organizations, more preoccupied with short-term issues not necessarily linked to environmental management (Arora and Cason 1995; Roy et al. 2001), usually invest less in pollution prevention technologies while being more reactive to environmental issues and regulations (Grant et al. 2002). However, they are under less scrutiny and will have less power over their suppliers. They also have less resources and knowledge to share with their major customers, which will likely translate into a decrease in cooperative activities with them. In this dissertation, the organizational size of the focal plants and their parent firm are introduced in the analysis to control for these potential discrepancies (Grant et al. 2002).

3.3.2. Equipment Age and Investment in New Equipment

The range of possibilities in terms of structural changes within existing products or processes is contingent on the capacity of the equipment to handle these changes. As the equipment ages, such possibilities diminish reducing the likelihood of managers to select pollution prevention technologies that require structural changes. In this type of situation, managers will aim for less disruptive technologies and favor end-of-pipe technologies along with infrastructural investments when faced with environmental challenges.

Investment in new equipment can provide an opportunity to improve the environmental performance of the process technologies employed in a plant (Klassen 2000a). However, it can also be argued that new technologies that increase the degree of automation will build complexity into the production process (Khurana 1999; Woodward 1965), rendering the new process less adaptable for environmentally-friendly structural changes (Roy et al. 2001; Vachon and Klassen 2001).

3.3.3. Supply and Customers Bases

So far the contextual variables have been associated with plant characteristics. Two characteristics of the supply chain structure are added for the analysis of GSCP. First, environmental cooperation and monitoring of suppliers are likely to be affected by the size of the supply network. The larger a supply base is the more difficult it is to develop long-term relationships and integration, which should impede the establishment of environmental cooperation. Similarly, a large supply network augments the managerial and environmental risk related to supply chain management. Hence, a larger supply network will be associated with more environmental monitoring activities. By analogy, customers may be subject to the same circumstances. A plant that has multiple customers might not be willing to invest resources in environmental cooperative activities with its customers. As such, we expect that the larger the customer base, the less environmental cooperation will occur.

3.4. Synthesis

Three major constructs — namely, green supply chain practices, supply chain integration, and environmental technologies — were further developed in this chapter. Several hypothetical relationships were developed among these three constructs and with operational performance. They are synthesized in Table 3.1. Not all the possible relationships were discussed and developed throughout the chapter. First, the relationship between environmental technology selection and operational performance has already been widely discussed and studied in the literature (e.g., Klassen and Whybark 1999b; King and Lenox 2002; Geffen and Rothenberg 2000). While no hypotheses were explicitly stated, environmental technology is included in the empirical analyses pertaining to operational performance.

Second, some relationships lack of theoretical support or they lead to an ambiguity in stating the actual relationship. For instance, the relationship between supply chain integration and environmental monitoring activities was not explicitly developed. Another example is the relationship between logistical integration and the level of investment in environmental technologies. Hence, these relationships were not hypothesized here.

The integrated model (Figure 2.6) is purposely analyzed in a sequential way: First, the front-end of the model, examining the antecedents of green operations management (i.e., green supply chain practices and environmental technology) is tested. Second, the influence of the green operations management on operational performance is examined. All the linkages will be tested using the research methodology described in Chapter 4.

Table 3.1 Hypothesized Relationship Between Constructs

Hypothesized Relations	Related Hypothesis	Expected Relationship
GSCP to Operational Performance		
Environmental cooperation to		
o Cost	H1a	+
o Quality	H1b	+
o Delivery	H1c	+
o Flexibility	H1d	+
o Environmental	H1e	+
Environmental monitoring to		
o Cost	H2a	–
o Quality	H2b	+
o Delivery	H2c	+
o Flexibility	H2d	–
o Environmental	H2e	+
GSCP to Environmental Technology		
Environmental cooperation to		
o Pollution prevention (form)	H3a	+
o Level of investment (extent)	H3b	+
Environmental monitoring to		
o Pollution control (form)	H4a	+
o Management systems (form)	H4a	+
o Level of investment (extent)	H4b	+
Supply Chain Integration to GSCP		
Technological integration to		
o Environmental cooperation	H5	+
Logistical integration to		
o Environmental cooperation	H5	+
Supply Chain Integration to Env. Technology		
Technological integration to		
o Pollution prevention (form)	H6a	+
o Level of investment (extent)	H6b	+
Logistical integration		
o Pollution control (form)	H6c	+
o Management systems (form)	H6c	+

4. RESEARCH METHODOLOGY

The next important step in this dissertation is to validate the conceptual model and proposed linkages between supply chain integration, green supply chain practices, environmental technology selection, and operational performance. As the literature shows, the examination of these linkages, separately or together, remains in its infancy. Several case-based and theory building research studies have been performed, however (Canning and Hanmer-Lloyd 2001; Gavaghan et al. 1998; Geffen and Rothenberg 2000; Handfield et al. 1997; Johnson and Leenders 1997; Krut and Karasin 1999; Wycherley 1999; Young and Kielkiewicz-Young 2001). Most of the studies using case-based methodology suggest the development of metrics and encourage the use of survey-based research to increase the generalizeability of the results (Carter and Dresner 2001; Handfield et al. 1997).

To date, very few large-scale survey studies were conducted regarding the influence of supply chain integration or of green supply chain practices on environmental management with, however, notable exceptions (e.g., Carter and Carter 1998, Bowen et al. 2001, Rao 2002). Moreover, these studies encouraged increasing the scope of research by incorporating more operating context constructs (Carter and Carter 1998) and to include operational performance (Bowen et al. 2001; Carter and Dresner 2001).

In this dissertation, a two-phase approach was undertaken to validate measurements and to test the conceptual model introduced in Chapter 2 and hypothesized in Chapter 3. Initially, a preliminary field study was conducted to augment the validity of the concepts and their respective linkages. This field study also helped in setting up the questionnaire used in the second phase, which consists of wide-scale data collection through a survey.

This dissertation research was conducted within a specific segment of the commercial printing industry that produces packages—folding carton, flexible package, and labels—for consumer and industrial goods. The selection of this industry was based on a set of criteria that are presented in the first section of this chapter. Other industries that were considered for this research are also briefly discussed in that first section. The second section of the chapter presents the major characteristics of the package printing industry, gleaned from the practitioner literature, cases from governmental and not-for-profit organizations sources (e.g., US Environmental Protection Agency, CleanPrint, and Printer's National Environmental Assistance Center), interviews with industry experts, and informal discussion with practitioners. The third section presents the results of the preliminary field study, which is an important component of the survey instrument development, which is discussed in section 4.4. Finally, the last section elaborates on how the survey was administered and implemented.

4.1. Industry Selection

A study focusing on one industry reduces the degree of heterogeneity of the industrial context, technology availability, and facility/process design. While this choice comes at the expense of the greater generalizeability of the results, this dissertation opts for a single industry research design.

Initially, several industries were considered in both the service and manufacturing sectors. The selection of an industry was based on a couple of specific criteria: (i) homogeneity in operating systems while having some variability in the selection of environmental technologies; and (ii) the existence of environmental challenges and of supply chain activities.

In the service sector, health care, specifically hospitals, was investigated because the industry recently took significant initiatives for more environmentally sound practices (Messelbeck and Whalley 1999). It was ruled out on the basis of the uncontrollable heterogeneity of services provided by each establishment (e.g., not every hospital provides cardiac surgeries or chemotherapy), which potentially would have compromised the empirical analysis.

Trucking and urban transit organizations were also considered as a research target. Both of these industries have substantial archival data collected by national institutions, and it would have been advantageous to combine these data with survey data. In the case of the urban transit industry, the number of sizeable organizations was insufficient to conduct meaningful empirical analysis using a survey. In the trucking industry, the preponderance of private companies and the diffusion (several small firms) in the industry make riskier the collection of data through a survey.

In the manufacturing sector, three industries were examined for the purpose of this research: aerospace, pharmaceutical, and commercial printing. The aerospace industry was interesting because of its important presence in Eastern Canada (particularly in Quebec); nevertheless, this industry also comprises several types of production process (e.g., batches vs. continuous flow) and many different products features (e.g., high vs. low technological content). These characteristics would have created a lot of noise that would have been difficult to control for in the empirical analysis. The pharmaceutical industry has very little variance in the application of environmental management, as it is tightly regulated and has a high public profile.

The printing industry, and particularly its packaging segment, fulfills all the selection criteria. Despite some minor differences in the printing process, discussed below, the operating systems and workflow are very similar from one plant to another (EPA 1995), however, the selection of environmental technologies, particularly between pollution control and prevention, varies across the industry (EPA 1997). Moreover, being closely associated with the consumer product sector assures its major customers' buying decisions are highly influenced by environmental management choices (Carter and Carter 1998).

4.2. Package Printing Industry – Description

The package printing industry comprises three segments—labels, folding carton, and flexible—that are not clearly identified in the North American Industrial Classification System (NAISC). This renders the assessment of the overall population of plants operating in that industry very difficult (EPA 2000a). However, estimates suggest that the package printing industry is a US$100 billion market in the United States, with 80% of the production being done by small companies with less than 50 employees (EPA 2000a).

Four major processes are used in the package printing industry: lithography, gravure, flexography, and screen printing (EPA 1995). Overall, in the commercial printing industry the lithographic process is widely used; however, in the packaging segment the most popular process is flexography, accounting for around 80% of total packaging printed in the United States (EPA 2000a). Gravure is known to be a printing process for high quality package. Screen printing is widely used on textile, glass, and non-traditional substrate. Because of these particularities, the research design proposed here excludes package printing plants using a screen printing process: hence, this dissertation focus on package printing plants that use one or a combination of the following printing process: lithography, flexography, and gravure.

4.2.1. Workflow Pattern and Manufacturing Challenge

Each printing plant's workflow is very similar, regardless of the printing process and the industry segment. Figure 4.1 represents the major operations associated with a complete printing job:

(i) imaging and pre-press operations, including the design, the plate making and presses setup;

(ii) the printing process itself where the ink is actually applied to a substrate (mainly paper/paperboard, film, and foil for package); and

(iii) post-press operations comprising activities such as trimming, die-cutting, folding, and gluing (EPA 1995).

Another important element in the workflow is the preparation of the ink prior to each job. A sound ink management process can lead to a substantial gain in print quality and productivity (Patterson 2001). A common strategy is to outsource the management of the ink room to an ink manufacturer. The ink manufacturer becomes responsible for the inventory and shares its know-how on that particular sub-process with the plant's employees.

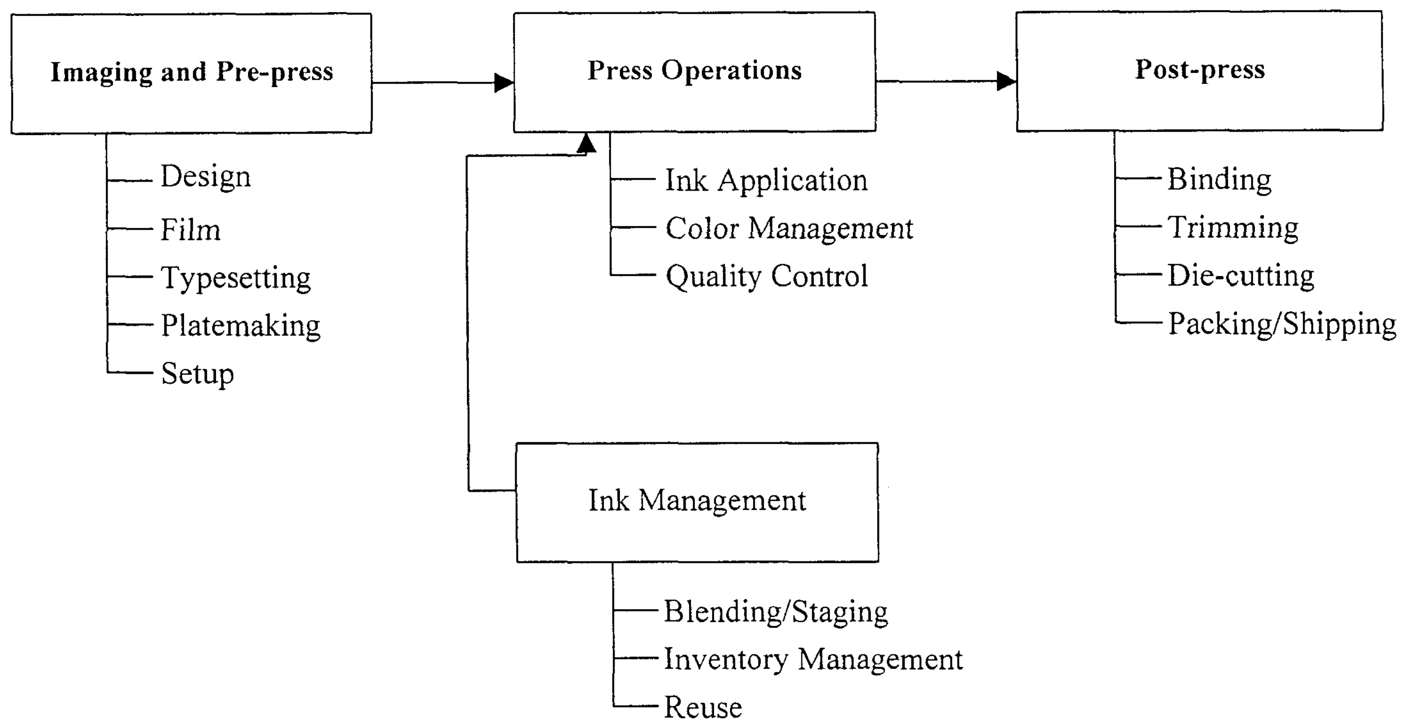

Figure 4.1 Typical Printing Workflow

There are also firms on the market that specialize in providing printing plants with pre-press operations. Several marketing/advertising companies have integrated forward to provided electronic files with all the imaging specifications ready for plate making. However, post-press operations are rarely outsourced. This dissertation did not explicitly considered such strategies (in-house operations vs. outsourcing) in the analysis.

4.2.2. Supply Chain Characteristics and Practices

Relative to the entire industry, there is a small number of big package printing firms (e.g., Shorewood Packaging, Smurfit-Stone, Rock-Tenn), and they are usually part of a conglomerate firm (e.g., Shorewood Packaging is a division of International Paper). Hence, in general, each segment of the industry—folding carton, flexible, and label—is fragmented into several single-plant companies (companies that have multiple plants usually do not have many). In contrast, the substrate and chemicals suppliers are part of more concentrated industries where large firms are the norm. For example, Sun Chemicals, Flint Inks, and INX International, all ink suppliers, capture nearly 60% of the United States flexographic ink market (EPA 2000a). A high level of concentration also characterizes the industries supplying substrates, comprising major paper companies, such as International Paper and Bowaters, and large film producers like Sonoco and Dupont.

Most of the package printing industry serves consumer product manufacturers, which means that a lot of production changes are customer-driven, as are the frequent design changes, which are driven by new marketing strategies or promotional campaigns. One has to keep in mind that package-printing plants are producing products involved in at least one other operation at the customer's plant. Therefore, structural and print-related properties become highly important in order to minimizing filling line stoppage or scrap at the customer's plant. Finally, a degree of interaction exists between package printing plants, their major suppliers (EPA 2000a; PNEAC 2000), and their customers (O'Brien 1999).

4.2.3. Environmental Challenges and Technologies

The printing industry, including the package segment, has had to deal with increasing regulations regarding in particular volatile organic compound (VOC) emissions (PNEAC 2000) and hazardous disposal, classified as hazardous air pollutant (HAP) and regulated under the Superfund Amendments and Reauthorization Act (SARA). Air emissions taking the form of VOCs are the primary environmental challenge for the industry. VOCs can come from ink evaporation, solvents used to clean up presses, and used wipes/towels (EPA 1995). Solid waste management is another environmental concern for printers, particularly when such waste contains hazardous substances (e.g., used solvent and obsolete inks).

A growing concern is associated with wastewater management (Monteleone 2001). With more printers using water-based inks to avoid VOC, the cleanup does not require as much solvent but rather more water. Since the water from cleanup contains pigments, auxiliary solvents, and additives, it can exceed the quantity of pollutant allowed in water discharge. Substrate scrap and waste due to malfunction of the press, setups, or cutting is another environmental challenge faced by package printers, although to a minor extent.

Dealing with environmental issues in the printing industry involves making technological choices to comply with regulations or to preempt them. A review of the popular press suggests that environmental technologies can indeed be categorized along the proposed pollution prevention, pollution control, and management systems portfolio. Several examples of environmental technologies can be found in different published and publicly available case studies (Table 4.1). For example, lower emission from the production processes can result from the use of enclosed doctor blades, which systematically wipe off excess ink for immediate reuse during the printing job in the flexography process (Monteleone 2000). Other examples include the covered ink pan in gravure printing that prevents premature evaporation of the ink during the printing process (EPA 1995) and closed-loop solvent/alcohol recuperation systems, which distill and condense room emissions into reusable material in lithography (Bauer 2000). Pollution prevention can also take the form of material substitution, exemplified by the transition toward water-based ink from solvent-based ink, or the use of alcohol-free ink solutions.

Table 4.1 Illustrative Case Studies on Environmental Technologies in the Printing Industry

Company (Environmental Technology)	Issues, Solution, Outcome
Keller Crescent (Jones 2001) (pollution prevention)	• Operations generated 350 barrels of used shop towels and 55 barrels of used blanket wash (mixture of 50/50 solvent and water). • Worked a year with a supplier to introduce microwave-processing unit to remove solvent from towels. • Eliminated hazardous waste cost, solvent recovery rate of 98% reusable in the shop, reduce solvent purchase by 25%.
John Roberts Company (Adrian 2002) (pollution prevention)	• Air temperature management required a lot of energy. • Two projects to reduce energy consumption related to in-plant temperature: (i) new pressurized air system reducing leakage, more reliable and more efficient; (ii) a new paper trim waste system reducing the air exchange (in-plant vs. outside). • Both projects led to annual savings in the neighborhood of $35,000.
John Roberts Company (EPA 1993) (management system) (pollution prevention)	• Solvent in towels was causing problem for the laundry facility. The laundry facility collaboratively worked with the printers to find a solution. • A meticulous operations audit led to solvent substitution (less volatile and more appropriate for the purpose). Training and press operators' involvement was key in the process. • Type wash solvent use was reduced significantly from 155 to 5 fifty-five-gallon drums, yielding a net saving of $18,000/year.
Americraft Carton Inc. (Anonymous 2000) (pollution prevention)	• Large quantity of isopropyl alcohol in ink solution creating concerns for employees' health. • Introduction of water-based solution system. • Less variability during setups, cost savings in purchased solvent (over $200,000 in 6 years), significant drop in VOC emissions.
WinCup Inc. (PNEAC 2000) (pollution prevention)	• Extensive use of isopropyl alcohol in cleaning presses and related soil after print runs. • Working with its supplier, WinCup substituted IPA for solvent that reduce VOC emissions. Pressroom crew needed training in the application and use of that new solvent. • VOC emission dropped from 4.32 tons to 2.85 tons, allowing an increase in the production within the permitted emission level.

Table 4.1 Illustrative Case Studies on Environmental Technologies in the Printing Industry (continued)

Company	Issues, Solution, Outcome
Custom Print (EPA 1996) (management system)	• Custom Print wanted to establish a pollution prevention program. • In order to fulfill its pollution prevention goal, Custom Print conducted a thorough process analysis, created teams of employees, and consulted its suppliers. • The use of multitask chemicals, eliminated duplication in chemical purchases. Number of chemicals on site dropped from 80 to 24, with an estimated recurrent annual savings of $5,000.
F.C. Meyer (Anonymous 1999) (management system)	• Generated 10 fifty-five-gallon drums of hazardous waste per week. • Employee training, reuse of waste water in black ink, modification of clean up procedures • Reduction to 1-2 fifty-five-gallon drums of non-hazardous waste yielding an annual saving of $47,000.
Hood Flexible Packaging (Deasy 1998) (management system)	• Hood produced nearly 1 million pounds of plastic film scrap in 1996 (scrap rate of 6.5%): wanted to be at par with industry average of 4% scrap rate. • Press operators training, increased coordination between extrusion and printing operations, recycling segregation. • Saving of $50,000 per year and reduction of 100,000 pounds of scrap film.
Packaging Specialties (EPA 1997b) (pollution control)	• Unsuccessful implementation of water-based inks combined with large quantities of VOC emissions forced Packaging Specialties to find other technological solutions. • Installed equipment with a 100% permanent enclosed area to capture VOC emissions. • The equipment captured 95% of emissions (emissions dropped from 702 to 35-40 tons/year).
Highland Supply Corporation (EPA 1997a) (pollution prevention)	• Highland was concerned about the impact of large VOC emissions on its employees' health and about future regulatory pressure. • Evaluated several options including capture and solvent recovery (pollution control) but opted for a switch from solvent- to water-based ink. • Significant reduction in VOC, savings in ink cost, and hazardous waste disposal cost, and saving in labor hours.
Dopaco Inc. (1996) (pollution prevention)	• Press parts washing was using a solution with high isopropyl acetate and toluene. Besides the environmental issues regarding these two components, employees' health and safety was also of concern. • Eliminated 22 tons of hazardous liquid waste per year by installing an automatic part washing machine.. Reduced disposal cost ($11k/yr) and improved working conditions.

Pollution control technologies take the form of filters and structural mechanisms to recoup and/or dispose of undesirable outputs from the production process. The confinement of working areas (also known as total enclosure area or clean room) in order to maximize the recovery and filtration of emissions (Luckey 1997) and the incorporation of oxidizers (which burns appropriately emissions) in the press, facilitating the recovery of VOCs during a press run (EPA 1997), are examples of pollution control technologies.

Finally, a wide range of management systems is proposed to reduce and control environmental issues within printing plants. Good inventory management of chemicals helps to reduce hazardous waste by decreasing the likelihood of material becoming obsolete (EPA 1996). Cleaning solvent can be reused in order to maximize its utilization (e.g., four stage solvent life cycle) (EPA 1998). Scheduling darker printing jobs at the end of a sequence reduces the cleaning solvent needed between jobs and during setups (EPA 1995).

4.3. Preliminary Study

The goal of this preliminary study was to increase the knowledge of the industry and to verify the veracity of the different constructs of interest, to assess the relationship among them, and to ensure a correct terminology and wording of the questionnaire. Another objective was to provide validity of the survey instrument (Ellram 1996; Mentzer and Flint 1997) and not to build new theory as described by Eisenhardt (1989).

Five plant visits were conducted—three in the folding carton industry, one in the flexible package industry, and one in the label business (the plants were using different combinations of printing processes). All these plants were located in Ontario, Canada.

The size of these plants varied from 90 to 360 employees, and each had different approaches regarding supply chain management and environmental issues (Table 4.2). These visits were extensive and comprised of semi-structured interviews with plant managers, using the protocol presented in Appendix A. The questions were aimed at gaining a better understanding of supply chain management, operating challenges, and environmental management in the industry.

Despite the difference between the printing plants and their major suppliers in term of size, three of the five plants visited exhibited a high degree of logistical and technological integration with their suppliers. Interestingly, this degree of integration was independent of the plant's size, as the largest (Plant A) and the smallest (Plant C) were both having regular monthly (or even bi-weekly) technical and planning meetings with their primary suppliers.

The literature in supply chain management is relatively silent regarding the collaboration with customers to initiate changes in the customer's or supplier's plant. However, it was found during these visits that extensive supply chain integration with customers was taking place. For instance, two plants (Plant A and B) have a manager, responsible for improving the processes at the customer's premises. As noted earlier, structural and print-related properties are important for efficient filling operations at the customers' plant. It is noteworthy that Plant A, which has extensive integration with their major customers, is the most environmentally proactive of the plants visited.

In contrast, the plant manager of Plant D mentioned that a lot of environmentally sound changes are not possible because of the lack of customer cooperation. He mentioned that logistical inefficiency is generated by the customers' unwillingness to make small changes in their filling operations, obviating the possibility of reducing transportation and packaging of the material shipped. With more collaboration from its customers, Plant D would certainly be more proactive in seeking source reduction opportunities.

Contrasting Plant A and D helps to distinguish between supply chain integration and green supply chain practices. For instance, Plant D is highly integrated with its customers while environmental cooperation is practically non-existent. One environment-related change undertaken at Plant E, a reactive plant with regards to environmental issues, was the result of an initiative by a chemical supplier that 'forced' them to substitute a solvent- for a water-based adhesive. This environmental cooperation took place in a very low supply chain integration environment.

Finally, the questionnaire was revised according to some of the findings coming from the visit and interviews. First, the term *scrap rate* can be misunderstood in the printing industry as another term—*spoilage rate*—is commonly used. Therefore, the question related to the scrap rate was modified to incorporate the term spoilage rate. Other specific terms were also added to several items (e.g., different types of environmental technologies) in order to increase the reliability of the response. Other important modifications to the questionnaire were in the last section, which pertains to the plant's characteristics. Discussion with plant managers disconfirmed the importance of a lot of descriptive information originally requested in the questionnaires. As a result, the number of questions in the last section of the survey was greatly reduced.

4.4. Development of the Survey Instrument

The primary objective of the broad scale survey was to collect data suitable for empirical assessment of the conceptual model presented in Chapters 2 and 3. The following discussion sequentially summarizes how each construct in the conceptual model was operationalized. A copy of the questionnaire and cover letter used during the survey is included in Appendix B, and the relevant questions' number is referenced in brackets throughout this section.

4.4.1. Supply Chain Integration

Supply chain integration has two dimensions: logistical and technological integration. Logistical integration has been defined as information sharing and flexibility regarding material flows. Technological integration involves a commitment of resources—financial, human, and knowledge—toward activities such as product design or process reengineering. Both type of integration are evaluated from an upstream and a downstream perspective using multi-item scales.

Based on the operations management (Carr and Pearson 1999; Frohlich and Westbrook 2001) and marketing relationship (Buvik and John 2000; Cannon and Perreault 1999; Noordewier et al. 1990) literatures, five items each are included to measure the degree of logistical integration with the primary suppliers (A1) and with major customers (B2b to B2f).

Technological integration items were inspired by supplier development studies (De Toni and Nassimbeni 2000; Krause 1999) and the strategic management literature (Dyer and Nobeoka 2000; Takeishi 2001). In total, four items each are included to evaluate resource integration with suppliers (A2a, A2d, A2e and A2g) and with customers (all items in B1).

4.4.2. Green Supply Chain Practices

Green supply chain practices have been defined as having two principal dimensions: environmental cooperation and environmental monitoring. Both of these constructs were measured using multi-item scales.

Five items for each were included to measure environmental cooperation with primary suppliers (D2) and with major customers (E2). These items were mainly inspired by the research of Ellinger et al. (2000) who studied interdepartmental integration. Five items from their research were adapted to an interorganizational and environmental management setting.

For environmental monitoring, the items were inspired by different green supply chain and supplier development studies (Bowen et al. 2001; Carter and Carter 1998; De Toni and Nassimbeni 2000) or were developed based on the anecdotal evidence coming from the literature or the industry (preliminary study of this dissertation). For instance, package printers' inclination to evaluate and control their primary suppliers is captured through five items (D3). These items were motivated by recent case studies (Handfield et al. 1997; Walton et al. 1998) and survey research (Carter and Carter 1998; Goldsby and Stank 2000). For example, most of the literature suggests that environmental purchasing starts with the consideration of environment-related criteria in the selection of suppliers (Bowen et al. 2001; Min and Galle 1997). A similar set of five questions was used to examine control and evaluative activities conducted by major customers upon the package printers (E3). Note that all the items were reported from the perspective of the responding plant manager in a manner that they did not have to speculate about the operations of another organization (i.e., my plant assesses supplier environmental behavior…; my customers assess my plant's environmental behavior…; etc.).

4.4.3. Environmental Technology Selection

Plant managers were asked to allocate 100 points across the five environmental technology categories based on the use of resources for environmental improvement for a two-year period preceding the survey (Klassen and Whybark 1999a; 1999b). A simple definition along with illustrative examples is provided for each category (F1). The first two categories are characteristic of pollution control while the last two categories are related to product adaptation and process modification, hence to pollution prevention. The category in the middle represents management systems.

The profile of environmental technology selection does not capture the extent of investment in environmental technologies. Therefore, the profile of investment is not enough to capture entirely environmental management practices at the plant. The investment in the environmental technology is also needed; therefore, two additional questions about the relative value of the investment in environment-related projects were asked (F3).

4.4.4. Operational Performance

Operational performance was defined as the combination of manufacturing and environmental performance. Manufacturing performance will be measured through a set of multi-item scales and objective measurements as in several operations management studies (De Toni and Nassimbeni 1999; Flynn and Flynn 1999; Klassen and Whybark, 1999b; MacDuffie et al. 1996) and major manufacturing research projects such as WCMP (Flynn et al. 1997), IMSS (Vachon 1999), and GMRG (Whybark and Vastag 1993). Hence, a series of sixteen items aiming to measure five operational performance metrics—namely cost, quality, delivery, flexibility, and environment[2] (all items in G1)—were presented to the respondents. These items required the respondent to evaluate his/her plant's performance against its major competitors.

Besides these perceptual metrics, objective data were collected for quality and delivery performance. For quality, the percent of production that is scrapped or returned from the customers was requested from the respondent (G5). On-time delivery (G2), and throughput time (G3) are two additional metrics used to determine, specifically, delivery performance. Finally, setup (make-ready) time (G4) measures flexibility performance. Respondents were asked to provide the current and past numbers (from the preceding two years). These numbers allow for the evaluation of the internal improvement (or deterioration) experienced by the plant during the two-year period preceding the survey.

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[2] A perceptual metric regarding environmental management performance was not used in the WCMP, IMSS or the GMRG. However, Judge and Douglas (1998) used such a perceptual metric for environmental performance.

4.4.5. *Plant Characteristics*

Plant characteristics of interest are plant size, parent company size, equipment age, and investment in new equipment. Respondents were asked to report the number of employees (full-time equivalent) working at their plants as of January 2002 (H1). To validate this metric, respondents reported the value of assets and sales (H8). There were also requested to report the number of employees for the entire organization or for the parent company (H2). Respondents were asked to report on the average age of the presses (H12). Finally, investment in new equipment was measured through the average percent of annual sales reinvested in new manufacturing equipment over the past two years (H9).

Two other variables are included to capture the operating context and, more specifically, the structure of the supply chain upstream and downstream. The supply base has been a topic of interest in the purchasing literature (Agrawal and Nahmias, 1997) and is an important variable in supply chain management. The respondents were asked to report the number of ink suppliers, substrate suppliers, and all other suppliers (questions in A4). Similarly, the customer base is an important variable to consider when studying inter-organizational activities downstream. The survey asked the plant managers to report the percentage of sales that were generated by the plant's three largest customers (B3). This last variable is used to assess the degree of customer concentration and is, therefore, an inverted indicator of the extent of customer base.

4.5. Survey Administration and Implementation

A number of empirical research design issues needs to be addressed before administering and implementing the survey: (i) the unit of analysis, (ii) the size of the targeted plant , and (iii) the targeted respondent. First, the unit of analysis should be selected. Different units of analysis have been used in the literature: the firm level (Henriques and Sadorsky 1995; Klassen and McLaughlin 1996), the divisional or business unit level (Christmann 2000), and the plant (Curkovic et al. 2000; Florida 1996; Florida and Davison 2001; Geffen and Rothenberg 2000; Klassen and Whybark 1999): the unit of analysis in this dissertation is the plant. While some decisions pertaining to supply chain integration might be exogenous to the plant (i.e., made at the SBU or the corporate level), green supply chain practices and the selection of environmental technologies are generally made at the plant level (Curkovic et al. 2000). Klassen and Whybark (1999a) noted that, in the furniture industry, environmental technology selection varied among the various plants of a firm and that most of the environmental technology-related decisions were made at the plant level. Anecdotal evidence of disparate environmental practices among plants belonging to the same firm was also gathered through informal discussion with the practitioners in the package printing industry.

A second parameter of interest is to establish a cut-off size for plants selected for this study. Curkovic et al. (2000) had plants that ranged from 15 to 3,500 employees, while Klassen and Whybark (1999a) had plants ranging from 40 to 2,350 employees. Hence, by selecting plants having more than 90 employees, a certain level of confidence that environmental considerations are explicitly integrated in the operations is assured for each of the selected plants in the sample frame (Klassen 2000a).

The final parameter to establish is the targeted respondent. Several respondents were used to conduct environmental management surveys: logistics managers (Ellinger et al. 2000; Goldsby and Stank 2000), purchasers (Carter et al. 1998), and environmental managers (Handfield et al. 1997). In this dissertation, the target respondent was the plant manager (Curkovic et al. 2000; Klassen and Whybark 1999b), as the breadth of the questionnaire required a holistic view of the plants practices and management.

4.5.1. Survey Sample

Given the non-existence of very few NAICS solely associated with the package printing industry, exhaustive third party sources from the industry were used to generate the sample frame: (i) the Packaging Sourcebook, for the US, and (ii) the Scott's industrial directory, for Canada. In the latter case, keywords were used to build the Canadian sample: lithography, flexography, gravure, printing, packaging, and containers. A total of 394 plants were retained for the survey, 102 from Canada and 292 from the United States.

Potential plants were contacted to verify their contact information, the compatibility of their activities (printing operations related to packaging), and their size. However some of that pre-screening was waived for some plants belonging to large, well-known companies (e.g., Smurfit-Stone, Mail-Well Label, Printpack), because all the information was available through the Internet. Around 10% of these initial contacts were inconclusive because of lack of cooperation by the receptionist (refusal to give or confirm the plant manager's name and fax number, or inability to confirm the type of activities or size). These plants were included in the sample frame and the survey was generically addressed to the *plant manager*.

4.5.2. *Survey Administration*

The respondents were promised a summary report with information on each question by sector (folding, flexible, and labels). Also, a $5 pledge to the not-for-profit organization *Médecins sans Frontières – Doctors Without Borders* was promised for each response received. The survey was translated in French for the plants located in the Province of Quebec. According to the regulations of the University of Western Ontario, A panel of academics reviews the questionnaire to assess its suitability and the ethics of the survey prior its broadcast (see letter of ethics approval in Appendix C).

The survey was administered using five contact points as suggested by Dillman (2000, p. 150), to maximize the response rate:

(1) A phone call to the potential respondent (plant manager) was made to briefly introduce the study and to notify them that a questionnaire in relation to the study would be sent to them by fax within the following 24 hours. Voice mail was left when the phone was unanswered.

(2) A fax was sent to the targeted respondent within 24 hours following the introductory phone call. The use of electronic fax through the e-mail system allowed an automatic sending overnight and control of reception.

(3) A reminder fax was sent a week after the first questionnaire was faxed.

(4) Three weeks after the first wave, a second wave was faxed for the plants that had not responded at this point.

(5) Finally, five weeks after the first wave, a third wave of the survey was faxed again for the plants that had not responded at this point.

Follow-ups by phone and fax were conducted in a less structured way after the third wave. A thank you note was sent to the respondents when the completed questionnaire was returned. Upon receipt all completed questionnaires were assigned a number for internal use. The returned fax cover page was destroyed, and the fax numbers on the edge of the completed questionnaires were covered with black ink to preserve confidentiality. A participant form with the respondent contact information, attached to questionnaire, was filed in a separate place from the completed questionnaire in order to keep the data confidential.

4.5.3. Response Rate

From the initial sample frame of 394, 28 cases were dropped. Some plants were duplicated in the database, some were out of business and some did not have significant printing activities. Hence, the effective sample frame was 368. A total of 84 surveys were received yielding a 23.0% response rate (Table 4.3). While this response rate seems to be satisfactory when compared to similar recent studies[3], it remains below the average of 32% recorded for operations management studies (Frohlich 2002). Even a similar survey conducted in Canada during the summer of 2001 achieved a 36 % response rate (Vachon and Klassen 2002a). The lower response rate might be explained by several factors, namely (i) survey fatigue (Klassen and Jacobs 2001), (ii) the lack of recognition of the investigator's institution (Dillman 2000), (iii) the length of the survey (Frohlich 2002), and (iv) the plants' characteristics of the chosen industry.

[3] For instance, Rao (2002) achieved a 10 % response rate, and Roy et al. (2001), in a Canadian setting, reached 12.5%. A recent article, published in *Journal of Operations Management*, even presented a response rate of 4.3% (Rondeau et al. 2000).

Table 4.3 Response Rate		
Response	**84**	
Non Response	**310**	
Fax not working / fax always busy		14
No plant manager		2
Doubled in database/wrong business		28
Refuse to participate		65
Unknown reason		201
Total Sample Frame		394
Effective Sample Frame (394-28)	**366**	
Response Rate (84/366)	**23%**	

Survey fatigue was observed in the follow-up calls; several plant managers expressed a certain degree of annoyance at the numerous survey participation requests. One plant manager detailed several Canadian organizations, both governmental and industrial, which are conducting annual surveys besides the sporadic requests from academics and consultant firms. Second, because the survey covered the North American continent (with the exception of Mexico), most of the targeted plants were in the United States (around two-thirds of the sample frame). The principal investigator being based in a Canadian university, not highly profiled in the United States, probably caused some potential United States respondents to be cautious in responding. Such reluctance is linked to the concept of social network and anonymity barrier (Dillman 2000). For instance, a plant manager from California phoned the principal investigator to verify the validity of research. The Ph.D. program coordinator also received a phone call to authenticate the institution and the principal investigator. Third, the survey instrument contains 165 items over 10 pages; the fax was 12 pages long (Appendix B), which is deemed long in management research (Roth and BeVier 1998). Finally, the printing industry is fragmented and comprises several one-plant firms. The target respondents were often responsible for several functions at the plant, limiting their availability to respond to outside survey requests.

4.5.4. Non-Response Bias

One major concern when conducting survey research is the non-response bias that might occur. Because inference about the entire population is made from the sample, non-response bias can contaminate the sample by over or under representing one particular segment of the targeted population. Three tests of independence were conducted to assess non-response bias (Table 4.4). The first test was performed across the three sub-sectors of the industry—folding, flexible, and labels. A second test assesses the response rate achieved in Canada and in the United States. A third test was to check on overrepresentation of plants that belong to multi-plant firms or conglomerates[4] at the expense of plants from smaller firms having one or very few plants. This distinction is important because supply chain and environmental management strategy might differ between the two groups. Contingency tables with Chi-square tests were compiled for each potential bias, and no significant differences in the response rate were encountered. Hence, no indication suggests that non-response bias should be considered as an issue for this dissertation.

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[4] Printpack, Rock-Tenn, Mead-Westvaco, Mail-Well Label, Smurfit Stone, CCL Labels, Sonoco, Lawson Mardon, Pechiney, Shorewood Packaging.

Table 4.4a Non Response Bias – Industry Segment

	Industry Segment			
Observed	Folding	Flexible	Label	**Total**
Target Sample	130	115	105	350
Responses	28	28	28	84
Expected				
Target Sample	127.4	115.3	107.3	350
Responses	30.6	27.7	25.7	84

$\chi^2 = 0.520$, df = 2, p-value = 0.771

Table 4.4b Non Response Bias – Country

	Country		
Observed	Canada	United States	**Total**
Target Sample	101	249	350
Responses	28	56	84
Expected			
Target Sample	104.0	246.0	350
Responses	25.0	59.0	84

$\chi^2 = 0.65$, df = 1, p-value = 0.420

Table 4.4c Non Response Bias – Firm's Size

	Size		
Observed	Large	Not Large	**Total**
Target Sample	91	259	350
Responses	21	63	84
Expected			
Target Sample	90.3	259.7	350
Responses	21.7	62.3	84

$\chi^2 = 0.04$, df = 1, p-value = 0.851

4.5.5. *Missing Values*

With a sample size of 84 observations, missing values can be an issue if they reduce substantially the sample available to factor and regression analyses. An electronic mail message was sent to the respondents with the request to submit a response for missing value items; despite this effort, some missing values remained in the database. Special attention was devoted to the missing value for items pertaining to supply chain integration and green supply chain practices. Out of a possible 2,100 items, only five values were missing, for a rate of 0.2%. The missing values to be estimated are:

Plant ID# 392 left A2a unanswered

Plant ID# 352 left A2g unanswered

Plant ID# 354 left B2g unanswered

Plant ID# 354 left B2h unanswered

Plant ID# 391 left D3a unanswered

Because these five missing values are from four different respondents, they can be assumed as non-systematic and random using estimations to fill the missing value is then justified (Hulland et al. 1996). Several techniques exist to estimate missing values (Little and Rubin 1987), among which is regression analysis using correlated or similar variables (Buck 1960). The technique used in this dissertation is to run a regression with the missing value's variable as dependent, and setting the items within the same question as independent variables. This technique is also known as *stochastic regression imputation* (Little and Rubin 1987). The procedure is as follows:

Step 1 Run a regression using the missing value's variable as a dependent variable (e.g., A2e).

Step 2 The variables within the same set of questions are used as independent variables. (e.g., A2a, A2b, A2c, A2d, A2f, A2g as independent variables for A2e)

Step 3 Save the regression residuals and assess the normality through a Shapiro-Wilk test (Kennedy 1998).

Step 4 Estimate the missing value by using the regression coefficients and the value of the independent variables. Add a random disturbance term from the residual distribution. This disturbance term accounts for the idiosyncratic variance related to the observation (Little and Rubin 1987).

The detailed computation of the estimated values is presented in Appendix D.

4.6. Limitations of the Research Design

There are three limitations of the research design developed for this dissertation: (i) there is only a single respondent from each targeted plant; (ii) only one industry is selected, which can limit the degree of generalizeability of the study's results; (iii) the influence of supply chain activities—supply chain integration and green supply chain practices—were only assessed on one plant's environmental technology selection and operational performance. This section addresses these concerns.

4.6.1. Single Respondent

Asking a single informant to evaluate managerial practices in an organization may increase the degree of subjectivity in the responses, hence creating some biases. Hence, it is highly desirable to have more than one respondent to the survey per organization. However, the use of multiple respondents is costly in terms of financial resources and response rate, forcing a lot of researchers to opt for a single informant (Miller and Roth 1994).

A way to minimize the potential bias introduced by using a single informant is to carefully select the target respondent. The selection of the plant managers as the targeted respondents was made with this bias in mind: they are aware of the different domains of interest in this dissertation, namely environmental management, supply chain management, and operational performance. In the future, a research design might incorporate a second targeted respondent with an inter-reliability test to assess the potential biases of a design such as the one used in this dissertation.

4.6.2. *Single Industry vs. Multi-Industry*

A single industry design was adopted to reduce the effect of the heterogeneity of the production processes and technologies used by the plants in the sample. A multi-industry approach permits the assessment of different positions in the supply chain. A multi-industry design allows a study to include different types of process used in plant (e.g., batch vs. continuous process) and is more representative of all industries in the manufacturing sector. This last point is particularly important in the context of environmental technology selection, as radical product- or process-based changes to reduce pollution are more complicated in a continuous process (e.g., tightly coupled chemical processes and sub-processes).

However, a multi-industry design makes it difficult to control for the difference in regulation and the degree of attention from lobby and community-based groups, as they could greatly differ from one industry to another (e.g., the smokestacks energy sector vs.

seemingly harmless food and beverage industries). Needless to say, interesting and insightful results could be achieved through well-designed, multi-industry research in this area. Vachon and Klassen (2002b) noticed that environmental technology selection and the level of environmental investment were different between industries. Using very broad categories they found that continuous process industries were less likely to invest in pollution prevention technologies but more likely to invest in environmental technologies in general. Their studies did not assess how industries differ in terms of the influence of green supply chain practices on environmental technology selection, however.

Along this research avenue, an interesting research design has been developed by the Global Manufacturing Research Group (GMRG) where two industries—non-fashion textile and small machine tools—were selected to build the survey sample (Whybark and Vastag 1993). This design allows for the comparison of two diametrically different production processes, the continuous (non-fashion textile) and batch (small machine tool), while keeping the two industries control feasible in multivariate analysis.

4.6.3. Assessing Environmental Management Along the Entire Supply Chain

One of the shortcomings of this dissertation is that it only assesses the influence of green supply chain practices in a single plant of the supply chain. Several questions can be raised from a multi-plant perspective. The study was not able to capture the extent of the impact of environmental monitoring and environmental cooperation on the supplier's environmental technology selection. For example, would it be the same as the one found in the focal plant? A similar question can be posed regarding the customer's plant. In other words should we expect a difference of the influence?

As we move upstream in a supply chain, processes are often more complex and less decoupled, rendering fundamental changes more challenging and difficult to implement. In such a context, environmental cooperation cannot be as conducive to pollution prevention selection and would merely lead to greener logistical procedures. In order to capture such a broad spectrum of environmental practices, the methodology can hardly be a large-scale survey as it was used here. A better choice would be a field study. A good approach would be to theoretically select a sample of a few supply chains, mapping them carefully, and applying a case-based approach to study them.

5. CONSTRUCT VALIDATION

Before assessing the conceptual model presented in Figure 2.6, the validity of the individual constructs need to be assessed. The preliminary field study and the literature review created a certain degree of face and content validity. This chapter is devoted to trait validity, often measured through constructs reliability, discriminant validity and convergence validity (Mentzer and Flint 1997). However, the answers provided by the respondents should be measured against a third-party source. This is known as the criterion validity and is first discussed in this chapter.

5.1. Criterion Validity

Criterion validity is the degree of correspondence between a measure and a benchmark metric evaluated outside the survey (Klassen 1995). Because benchmark metrics were not available for most of the scales, only one assessment was possible; plant size, evaluated by the number of employees, was available from a third party source. The *Packaging Sourcebook* (2001) for the American plants and the *Scott Industrial Directory* (2001) for Canadian plants supplied the number employees for most of the plants in the sample. From these archival sources, the number of employees for 39 plants of the sample (46%) was provided. The correlation between the two sets of values was 80.9%; given the time lag between the sources (2001) and the economic downturn (2002), this correlation provided limited evidence of criterion validity.

5.2. Construct Reliability, Convergence, and Discriminant Validity

Construct reliability (or internal consistency) refers to the degree of inter-correlation between the items measuring a latent variable (Mentzer and Flint 1997). The reliability will be assessed through the Cronbach alpha (Cronbach-α). Based on that statistic, weak items will be dismissed. A weak item is defined as an item that brings down substantially the Cronbach-α value. Factor reliability can also be assessed through both the composite reliability and the average variance extracted using the results from the confirmatory factor analysis (CFA). For the Cronbach-α and composite reliability, values above 0.70 are judged acceptable (Hair et al. 1995; O'Leary-Kelly and Vokurka 1998). The variance extracted represents the shared representation of the items with the construct and should be over 50% (Hair et al. 1995).

Discriminant validity measures the degree to which items intended to measure a certain latent variable are unique to that variable (O'Leary-Kelly and Vokurka 1998). Convergence validity measures the extent of correlation among items that, theoretically, are intended to capture the essence of a latent abstract variable or construct. In other words, convergence validity is the extent to which *items intended to measure a latent variable statistically converge together* (Garver and Mentzer 1999).

After performing construct reliability assessment with the Cronbach-α, convergence and discriminant validity were tested using CFA computed with structural equation modeling (Amos in SPSS). The CFA permits the evaluation of individual factor loadings by providing critical ratios or t-statistics. It also supplies overall fit indices of the model linking the factors. Finally, a constrained model forcing a perfect correlation between the constructs (i.e., evaluated with all the items loading into a single construct) was evaluated and compared to the unconstrained model (i.e., items loading onto their respective constructs) to assess discriminant validity.

To restate, the procedure used to assess trait validity is as follows:

Step I Compute the Cronbach-α. Remove any items that are substantially diminishing the Cronbach-α value. The threshold value for the Cronbach-α is 0.70.

Step II Run a confirmatory factor analysis (CFA). Evaluate individual items through modification indices (assess potential cross-loading) and item loadings/significance. Evaluate the overall model with fit indices (detailed throughout the analysis).

Step III Using the results from the CFA, evaluate discriminant and convergence validity by contrasting a constrained and an unconstrained model.

5.2.1. Supply Chain Integration

Supply chain integration was defined as comprising two dimensions: (i) logistical integration, and (ii) technological integration. These activities can be performed with the suppliers (upstream) or with the customers (downstream) and can be related to the inter-organizational activities that are tactical (in the case of logistical integration) or strategic (in the case of technological integration). Reliability, discriminant validity, and convergence validity for supply chain integration constructs upstream and downstream were assessed in a sequential way.

Supply Chain Integration with Suppliers

For logistical integration, five items were selected—A1a, A1b, A1c, A1d, and A1e—while for technological integration only four items were used—A2a, A2d, A2e, and A2g.

The selection of items to measure logistical and technological integration was determined by the availability of similar items for supply chain integration downstream.

STEP I. The Cronbach-α is equal to 0.713 for all five logistical integration items and 0.828 for all four technological integration items. The results for the CFA are presented in Table 5.1. We note that, for both constructs, composite reliability is above the recommended threshold of 0.70. However, the variance extracted for the logistical integration construct was low, at only 36.5%. Further analysis indicated that, even after removal of the weak items from the CFA (i.e., A1c and A1d which has low standardized loadings), the variance extracted did not improve significantly. While the results of Table 5.1 are kept for further assessment and analysis in this dissertation, the items for the logistical integration scale in future research will need to be reused with caution and revised.

Table 5.1 Confirmatory Factor Analysis
Supply Chain Integration with Suppliers

Items	Standardized Loading		T-statistics
	Logistical Integration	Technological Integration	
A1a	0.756		–[1]
A1b	0.707		5.424
A1c	0.435		3.504
A1d	0.401		3.236
A1e	0.637		5.010
A2a		0.687	–[1]
A2d		0.734	5.879
A2e		0.876	6.563
A2g		0.671	5.431
Cronbach-α	0.713	0.828	
Composite Reliability	0.731	0.822	
Variance Extracted	0.365	0.541	

Fit Statistics	
Chi-Square	29.043 (df = 26, p = 0.31)
Normed Chi-square	1.117 (df =1, p = 0.29)
Goodness-of-fit index (GFI)	0.933
Tucker-Lewis index (TLI)	0.981
Adjusted goodness-of-fit (AGFI)	0.884
Comparative-fit index (CFI)	0.986
Normed fit index (NFI)	0.888
Root Mean Square Error of Approximation (RMSEA)	0.038

[1] t-statistics for these parameters were not available because they were fixed for scaling purposes.

STEP II. The items were all significant, with critical ratios above 3.2. Item loadings for A1c and A1d were low, but, given their high significance, no further inquiries on the data were made. Item cross-loading was not an issue as no modification index was above four.

The fit indices suggest a good model fit: (i) Both the Chi-square and normed Chi-square were non-significant; (ii) GFI, TLI, and CFI are all over the recommended 0.90 while AGFI and NFI are marginally acceptable at 0.88; (iii) RMSEA is equal to 0.038 well below the critical range of 0.05 to 0.08. Garver and Mentzer (1999) suggested in that research using structural equation modeling, the construct validity assessment should focus on indices that are independent of sample size. They recommended that fit be assessed through the TLI, CFI, and RMSEA; with these criteria the fit is acceptable.

Step III. Discriminant validity was assessed by contrasting two models: constrained (one construct with all items) and unconstrained (items loading on their respective construct). The constrained model reveals a significantly lower GFI, suggesting that it fits the theoretical matrix less well. The difference between the models' Chi-square value was significant at the 1% level[5]. These results confirm reasonable discriminant validity. Note that the correlation between the constructs was significant at 62.9%, providing more evidence of convergence validity.

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[5] For the constrained model, the Chi-square was 63.067 with 27 degrees of freedom. The unconstrained model had a Chi-square of 29.043 with 26 degrees of freedom. The difference is a Chi-square of 34.024 with one degree of freedom, which is significant at 1%.

Supply Chain Integration with Customers

The selection of items to measure logistical and technological integration was determined by the availability of similar items for upstream supply chain integration. For logistical integration, five items were selected—B2b, B2c, B2d, B2e, and B2f—while for technological integration, four items were used—B1a, B2b, B2c, and B2d.

STEP I. The Cronbach-α is equal to 0.792 for the logistical integration items and 0.731 for the technological integration items. One item related to technological integration (B1d) was pulling down the Cronbach-α value (from .734). Since rejecting this item would have only marginally improved the Cronbach-α, it was kept in for the CFA.

The results of the CFA are presented in Table 5.2. The composite reliability of both constructs is above the recommended threshold of 0.70. The variance extracted is weak on both constructs, at 43% for logistical integration and 42% for technological integration. Further analysis suggested that, even with the weak items (i.e., B2d, B2F, and B1d which has low standardized loadings) out of the CFA, the variance extracted was not improved significantly; therefore, the results of Table 5.2 were kept for further assessment. A similar word of caution as the one for logistical integration with suppliers regarding the future use of the scale is applicable here.

Table 5.2 Confirmatory Factor Analysis
Supply Chain Integration with Customers

Items	Standardized Loading: Logistical Integration	Standardized Loading: Technological Integration	T-statistics
B2b	0.804		–[1]
B2c	0.681		5.923
B2d	0.554		4.769
B2e	0.647		5.622
B2f	0.562		4.843
B1a		0.580	–[1]
B1b		0.725	4.585
B1c		0.750	4.656
B1d		0.506	3.617
Cronbach-α	0.792	0.731	
Composite Reliability	0.787	0.739	
Variance Extracted	0.430	0.420	

Fit Statistics	
Chi-Square	45.889 (df = 26, p = 0.010)
Normed Chi-square	1.750 (df =1, p = 0.186)
Goodness-of-fit index (GFI)	0.906
Tucker-Lewis index (TLI)	0.879
Adjusted goodness-of-fit (AGFI)	0.837
Comparative-fit index (CFI)	0.912
Normed fit index (NFI)	0.824
Root Mean Square Error of Approximation (RMSEA)	0.095

[1] t-statistics for these parameters were not available because they were fixed for scaling purposes.

STEP II. All the item loadings are significant despite some low values. The technological integration dimension is affected by two relatively weak items: B1a and B1d. However, the fit indices suggest a good model fit: (i) the Chi-square was significant (45.489 df = 26, p = 0.01) and the normed Chi-square was not significant (1.750, df = 1, p = 0.186); (ii) GFI and CFI are over the recommended 0.90, while TLI and NFI are marginally acceptable at 0.88; (iii) RMSEA is equal to 0.095, just above the recommended range of 0.05 to 0.08 but below the upper limit of 0.10 suggested in the literature (Hair et al. 1995).

STEP III. The constrained model reveals a significantly lower GFI than the unconstrained model, suggesting that latter model provides a better fit. The difference between the models' Chi-square value was significant at the 1% level[6]. These results confirm reasonable discriminant validity. Note that the correlation between the constructs was significant at 76.7%, providing more evidence of convergence validity.

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[6] For the constrained model, the Chi-square was 59.661with 27 degrees of freedom. The unconstrained model had a Chi-square of 45.889 with 26 degrees of freedom. The difference is a Chi-square of 13.772 with one degree of freedom, which is significant at 1%.

5.2.2. *Green Supply Chain Practices*

Green supply chain practices (GSCP) consist of environmental cooperation and environmental monitoring taking place between a plant and its primary suppliers and major customers. Environmental cooperation refers to joint environmental planning and problem-solving approaches in inter-organizational activities, while environmental monitoring comprises control and evaluative activities of suppliers or by the customers. Reliability, discriminant validity, and convergence validity for upstream and downstream green supply chain practices constructs are assessed sequentially.

Green Supply Chain Practices with Suppliers

Overall, ten items were retained from the survey instrument to measure GSCP with suppliers. Five items—D2a, D2b, D2c, D2d, and D2e—were used to be reflective of environmental cooperation, while five other items—D3a, D3b, D3c, D3d, D3e—were used for environmental monitoring.

STEP I. The Cronbach-α is equal to 0.967 for environmental cooperation with suppliers and equal to 0.901 for environmental monitoring of suppliers. All items contributed positively to the Cronbach-α so they were all retained for the CFA. The CFA results are presented in Table 5.3. One item (D3a) was rejected from the analysis, as it was cross-loaded with the environmental cooperation construct (modification index = 5.433). The Cronbach-α for the remaining four items is 0.881, well above the threshold of 0.70. The composite reliability for both constructs is high, and both variances extracted are well above the recommended level of 50%.

Table 5.3 Confirmatory Factor Analysis
Green Supply Chain Practices with Suppliers

Items	Standardized Loading		T-statistics
	Environmental Cooperation	Environmental Monitoring	
D2a	0.901		–[1]
D2b	0.905		13.287
D2c	0.922		13.967
D2d	0.933		14.445
D2e	0.955		15.546
D3b		0.822	–[1]
D3c		0.868	9.023
D3d		0.754	7.535
D3e		0.789	7.798
Cronbach-α	0.967	0.881	
Composite Reliability	0.967	0.883	
Variance Extracted	0.853	0.655	

Fit Statistics	
Chi-Square	79.832 (df = 26, p = 0.000)
Normed Chi-square	3.070 (df =1, p = 0.080)
Goodness-of-fit index (GFI)	0.840
Tucker-Lewis index (TLI)	0.905
Adjusted goodness-of-fit (AGFI)	0.723
Comparative-fit index (CFI)	0.931
Normed fit index (NFI)	0.903
Root Mean Square Error of Approximation (RMSEA)	0.158

[1] t-statistics for these parameters were not available because they were fixed for scaling purposes.

STEP II. The item loadings were all above 0.70 and significant, with t-statistics all greater than 7.5. The CFA, with only nine items, shows no modification index above four. Fit indices range from good to marginal: the Chi-square was significant (79.832, df = 26, p-value = 0.000), while the normed Chi-square was not significant (3.070, df = 1, p-value = 0.080). A marginal fit was also reported for GFI, AGFI, and RMSEA. However, the Tucker-Lewis index (TLI), the comparative fit index (CFI), and the normed fit index (NFI) were all above the recommended threshold of 0.90 (Hair et al. 1995). On the basis of the TLI, CFI and RMSEA, the proposed model achieves a reasonable fit despite the high value recorded for the RMSEA (.155), which was over the recommended threshold of 0.10.

STEP III. A constrained model, forcing a perfect correlation between the two constructs, reveals a significantly lower GFI, suggesting that the unconstrained model provides a better fit. Furthermore, the difference between the models' Chi-square values was significantly different than zero, meaning, again, that the unconstrained constructs lead to a better-fit model[7]. Note that the correlation between the constructs was significant at 67.5%, offering evidence of convergence validity.

[7] For the constrained model, the Chi-square was 177.976 with 27 degrees of freedom. The unconstrained model had a Chi-square of 79.832 with 26 degrees of freedom. The difference in the Chi-square is 98.144 with one degree of freedom, which is significant at 1%.

Green Supply Chain Practices with Customers

Overall, ten items were retained from the survey instrument to measure GSCP with customers. Five items—E2a, E2b, E2c, E2d, and E2e—were used to be reflective of environmental cooperation, while five items—E3a, E3b, E3c, E3d, and E3e—were used for environmental monitoring.

STEP I. The Cronbach-α is equal to 0.967 for environmental cooperation with customers and equal to 0.908 for environmental monitoring by customers. All items contributed positively to the Cronbach-α, and they were all retained for the CFA. The CFA results are presented in Table 5.4. The composite reliability of both constructs is high, being above 0.90, and both variances extracted are well above the recommended level of 50% at 84.8% for environmental cooperation and 64.6% for environmental monitoring.

STEP II. The items loading were all above 0.70 and significant, with t-statistics all greater than 7.8 ($p < .01$). No modification index above four was reported, suggesting that cross-loading was not an issue for this analysis. Fit indices suggest that the model fit was adequate. The Chi-square (51.671, df = 34, p = 0.027) and the normed Chi-square (1.520, df = 1, p = 0.218) were not significant. GFI, TLI, CFI, and NFI were all greater than the recommended 0.90, while the AGFI was marginal at 0.838. RMSEA was within the recommended range of 0.05 to 0.08.

Table 5.4 Confirmatory Factor Analysis
Green Supply Chain Practices with Customers

Items	Standardized Loading		T-statistics
	Environmental Cooperation	**Environmental Monitoring**	
E2a	0.888		–[1]
E2b	0.965		15.224
E2c	0.942		14.204
E2d	0.915		13.141
E2e	0.893		12.378
E3a		0.886	–[1]
E3b		0.801	9.371
E3c		0.810	9.556
E3d		0.877	11.087
E3e		0.720	7.875
Cronbach-α	0.967	0.908	
Composite Reliability	0.965	0.911	
Variance Extracted	0.848	0.646	
Fit Statistics			
Chi-Square			51.671 (df = 34, p = 0.027)
Normed Chi-square			1.520 (df =1, p = 0.218)
Goodness-of-fit index (GFI)			0.900
Tucker-Lewis index (TLI)			0.972
Adjusted goodness-of-fit (AGFI)			0.838
Comparative-fit index (CFI)			0.979
Normed fit index (NFI)			0.942
Root Mean Square Error of Approximation (RMSEA)			0.079

[1] t-statistics for these parameters were not available because they were fixed for scaling purposes.

STEP III. The constrained model reveals a significantly lower GFI and the difference in the models' Chi-square values was significant at the 1% level[8]. Note that the correlation between the constructs was significant at 69.4%, providing evidence of convergence validity.

5.2.3. Environmental Technology Selection

The environmental technology portfolio construct was validated using multiple measures as suggested by Klassen (1995) and subsequently reported in the scientific literature (Klassen and Whybark 1999a; 1999b). Therefore, no further validation of these constructs was conducted in this chapter.

5.2.4. Operational Performance

Operational performance was assessed through two types of metrics: objective and subjective. Construct validity needs to be assessed for the subjective metrics. Hence a reliability analysis and a CFA was conducted on the five dimensions of operational performance—cost, quality, delivery, flexibility, and environment. Note that discriminant and convergent validity do not need to be assessed.

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[8] For the constrained model, the Chi-square was 196.781 with 35 degrees of freedom. The unconstrained model had a Chi-square of 51.671 with 34 degrees of freedom. The difference in the Chi-square is 145.110 with one degree of freedom, which is significant at 1%.

STEP I. Table 5.5 shows the results of the CFA along with the Cronbach-α values for each performance dimension. Cronbach-α values were all above the threshold of 0.70, as was the composite reliability of each construct. The variance extracted was above 50% for each of the operational performance dimensions. All the items have a significant loading, as all t-statistics are above four. There was some indication of cross-loading, as some items (G1c, G1g and G1k) had high modification indices. Eliminating these items would lead to some operational performance constructs being measured by only two items. It was decided to keep all items in the analysis because of a good overall model fit with normed Chi-square being non-significant and TLI, CFI and, RMSEA being within the recommended ranges.

Table 5.5 Confirmatory Factor Analysis for Operational Performance

Items	Standardized Loading	T-Statistics	Composite Reliability	Variance Extracted
Cost (α = .799)			**0.806**	**0.586**
G1a	0.897	–[1]		
G1b	0.763	6.109		
G1c	0.609	5.081		
Quality (α = .773)			**0.793**	**0.501**
G1d	0.841	–[1]		
G1e	0.627	5.331		
G1f	0.817	6.642		
G1g	0.484	4.027		
Delivery (α = .765)			**0.778**	**0.539**
G1h	0.729	–[1]		
G1i	0.758	5.470		
G1j	0.714	5.277		
Flexibility (α = .857)			**0.823**	**0.612**
G1k	0.628	–[1]		
G1l	0.887	5.546		
G1m	0.809	5.468		
Environment (α = .799)			**0.865**	**0.687**
G1n	0.642	–[1]		
G1o	0.872	6.247		
G1p	0.942	6.210		
Fit Statistics				
Chi-Square			123.33 (df = 94, p = 0.023)	
Normed Chi-square			1.312 (df = 1, p = 0.252)	
Goodness-of-fit index (GFI)			0.847	
Tucker-Lewis index (TLI)			0.924	
Adjusted goodness-of-fit (AGFI)			0.779	
Comparative-fit index (CFI)			0.941	
Normed fit index (NFI)			0.799	
Root Mean Square Error of Approximation (RMSEA)			0.064	

[1] t-statistics for these parameters were not available because they were fixed for scaling purposes.

Correlations between objective metrics and perceptual metrics also indicate some consistency. These correlations are only a supplemental indication of validity but should be carefully interpreted, as they are not totally comparable. The perceptual metric is relative to the major competitors while the objective metric is focusing on internal processes. That might explain the positive correlation between the quality performance (perceptual) and the scrap rate ($r = .24$; $p = .04$). The scrap rate is an internal- and process-oriented metric of quality while the quality items are more product-based and externally oriented. Besides this seemingly unusual result, the correlation between delivery performance (perceptual) and on-time deliveries (objective) was positive and significant ($r = .228$; $p = .02$) suggesting some further validity of the scale used to measure delivery performance. The correlations between cycle time and cost ($r = -.20$; $p = .07$) and flexibility ($r = -.17$; $p = .11$) also suggest scale validity.

5.2.5. *Plant Characteristics*

Five control variables have been suggested in section 3.3: organizational size, equipment age, investment in new equipment, supply base, and customer base. The last three are not validated further in this section as they are objective metrics and no correlated variables can be used to assess their reliability. However, organizational size is examined more closely.

Organizational size has been measured by several variables in the literature, including value of assets, sales, and number of employees. Because of the reluctance of plant managers to supply financial information, the chosen metric in this dissertation is the number of employees. In order to validate this metric, two statistical tests are conducted.

First, the survey asked the respondent to report the category that their plants belong in terms of asset value and annual sales (H8). A Spearman correlation was run between the category reported and the number of employees in the plant (Table 5.6). Both correlations were positive and significant.

Table 5.6 Correlation between Asset Value, Annual Sales, and Number of Plant Employees

	Asset value	Annual sales
Spearman correlation with # plant employees	0.413	0.697
Number of cases	78	81
p-value	0.000	0.000

A second test used an archival source to evaluate the correlation between the number of employees and annual sales. The *Packaging Sourcebook* provides such data for several package printing plants in North America. One hundred organizations randomly selected (but equally representing the three industries, folding, flexible, and labels) from the *Packaging Sourcebook* serve to test the correspondence between annual sales and the number of employees: The randomly selected sample from the Packaging Sourcebook provided a Pearson correlation of 96 %. The survey sample contained 17 plants that had this information and there was a Pearson correlation of 93.4%. Therefore, the number of employees is a good substitute for annual sales in gauging organizational size appropriately. Note that this data is for a single, fairly homogenous industry, so high correlations between sales and the number of employees is not unexpected.

6. Results and Discussion

The validation of the different constructs presented in Figure 2.6 has been reported in the previous chapter. In this chapter, the relationships among these constructs, as hypothesized in Chapter 3, are tested through statistical analysis of the data collected with the survey. The analysis is presented in the same order as the hypotheses presented in Table 3.1 and includes:

(1) The impact of green supply chain practices (GSCP), which includes environmental cooperation and environmental monitoring, on operational performance (hypotheses H1a to H1e, H2a to H2e);

(2) The influence of GSCP and supply chain integration on environmental technology (hypotheses H3a, H3b, H4a, H4b, H6a, H6b and H6c);

(3) The role of supply chain integration on the level of environmental cooperation in the supply chain (hypothesis H5).

6.1. Operational Performance—Analysis

This section examines the impact of green supply chain practices and environmental technology on operational performance. The analyses are conducted on nine different performance metrics—five perceptual and four objective—each one being regressed on a set of independent variables that are grouped in three categories of interest:

(1) A set of control variables that includes plant size, parent company size, reinvestment rate, age of presses, supplier base, customer concentration, and past performance (for the objective metrics only);

(2) A set of variables pertaining to environmental technology, which includes a measurement of the extent of investment and its allocation in three forms of environmental technologies—pollution prevention, pollution control, and management systems;

(3) A set of variables that measures the extent of green supply chain practices with primary suppliers and major customers.

The relationships between each operational performance metric and the independent variables were tested using hierarchal linear regression and ordinary least squares estimators. For each regression model, the block of control variables is first introduced, followed respectively by the environmental technology selection variables and the green supply chain practices variables. By structuring the analysis this way, the incremental variance explained by the environmental technology selection and, subsequently, the green supply chain practices variables could be assessed explicitly. The incremental squared multiple correlation coefficient (R^2) are reported for each model but only the coefficient estimates for the full model (with all the independent variables introduced) are reported and analyzed; that way the result discussion is not affected by the order in which the blocks of variables are introduced.

The questionnaire was designed to obtain a sense of managerial practices over the past two years[9]. These practices, related to supply chain integration, GSCP and environmental technologies, are regressed against performance metrics that were evaluated contemporaneously with the survey. Therefore, while the results reported in this section do not explicitly imply causality because no longitudinal data per se were collected, some degree of cause and effect, as supported by the theoretical development of the hypotheses, can be assumed.

[9] The environmental technology selection and green supply chain practices items were all cast in a two-year frame; phrases such as *over the last two years* or *during the past two years* were used in the questions.

Pairwise correlations for performance metrics and all independent variables are presented in Table 6.1 (descriptive statistics for each variable are presented in Appendix E). From these correlations, model specification adjustments are needed to avoid multi-colinearity and overfitting. First, by design, environmental technology selection variables are mutually dependent, as an increase in one form of technology (e.g., pollution prevention) is directly related to a reduction in a linear combination of the other two forms (e.g., pollution control and management systems). Hence, pollution prevention will be introduced in a different model than pollution control and management systems, as the correlation on the last two forms of technology is the lowest in all three pairs ($r = -0.36$).

Second, the high correlations among GSCP variables, ranging from 0.53 to 0.74, indicate that models evaluating GSCP upstream with suppliers and downstream with customers separately is necessary to reduce multi-collinearity to acceptable levels. As such, two models are assessed for each performance metric: (i) a supplier-oriented model controlled for supply base, and (ii) a customer-oriented model controlled for customer concentration. Considering the split of the environmental technology selection variables into two groups, a total of four regressions are conducted for each performance metric—two regressions evaluating GSCP with suppliers (one with pollution prevention technology and the other with pollution control and management systems) and two regressions, similarly structured, evaluating GSCP with customers. Discussions of the results are presented in section 6.2.

Table 6.1 Correlations Table—Operational Performance Analysis[a,b]

	1	2	3	4	5	6	7	8	9	10	11	12	13
Operational Performance													
1. Cost (perceptual)													
2. Quality (perceptual)	.07												
3. Delivery (perceptual)	.36	.23											
4. Flexibility (perceptual)	.29	.31	.53										
5. Environmental (perceptual)	.11	.31	.13	.17									
6. On-time delivery (objective)	.08	.09	.25	.16	.24								
7. Cycle time (objective)	-.20	.01	.03	-.18	.02	-.10							
8. Setup time (objective)	.04	.15	-.04	.06	-.13	-.31	-.04						
9. Scrap rate (objective)	-.01	.24	-.03	-.00	.13	-.10	.23	.05					
Environmental technology selection													
10. Investment in environmental technology	.05	-.11	-.04	.01	.24	.13	.08	.09	-.03				
11. Pollution prevention index	-.01	-.03	-.05	.03	.00	-.17	-.09	-.11	-.10	-.08			
12. Pollution control index	.04	-.06	-.04	.02	-.13	-.04	.19	.20	.05	.29	-.48		
13. Management systems	-.02	.09	.09	-.05	.11	.21	-.07	-.06	.06	-.17	-.64	-.36	
Green supply chain practices													
14. Environmental cooperation with suppliers	.19	.26	.38	.40	.33	.14	.08	.12	-.11	.25	.12	.04	-.16
15. Environmental monitoring of suppliers	.02	.26	.05	.19	.39	.28	.08	.08	-.03	.23	-.08	.05	.04
16. Environmental cooperation with customers	.04	.31	.03	.27	.39	.10	.08	.12	-.08	.24	.11	.09	-.20
17. Environmental monitoring by customers	.05	.27	.12	.31	.33	.30	.06	.03	-.08	.25	.09	-.01	-.09
Control Variables													
18. Plant size	.04	-.02	-.26	-.04	-.10	.03	.15	.12	-.15	.15	-.05	.10	-.03
19. Parent company size	-.07	.11	-.14	-.09	.17	.27	.05	.18	.06	.10	-.36	.18	.23
20. Reinvestment rate	.04	.03	.07	.06	-.01	-.03	.01	-.09	.10	.03	.17	.05	-.22
21. Age of presses	.05	-.21	.05	.06	.13	-.06	.16	.05	-.18	.16	-.21	.08	.15
22. Supplier base	-.14	-.08	-.05	-.07	-.02	.18	-.03	-.08	.06	.00	.23	-.07	-.18
23. Customer concentration	.20	.29	.22	.13	.16	.31	-.01	.14	-.05	.06	-.20	.08	.14

[a] Correlations over 0.29 have p-value < 0.01 and correlations over 0.21 have p-value < 0.05. (77 < n < 84).
[b] Descriptive statistics for each variables are presented in Appendix E.

Table 6.1 (continued) Correlations Table—Operational Performance Analysis[a,b]

	14	15	16	17	18	19	20	21	22
Green supply chain practices									
14. Environmental cooperation with suppliers									
15. Environmental monitoring of suppliers	.62								
16. Environmental cooperation with customers	.64	.63							
17. Environmental monitoring by customers	.53	.74	.65						
Control Variables									
18. Plant size	.10	.19	.06	.21					
19. Parent company size	-.02	.21	.05	.11	.33				
20. Reinvestment rate	.21	.21	.20	.21	.04	-.18			
21. Age of presses	.09	.03	.05	-.05	.06	.32	-.29		
22. Supplier base	-.23	-.08	-.11	-.08	-.19	-.02	-.06	-.05	
23. Customer concentration	.12	.16	.08	.19	.02	.40	-.12	.13	-.18

[a] Correlations over 0.29 have p-value < 0.01 and correlations over 0.21 have p-value < 0.05. (77 < n < 84).

[b] Descriptive statistics for each variables are presented in Appendix E.

6.1.1. Cost Performance

The results for the regressions pertaining to cost performance are presented in Table 6.2. Partial support for hypothesis H1a was found, as environmental cooperation with suppliers was marginally significant and positively linked to cost performance (Models 1a and 1b; $p < 0.10$). However, such support was not found with environmental cooperation with customers, although the coefficient was directionally consistent with hypothesis H1a.

No indication for support of hypothesis H2a was found in the results. Again, environmental monitoring of suppliers and environmental monitoring by customers were directionally consistent with H2a.

There is no indication that any of the environmental technology (i.e., pollution prevention, pollution control, or management systems) affected cost performance. A higher degree of customer concentration has a positive and significant effect on cost performance (Models 1c and 1d; $p < 0.05$). Serving fewer customers reduces a plant's goal diversity and, among other things, can translate into less product variety (Galbraith 1973), helping cost performance (Van Donk and Van Dam 1996).

Table 6.2 Green Supply Chain Practices and Cost Performance (perceptual)[†]

	GSCP with Suppliers				GSCP with Customers			
	Model 1a		Model 1b		Model 1c		Model 1d	
	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.023		.023		.098		.098
Plant size[1]	.062		.063		.145		.145	
Parent company size[2]	-.029		-.028		-.235		-.234	
Reinvestment rate[3]	.034		.037		.062		.064	
Age of presses	.009		.008		.048		.047	
Supply base[4]	-.036		-.034					
Customer concentration[5]					.342**		.342**	
Environmental Technology Selection		.001		.001		.000		.000
Investment in environmental technology[6]	-.015		-.009		-.001		.002	
Pollution prevention index	-.062				.003			
Pollution control index			.038				-.011	
Management systems index			.071				.004	
Green Supply Chain Practices		.052		.052		.004		.004
Environmental cooperation	.323*		.327*		.056		.058	
Environmental monitoring	-.204		-.209		-.094		-.097	
R^2	.075		.076		.102		.102	
F Statistics	0.608		0.854		0.809		0.718	
Number of observations	77		77		74		74	

† Standardized betas reported.

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.
2 Natural logarithm of the number of employees in the parent company.
3 Percentage of annual sales invested in new equipment on average over the last two years.
4 Total number of suppliers divided by the number of employees at the plant.
5 The percentage of sales coming from the three largest customers.
6 Percentage of the capital budget invested in environmental technologies over the last two years.

6.1.2. Quality Performance

Tables 6.3 and 6.4 present the regression results for respectively, the perceptual scale using essentially external-oriented items, which are related to the product and customers, and for the scrap rate, which is mainly linked to internal production process. It is noteworthy that the two measurements used here need to be interpreted differently, as a high scrap rate implies poor internal quality performance.

One case was rejected based on a bad reporting from the respondent: a reported scrap of 85% was considered very unlikely, and, it created problems in the regressions (producing standardized residuals above five for all regressions)[10]. The regression analysis was run with 75 observations for the analysis pertaining to GSCP with suppliers and 72 observations for the analysis related to GSCP with customers. The difference in the number of observations used in each model is due to three respondents leaving the question pertaining to customer concentration unanswered.

Strong support was found for hypothesis H1b, as environmental cooperation with suppliers was positively linked to higher quality performance (Model 2a and 2b; $p < 0.10$). In the regressions with GSCP with customers (Models 2c and 2d), the changes in R-square (ΔR^2) were significant at the 5% level however the coefficient for both environmental cooperation and environmental monitoring were non-significant.

[10] This observation was rejected for this analysis only as no other anomaly was detected. The different statistics that involve the scrap rate (whether 2002 or 2000) were re-run without this observation and changed throughout the dissertation (e.g., correlations Table 6.1 and descriptive statistics in Table E1, Appendix E). Hence, all correlations and descriptive statistics related to the scrap rate does not include this outlying observation.

Table 6.3 Green Supply Chain Practices and Quality Performance (perceptual)[†]

	GSCP with Suppliers				GSCP with Customers (‡)			
	Model 2a		Model 2b		Model 2c		Model 2d	
	Beta	**ΔR^2**	**Beta**	**ΔR^2**	**Beta**	**ΔR^2**	**Beta**	**ΔR^2**
Control Variables		.088		.088		.157**		.157**
Plant size[1]	-.109		-.104		-.040		-.035	
Parent company size[2]	.154		.158		-.003		-.002	
Reinvestment rate[3]	-.053		-.038		-.032		-.014	
Age of presses	-.295**		-.300**		-.253**		-.258**	
Supply base[4]	-.039		-.029					
Customer concentration[5]					.286**		.288**	
Environmental Technology Selection		.006		.012		.011		.023
Investment in environmental technology[6]	-.166		-.141		-.184		-.148	
Pollution prevention index	-.072				-.084			
Pollution control index			.001				-.017	
Management systems index			.120				.142	
Green Supply Chain Practices		.111**		.112**		.087**		.088**
Environmental cooperation	.293*		.311**		.232		.251	
Environmental monitoring	.111		.092		.119		.096	
R^2	.205*		.212*		.254**		.268**	
F Statistics	1.914		1.774		2.427		2.306	
Number of observations	77		77		74		74	

† Standardized betas reported. * p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The percentage of sales coming from the three largest customers.

6 Percentage of the capital budget invested in environmental technologies over the last two years.

‡ **A more detailed analysis of Models 2c and 2d is presented in Table F1 of Appendix F.**

Table 6.4 Green Supply Chain Practices and Scrap Rate (objective)[†]

	GSCP with Suppliers				GSCP with Customers			
	Model 3a		Model 3b		Model 3c		Model 3d	
	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2
Past Performance		.901***		.901***		.900***		.900***
Scrap rate (2000)	.975***		.970***		.968***		.964***	
Control Variables		.026***		.026***		.025***		.025***
Plant size[1]	.134***		.129***		.101**		.098*	
Parent company size[2]	.067		.064		.092**		.094	
Reinvestment rate[3]	-.028		-.045		-.036		-.054	
Age of presses	-.028		-.024		-.024		-.022	
Supply base[4]	.056		.045					
Customer concentration[5]					-.041		-.046	
Environmental Technology Selection		.001		.011**		.001		.011**
Investment in environmental technology[6]	-.014		-.042		-.002		-.035	
Pollution prevention index	-.033				-.008			
Pollution control index			.095**				.087**	
Management systems index			-.027				-.049	
Green Supply Chain Practices		.001		.001		.004		.005*
Environmental cooperation	-.018		-.036		-.077		-.092**	
Environmental monitoring	-.028		-.005		.016		.037	
R^2	.929***		.939***		.929***		.941***	
F Statistics	84.631		88.010		80.299		86.719	
Number of observations	75		75		72		72	

† Standardized betas reported. * p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The percentage of sales coming from the three largest customers.

6 Percentage of the capital budget invested in environmental technologies over the last two years.

While the VIF for the all the variables was not higher than 2.2, the high correlations between environmental cooperation with customers and environmental monitoring by customers ($r = .65$) might have adversely affected the coefficients' t-statistics[11]. Hence, a complementary analysis was performed in which Models 2c and 2d were re-run and coefficients associated with environmental cooperation with customers and environmental monitoring by customers were sequentially estimated. The detailed results of that complementary analysis are presented in Table F1 in Appendix F. This additional step indicates that, when introduced alone, environmental cooperation with customers became highly significant ($p < 0.01$). Environmental monitoring by customers also became significant and positive ($p < 0.05$). However, the variance in the dependent variable that is explained uniquely by environmental cooperation (ΔR^2) is only marginally significant for Model 2d; it was not at all significant for environmental monitoring of customers. Hence, most of the variance in quality performance that is explained by green supply chain practices is common to both variables—environmental cooperation with customers and environmental monitoring by customers—limiting the possibility for assessing the influence of each individual variable and offering only limited support to hypothesis H1b (from an environmental cooperation with customers perspective).

[11] The VIF that exceed 10 are indication of harmful correlation. A more conservative threshold is 5 as suggested in Kennedy (1998)

Hypothesis H2b, which stipulates that environmental monitoring is positively linked to quality performance, was not supported by the regression results. However, both environmental monitoring of suppliers and environmental monitoring by customers were directionally consistent with H2b.

Environmental technology selection impacted the scrap rate. In particular, a greater allocation of resources toward pollution control technologies (at the expense of pollution prevention and/or management systems) is associated with a higher level of scrap (Model 3b and 3d; $p < 0.05$), hence, poorer quality performance.

Regarding the control variables, the age of the presses adversely affected quality performance (Models 2a-2d; $p < 0.05$). Also, the coefficient for customer concentration was positively linked to quality performance (Model 2c and 2d; $p < 0.05$). The coefficients for plant size suggest that size is positively related to scrap level (Models 3a-3c; $p < 0.05$).

6.1.3. Delivery

There were three performance metrics related to delivery performance: a three-item scale (perceptual; Table 6.5), the percentage of deliveries that were on time (objective; Table 6.6), and cycle time (objective; Table 6.7). Two outlying cases, with standardized residuals ranging between 3.5 and 4, were flagged in the on-time delivery regressions (Table 6.6). Because the values of the dependent variables were reasonable (75% and 80% of deliveries on time), the regressions were re-run to assess the impact of these outliers on the coefficient's value and significance; no change was recorded in the variables of interest. Hence, the original results were kept for interpretation.

Table 6.5 Green Supply Chain Practices and Delivery Performance (perceptual)†

	GSCP with Suppliers (‡)				GSCP with Customers			
	Model 4a		Model 4b		Model 4c		Model 4d	
	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.072		.072		.135*		.135*
Plant size[1]	-.174		-.167		-.157		-.155	
Parent company size[2]	-.032		-.026		-.253*		-.253*	
Reinvestment rate[3]	.124		.144		.140		.147	
Age of presses	-.028		-.035		.097		.095	
Supply base[4]	.120		.134					
Customer concentration[5]					.284**		.285**	
Environmental Technology Selection		.007		.009		.011		.013
Investment in environmental technology[6]	-.126		-.090		-.078		-.065	
Pollution prevention index	-.252**				-.106			
Pollution control index			.126				.057	
Management systems index			.312**				.123	
Green Supply Chain Practices		.236***		.248***		.009		.008
Environmental cooperation	.688***		.713***		-.061		-.054	
Environmental monitoring	-.377***		-.404***		.141		.133	
R^2	.315***		.329***		.155		.156	
F Statistics	3.420		3.241		1.300		1.166	
Number of observations	77		77		74		74	

† Standardized betas reported

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The percentage of sales coming from the three largest customers.

6 Percentage of the capital budget invested in environmental technologies over the last two years.

‡ **A more detailed analysis of Models 4a and 4b is presented in Table F2 of Appendix F.**

Table 6.6 Green Supply Chain Practices and On-Time Delivery (objective)†

	GSCP with Suppliers (‡)				GSCP with Customers			
	Model 5a		Model 5b		Model 5c		Model 5d	
	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2
Past Performance		.341***		.332***		.336***		.336***
On-time delivery (2000)	.481***		.491***		.440***		.455***	
Control Variables		.057		.057		.067		.067
Plant size[1]	-.048		-.037		-.096		-.089	
Parent company size[2]	.128		.134		.170		.167	
Reinvestment rate[3]	-.102		-.070		-.117		-.096	
Age of presses	-.124		-.132		-.141		-.144	
Supply base[4]	.196*		.215**					
Customer concentration[5]					.062		.062	
Environmental Technology Selection		.021		.060*		.019		.043
Investment in environmental technology[6]	.030		.085		.052		.093	
Pollution prevention index	-.155				-.134			
Pollution control index			-.001				.011	
Management systems index			.262**				.200*	
Green Supply Chain Practices		.048*		.045*		.053**		.047*
Environmental cooperation	.095		.133		-.044		-.021	
Environmental monitoring	.175		.132		.293**		.263*	
R^2	.468***		.503***		.476***		.493***	
F Statistics	5.802		5.982		5.714		5.487	
Number of observations	77		77		74		74	

† Standardized betas reported. * p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The percentage of sales coming from the three largest customers.

6 Percentage of the capital budget invested in environmental technologies over the last two years.

‡ **A more detailed analysis of Models 5a and 5b is presented in Table F3 of Appendix F.**

Table 6.7 Green Supply Chain Practices and Cycle Time (objective)[†]

	GSCP with Suppliers				GSCP with Customers			
	Model 6a		Model 6b		Model 6c		Model 6d	
	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2
Past Performance		.802***		.802***		.809***		.809***
Cycle time (2000)	.897***		.890***		.915***		.908***	
Control Variables		.015		.015		.015		.015
Plant size[1]	.081		.079		.041		.039	
Parent company size[2]	.030		.027		.059		.057	
Reinvestment rate[3]	-.008		-.016		-.011		-.019	
Age of presses	.058		.062		.076		.079	
Supply base[4]	.044		.038					
Customer concentration[5]					-.055		-.055	
Environmental Technology Selection		.002		.005		.003		.003
Investment in environmental technology[6]	.044		.029		.070		.054	
Pollution prevention index	.007				.052			
Pollution control index			.028				-.003	
Management systems index			-.036				-.076	
Green Supply Chain Practices		.002		.001		.010		.010
Environmental cooperation	.028		.019		-.123*		-.130*	
Environmental monitoring	-.062		-.050		.028		.038	
R^2	.821***		.823***		.809***		.840***	
F Statistics	30.217		27.490		32.384		29.545	
Number of observations	77		77		74		74	

† Standardized betas reported . * p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01
1 Natural logarithm of the number of employees in the plant.
2 Natural logarithm of the number of employees in the parent company.
3 Percentage of annual sales invested in new equipment on average over the last two years.
4 Total number of suppliers divided by the number of employees at the plant.
5 The percentage of sales coming from the three largest customers.
6 Percentage of the capital budget invested in environmental technologies over the last two years.

Strong support was found for hypothesis H1c, as environmental cooperation with suppliers was highly significant and positively linked to the perceptual scale (Model 4a and 4b)[12]. Again, while the VIF were within the recommended range, the high correlation between environmental cooperation with suppliers and environmental monitoring of suppliers (r = 0.62) might have adversely affected the coefficients' t-statistics in the on-time delivery regressions, as the changes in the R-square (ΔR^2) were marginally significant, but none of the GSCP variables was significant (Models 5a and 5b).

Models 5a and 5b were re-run, and coefficients associated with environmental cooperation with suppliers and environmental monitoring of suppliers were sequentially estimated in a complementary analysis. The results of this complementary analysis, presented in Table F3 of Appendix F, indicate that, when introduced alone, environmental cooperation with suppliers is significantly and positively linked to on-time delivery ($p < 0.05$), suggesting further support for H1c. A similar result was obtained for environmental monitoring of suppliers. However, the variance in the dependent variable that is uniquely explained by environmental cooperation with suppliers or by environmental monitoring of suppliers was not significant. Hence, most of the variance in on-time delivery is jointly explained by both variables—environmental cooperation with suppliers and environmental monitoring of suppliers—offering only little support for hypothesis H1c.

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[12] Some concerns of potential spurious regressions can be raised, as the variance explained by the block of environmental technology selection was not significant, but the coefficients for pollution prevention (Model 4a) and management systems (Model 4b) were significant at the 5% level. A detailed analysis reported in Table F2 of Appendix F suggests that indeed pollution prevention and management systems contribute significantly to the total variance explained (R^2).

Finally, marginal evidence that environmental cooperation with customers reduces the cycle time was found in Table 6.7 (Models 6c and 6d; $p < 0.10$). This last result provides support to hypothesis H1c as environmental cooperation with customers improves speed; a dimension of delivery performance.

Environmental monitoring by customers was positively associated with a higher percentage of on-time delivery (Models 5a and 5b; $p < 0.10$) providing support for hypothesis H2c. The results of the complementary analysis discussed in the previous paragraph also suggest support for hypothesis H2c, as it confirms a significant (but marginal) relationship between environmental monitoring of suppliers and on-time delivery performance. However, environmental monitoring of suppliers was highly significant and negatively related to the perceptual scale (Models 4a and 4b; $p < 0.01$), which counters hypothesis H2c. Monitoring activities aimed at the suppliers appears to hamper delivery speed and dependability.

Few of the environmental technology selection variables were significant. The allocation of resources to pollution prevention technologies was negatively associated with delivery performance (Model 4a; $p < 0.10$). However, investments in management systems was positively linked to delivery performance (Model 4b; $p < 0.10$). A greater allocation of resources toward management systems was positively associated with more on-time deliveries across all regressions (Model 5b and 5d; $p < .10$). Hence, the results suggest that infrastructural investments related to the environment can help to achieve faster and more dependable deliveries.

As with previous perceptual metrics, customer concentration was again positively associated with performance (Models 4c and 4c; $p < 0.10$). Some evidence also suggests that a large supply base helps to achieve better on-time deliveries (Models 5a and 5b; $p < 0.10$). It is widely argued in the literature that having multiple suppliers reduces the risk of shortage and increases inbound delivery reliability, therefore helping the focal plant to keep their production scheduling and planning stable, which can lead to more reliable deliveries to customers.

6.1.4. Flexibility

There are two performance metrics related to flexibility performance: a three-item scale (perceptual; Table 6.8) and setup time (objective; Table 6.9). The results strongly support hypothesis H1d, as environmental cooperation with suppliers was highly significant and positive (Models 7a and 7b; $p < 0.01$) for perceptual performance. The high correlation between environmental cooperation with customers and environmental monitoring by customers ($r = 0.65$) might have adversely affected the coefficients' t-statistics for GSCP with customers, as the changes in R-square (ΔR^2) were significant at the 10% level, but none of the coefficients was significant (Models 7c and 7d).

Table 6.8 Green Supply Chain Practices and Flexibility Performance (perceptual)†

	GSCP with Suppliers				GSCP with Customers (‡)			
	Model 7a		Model 7b		Model 7c		Model 7d	
	Beta	**ΔR^2**	**Beta**	**ΔR^2**	**Beta**	**ΔR^2**	**Beta**	**ΔR^2**
Control Variables		.028		.028		.078		.078
Plant size[1]	.023		.023		.041		.039	
Parent company size[2]	-.102		-.102		-.269*		-.269*	
Reinvestment rate[3]	.040		.039		.043		.035	
Age of presses	.023		.023		.129		.131	
Supply base[4]	.073		.073					
Customer concentration[5]					.197		.197	
Environmental Technology Selection		.001		.003		.003		.005
Investment in environmental technology[6]	-.132		-.134		-.130		-.144	
Pollution prevention index	-.112				-.062			
Pollution control index			.096				.086	
Management systems index			.103				.035	
Green Supply Chain Practices		.166***		.164***		.075*		.075*
Environmental cooperation	.539***		.538***		.147		.139	
Environmental monitoring	-.162		-.161		.185		.194	
R^2	.196*		.196		.156		.158	
F Statistics	1.814		1.608		1.310		1.180	
Number of observations	77		77		74		74	

† Standardized betas reported . * p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The percentage of sales coming from the three largest customers.

6 Percentage of the capital budget invested in environmental technologies over the last two years.

‡ **A more detailed analysis of Models 5a and 5b is presented in Table F4 of Appendix F.**

Table 6.9 Green Supply Chain Practices and Setup Time (objective)†

	GSCP with Suppliers				GSCP with Customers			
	Model 8a		Model 8b		Model 8c		Model 8d	
	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2	Beta	ΔR^2
Past Performance		.926***		.926***		.704***		.704***
Setup time (2000)	.978***		.973***		.876***		.892***	
Control Variables		.006		.006		.021		.021
Plant size[1]	.074**		.071**		.136**		.130*	
Parent company size[2]	-.010		-.012		-.048		-.050	
Reinvestment rate[3]	-.034		-.045		-.085		-.107	
Age of presses	.035		.038		.060		.065	
Supply base[4]	.020		.014					
Customer concentration[5]					.026		.022	
Environmental Technology Selection		.006**		.011***		.028**		.049***
Investment in environmental technology[6]	-.074**		-.091***		-.164**		-.211***	
Pollution prevention index	-.004				.027			
Pollution control index			.044				.080	
Management systems index			-.032				-.102	
Green Supply Chain Practices		.004		.003		.005		.004
Environmental cooperation	.020		.009		.015		-.007	
Environmental monitoring	-.076*		-.062		-.089		-.064	
R^2	.941***		.945***		.759***		.778***	
F Statistics	105.82		101.03		19.801		19.736	
Number of observations	77		77		74		74	

† Standardized betas reported. * p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The percentage of sales coming from the three largest customers.

6 Percentage of the capital budget invested in environmental technologies over the last two years.

Models 7c and 7d were re-run in a complementary analysis where the coefficients related to both environmental cooperation with customers and environmental monitoring by customers were estimated sequentially in the models. The results indicate that, when introduced alone, environmental cooperation with customers became significant ($p < 0.05$). A similar result was obtained for environmental monitoring by customers. However, the variance in flexibility performance that is explained uniquely by environmental cooperation with customers or by environmental monitoring by customers was not significant. Hence, most of the variance explained by GSCP is common to both constructs—environmental cooperation with suppliers and environmental monitoring of suppliers—offering only limited support to hypothesis H1d.

Environmental monitoring of suppliers was significant and positively linked to setup time improvement, which does not support H2d. Similarly, the complementary analysis discussed in the previous paragraph also suggests a positive linkage between environmental monitoring by customers and flexibility performance. Finally, environmental monitoring of suppliers was marginally significant and positively related to setup time improvement (Model 8a; $p < 0.10$), which is counter to H2d as well.

Environmental technology investments were negatively associated with setup time (Models 8a to 8d; $p < 0.05$). The results also suggest that plant size is marginally positively related to longer set-up performance (Models 8a to 8d; $p < 0.10$).

6.1.5. *Environment*

Significant support for hypothesis H1e was provided (shown in Table 6.10); environmental cooperation with customers was positively associated with a higher degree of environmental performance (Models 9c and 9d; $p < 0.05$). There is also evidence to support H2e, as environmental monitoring of suppliers was positively associated with environmental performance (Models 9a and 9b; $p < 0.10$).

Investments in pollution control technologies were negatively related to environmental performance (Model 9b; $p < 0.10$), while the level of investment in all environmental technologies was positively linked to environmental performance (Models 9b and 9d; $p < 0.10$). The size of the plant was significantly and negatively associated with environmental performance suggesting that larger plants have more difficulty dealing with environmental issues related to air and water emissions (Models 9a to 9d; $p < 0.10$).

Table 6.10 Green Supply Chain Practices and Environmental Performance (perceptual)[†]

	GSCP with Suppliers				GSCP with Customers			
	Model 9a		Model 9b		Model 9c		Model 9d	
	Beta	**ΔR^2**	**Beta**	**ΔR^2**	**Beta**	**ΔR^2**	**Beta**	**ΔR^2**
Control Variables		.065		.065		.067		.067
Plant size[1]	-.311**		-.300**		-.233*		-.223*	
Parent company size[2]	.182		.192		.197		.199	
Reinvestment rate[3]	-.029		.007		-.009		.026	
Age of presses	.023		.007		-.013		-.024	
Supply base[4]	-.044		-.019					
Customer concentration[5]					.039		.043	
Environmental Technology Selection		.074*		.121**		.068*		.110**
Investment in environmental technology[6]	.173		.235**		.160		.228*	
Pollution prevention index	.098				.029			
Pollution control index			-.222*				-.185	
Management systems index			.038				.092	
Green Supply Chain Practices		.133***		.129***		.137***		.143***
Environmental cooperation	.151		.199		.342**		.380**	
Environmental monitoring	.296**		.248*		.083		.042	
R^2	.272***		.316***		.271**		.320***	
F Statistics	2.742		2.999		2.608		2.917	
Number of observations	76		76		73		73	

† Standardized betas reported .

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The percentage of sales coming from the three largest customers.

6 Percentage of the capital budget invested in environmental technologies over the last two years.

6.2. Operational Performance—Discussion

This section synthesizes and discusses the implications of the results from the operational performance analysis. First, a summary of the results regarding the influence of environmental cooperation on operational performance is presented. The second sub-section comprises a similar discussion on environmental monitoring. The results pertaining to environmental technology selection and other control variables are summarized in the third sub-section.

6.2.1. Environmental Cooperation

Overall, the results provide substantial support for hypotheses H1a to H1e, which posited that environmental cooperation between organizations in a supply chain taking the form of collaborating in environmental planning, establishing common environmental goals, and jointly addressing product/process-related issues impact a plant's operational performance.

A positive link between environmental cooperation with major customers and quality performance was found. In particular, the evidence suggests that environmental cooperation was positively linked to the quality performance scale, as evaluated relative to primary competitors, and negatively linked to scrap rate. Hence, the collaboration with customers regarding environmental issues can create synergy that will render production to specifications easier for the suppliers. This type of interaction was fostered in two of the plants visited during the first phase of this dissertation. The package printers had a representative that acted as a continuous improvement manager at the customers' premises. Any changes in product specifications (e.g., colors, design, structural properties) were not made unilaterally by the customers but in collaboration with the printers, considering the process capabilities of both the printing plant and the customers' filling lines. Such cooperation related to production to specifications at the printing plant and reliability at the customers filling lines is ultimately reflected in environment-related improvement such as source reduction and waste minimization.

The last example can be illustrative of the fact that environmental performance, taking the form of air emission, solid waste disposal, and water emissions lower than competitor, was also positively linked to environmental cooperation with customers. It is already established that an internal environmental planning and environmental problem-solving culture, characteristics of an environmental management system such as ISO 14001, help to improve environmental performance (Jayathirtha 2001; Kitazawa and Sarkis 2000; Raiborn et al. 1999). The result here implies that a plant's environmental performance can benefit from the same type of activities beyond its boundaries and more specifically in collaboration with its major customers.

Despite the relationship found between environmental cooperation with customers and operational performance (quality and environment), the bulk of the significant results relating GSCP to operational performance was found in environmental cooperation with suppliers. Cost, quality, delivery, and flexibility performance were all positively linked to environmental cooperation with suppliers. Hence, engaging in collaborative environmental planning and establishing environmental goals with the suppliers can improve the competitiveness in regards to speed, delivery reliability, and the ability to react to unforeseen events as measured through perceived performance against primary competitors. It can also positively affect labor productivity and overall product cost. For example, Custom Print of Arlington, Virginia collaborated with its ink/chemicals suppliers to reduce the number of stock keeping units (SKU) of different chemicals on-site. This reduction of SKUs (from 80 to 24) helped Custom Print to avoid obsolescence in its chemicals inventory, simultaneously reducing cost and cutting waste (Table 4.1) (EPA 1996). This type of outcome from cooperation is consistent with other findings in the general supply chain management literature (e.g., Corbett et al. 1999).

6.2.1.1 Implications

Environmental cooperation with primary suppliers and major customers has been defined as encompassing joint environmental planning activities and collaboration in finding solution to environmental challenges. Considering that these challenges need non-trivial solutions, environmental cooperation requires organizations' respective know-how and technologies to be shared and integrated. Two direct outcomes of environmental cooperation are the development of knowledge sharing routines and the development of the capability to integrate external resources (Dyer and Singh 1998). Such a combination of resources can lead to a competitive advantage (Grant 1996b; Lorenzoni and Lipparini 1999; St. John and Harrison 1999). Hence, environmental cooperation can lead to the capability for integration of internal and external know-how and technologies. This capability can generate resources difficult to replicate, lading in turn to a competitive advantage. As such, environmental cooperation could be analyzed with the natural resource-based view (Hart 1995).

The positive linkage between environmental cooperation, particularly with suppliers, and different dimensions of operational performance as evaluated against major competitors supports the natural resource-based view of the firm (Hart 1995). From the natural resource-based view, the results obtained here are consistent with the findings of Delmas (2001) who obtained a strong linkage between the involvement of external stakeholders, including customers and distributors, in the implementation of an ISO certified environmental management systems and the degree of competitive advantage derived from the ISO 14000 certification.

Empirically, the results are also consistent with a recent study that linked supply chain environmental management to environmental performance and cost competitiveness in South East Asian plants (Rao 2002). Considering that operational performance ultimately has repercussion in financial performance, the results linking environmental cooperation to operational performance are compatible with the finding of Carter et al. (2000). They found that environmental purchasing, defined as the involvement of the purchasing function in environment-related projects within the organization, was positively linked to net income and negatively linked to cost.

Together, these results have direct implications for operations managers. If quality performance, taking the form of excellence in production to specifications, product durability, and customers' satisfaction, is the competitive dimension that the plant is emphasizing, then environmental cooperation with the customers can be leveraged to achieve a higher level of performance along that dimension. However, collaboration with suppliers with regards to environmental issues can lead to improvement in all four dimensions of manufacturing performance: cost, quality, delivery, and flexibility.

6.2.2. *Environmental Monitoring*

Overall, little support for hypotheses H2a and H2e was found. Environmental monitoring by customers was associated with a greater percentage of on-time delivery, supporting hypothesis H2c. Hence, the different forms of environmental monitoring communication by customers—questionnaires, audits, environmental management systems— help to establish a better understanding of customers' expectations, as suggested by anecdotal evidence in the literature (Gavaghan et al. 1998; Wycherley 1999). Having such an understanding of customers' expectations assures greater likelihood of production within specifications and on time deliveries.

Environmental monitoring was conceptualized as activities in the supply chain that used market mechanisms (the externalization component of the externalization/internalization framework) to control and evaluate suppliers' environmental management. As such, it was argued not to be a source of competitive advantage or a capability as it is available on the market to all organizations in the industry. However, the entanglement of environmental monitoring with environmental cooperation on different performance dimensions suggests that environmental monitoring can contribute to performance.

In order to evaluate environmental monitoring the following two points need to be investigated. First, there might be a competitive capability derived from implementing control and evaluative activities in the supply chain that it is difficult to replicate for competitors. This effect is not assessed in this dissertation. Second, environmental monitoring can be complementary to the effort to collaborate with suppliers and customers. In such a case, the ability to proficiently conduct environmental monitoring can be viewed as an asset that generates a competitive advantage when combined with another capability (e.g., environmental cooperation). This last possibility is often referred to as complementary asset perspective, a segment of the resource-based view of the firm (Christmann 2000).

6.2.3. Other Variables

The impact of environmental technologies on operational performance was also assessed based on previous research (e.g., Klassen and Whybark 1999b, Christmann 2000). A few variables were significant and are discussed here. For example, management systems was significant if related to the perceptual and objective metrics of delivery performance (on-time delivery). Hence, efforts in the areas of operating procedures, training, and auditing, related to reducing the environmental impact of operations help to achieve more dependable delivery performance.

The environmental technology results also suggest that the allocation of resources to pollution prevention was negatively linked to delivery performance. This result differs from another study in the United States furniture industry (Klassen and Whybark 1999b), where the allocation of resources to pollution prevention was positively linked to different delivery performance dimensions. Also, Klassen and Whybark's study revealed no significant relationship between management systems and operational performance.

Moreover the timing of the two studies and the industry-specific characteristics can help explaining the difference between the two studies. The regulatory climate in the first half of the nineties, with foreseeable new regulations, particularly in the furniture industry, was more dynamic than the one in the printing industry in 2002. This climate forced the plant managers in the furniture industry to be more active in finding solutions that can take the form of fundamental process or product changes (Klassen 1995). Also, the package printing industry is, on average, one echelon further away from the end-consumers, presenting a different supply chain dynamic and production process. In general, the pressroom is more automated than most of the plants in the furniture industry, suggesting that pollution prevention technologies in printing might be more difficult to implement and more disruptive, hence, not as beneficial from an operational performance perspective. This strengthens the observations that differences can exist between industries.

Other studies examined the impact of environmental process-based change (pollution prevention) on performance. Christmann (2000) found that, in the chemical industry, the use of pollution prevention technologies, when combined with process innovation and implementation capability, was positively related to cost performance (i.e., cost diminishes). However, she did not find a main effect between pollution prevention and cost performance with results that were directionally consistent with the results in this dissertation. King and Lenox (2002) found that pollution prevention taking the form of waste reduction was positively linked to return on assets and the Tobin's q (a financial indicator of a firm's inherent value). Waste reduction can arguably be the result of structural and/or infrastructural investments. Delivery performance, a dimension of customer satisfaction, hence an important element of sales and revenues, can be considered as an ultimate element of profitability, suggesting that the results of King and Lenox (2002) are somewhat coherent with those of this dissertation.

From the set of control variables, two variables regularly comes up as significant: customer concentration and plant size. Customer concentration was mostly related to improved operational performance. This last result can lead one to believe that a smaller customer base would be easier to deal with than larger one. A strategic concern with this result is that it comes from a linear relationship between customer concentration and operational performance. While it can be assumed that high customer concentration is preferable, the results do not allow assessing the strategic or long-term consequences of having very few customers. The results also suggest that plant size is associated with poorer quality performance (through its positive relationship with scrap rate), poorer delivery performance (through its positive relationship with set-up time), and poorer environmental performance.

6.3. *Environmental Technology—Analysis*

This section evaluates the influence of supply chain integration and green supply chain practices on environmental technology selection—pollution prevention, pollution control, and management systems—and the level of investment in environmental technologies. This section is directly linked to hypotheses H3, H4, H6a, H6b, H6c, and H6d. Table 6.11 shows the correlation among the variables of interest in the analysis conducted in this section (note that the correlations among the control variables were already presented in Table 6.1 and are omitted in Table 6.11). Descriptive statistics for each variable are reported in Appendix E. Again, hierarchal regressions were used with three blocks of variables—control, supply chain integration, and green supply chain practices—sequentially entered in the models.

Table 6.11 Correlations Table—Environmental Technology Selection Analysis[a,b,c]

	1	2	3	4	5	6	7	8	9	10	11
Environmental Technology											
1. Investment in environmental technology											
2. Pollution prevention	-.08										
3. Pollution control	.29	-.48									
4. Management systems	-.17	-.64	-.36								
Green supply chain practices											
5. Environmental cooperation with suppliers	.25	.12	.04	-.16							
6. Environmental monitoring upon suppliers	.23	-.08	.05	.04	.62						
7. Environmental cooperation with customers	.24	.11	.09	-.20	.64	.63					
8. Environmental monitoring by customers	.25	.09	-.01	-.09	.53	.74	.65				
Supply chain integration											
9. Logistical integration with suppliers	.05	-.06	.09	-.02	.38	.37	.45	.47			
10. Resource integration with suppliers	-.04	.30	-.12	-.21	.40	.31	.38	.42	.49		
11. Logistical integration with customers	-.22	.06	-.20	.12	.22	.20	.22	.24	.33	.33	
12. Resource integration with customers	-.10	-.01	.11	-.08	.31	.36	.39	.42	.47	.40	.46
Control variable											
13. Plant size	.15	-.05	.10	-.03	.10	.19	.06	.21	.09	-.10	.00
14. Parent company size	.10	-.36	.18	.23	-.02	.21	.05	.11	.09	-.09	-.06
15. Reinvestment rate	.03	.17	.05	-.22	.21	.21	.20	.21	.22	.25	.14
16. Age of presses	.16	-.21	.08	.15	.09	.03	.05	-.05	-.10	-.18	-.15
17. Supplier base	.00	.23	-.07	-.18	-.23	-.08	-.11	-.08	.00	.02	-.08
18. Customer concentration	-.06	.20	-.08	-.14	-.12	-.16	-.08	-.19	-.08	-.08	-.14

[a] Correlations over 0.29 have p-value < 0.01 and correlations over 0.21 have p-value < 0.05 (79 < n < 84).

[b] Descriptive statistics for each variables are presented in Appendix E.

[c] Correlations among the control variables were already presented in Table 6.1.

As in the analyses pertaining to operational performance, GSCP upstream and downstream are evaluated in two different models. This is also the case for the supply chain integration variables, logistical and technological integration. Hence, a total of two regressions, one with upstream (suppliers) GSCP and supply chain integration and one with downstream (customers) GSCP and supply chain integration, were run for each form of environmental technology.

6.3.1. *Pollution Prevention*

Regression results for the selection of pollution prevention technology are presented in Table 6.12. Results indicate marginal support for hypothesis H3a, as environmental cooperation with suppliers is positively related to pollution prevention (Model 10a; $p < 0.10$).

While not significant, the sign of the influence of environmental monitoring upon suppliers was directionally consistent with the relation proposed in hypothesis H4a, which suggested that pollution control and management systems would be positively linked to environmental monitoring. However, no influence from GSCP with customers on the selection of pollution prevention technology was found (Model 10b).

Table 6.12 Green Supply Chain Practices and Pollution Prevention Selection†

	GSCP with Suppliers Model 10a		GSCP with Customers Model 10b	
	Beta	**ΔR^2**	**Beta**	**ΔR^2**
Control Variables		.225***		.164**
Plant size[1]	.162		.070	
Parent company size[2]	-.296**		-.315**	
Reinvestment rate[3]	.074		.071	
Age of presses	-.094		-.111	
Supplier base[4]	.279***			
Customer concentration[5]			.049	
Supply Chain Integration		.093***		.001
Logistical integration	-.252**		.026	
Technological integration	.317***		-.112	
Green Supply Chain Practices		.031		.033
Environmental cooperation	.240*		.205	
Environmental monitoring	-.177		-.003	
R^2	.349***		.197*	
F Statistics	4.115		1.803	
Number of observations	79		76	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01
† The standardized betas (β) are reported in the table.
1 Natural logarithm of the number of employees in the plant.
2 Natural logarithm of the number of employees in the parent company.
3 Percentage of annual sales invested in new equipment on average over the last two years.
4 Total number of suppliers divided by the number of employees at the plant.
5 The % of sales coming from the three largest customers.

Technological integration with suppliers was significant and positive, supporting hypothesis H6a (Model 10a; $p < 0.01$). Logistical integration with suppliers was also significant and negative, providing strong support for hypothesis H6b (Model 10a; $p < 0.05$). Logistical and technological integration with the customers did not have the same influence on the allocation of environmental investment toward pollution prevention, as they were both non significant.

The relative size of the supply base was positively associated with pollution prevention, which was puzzling. The original belief was that pollution prevention, requiring more knowledge in order to be less disruptive in the organization, would benefit from the buyer-supplier integration that comes with a smaller set of suppliers. However, the results suggest otherwise. One speculative avenue is that one of the major drivers of process- or product-based changes in the printing industry is typically technical innovations made by suppliers (e.g., ink); such innovations are often used by suppliers to increase their sales at any given plant. In this context, plant managers prefer having several suppliers competing, hence increasing the possibilities to keep the plant with the state-of-the-art material and equipment (Bonifant et al. 1995).

Finally, parent company size was consistently negatively related to pollution prevention technology selection. As the *parent* firm size increased, less of the environmental technology portfolio was allocated toward pollution prevention (after controlling for plant size). Instead, resources were shifted to management systems. This may have occurred because larger, more complex organizations often must deal with a greater variety of demands from the parent firm and a greater number of suppliers, customers, and regulatory agencies.

6.3.2. *Pollution Control*

Results of the analysis pertaining to pollution control are presented in Table 6.13. None of the GSCP variables was significant. Only two variables were significantly related to pollution control selection: (i) technological integration with customers was positively related to pollution control selection (Model 10a; $p < 0.01$), and (ii) logistical integration with customers was negatively related to pollution control selection (Model 10a; $p < 0.05$), which contradicts hypothesis H6c.

Table 6.13 Green Supply Chain Practices and Pollution Control Selection†

	GSCP with Suppliers Model 11a		GSCP with Customers Model 11b	
	Beta	**ΔR^2**	**Beta**	**ΔR^2**
Control Variables		.052		.042
Plant size[1]	-.013		.040	
Parent company size[2]	.199		.101	
Reinvestment rate[3]	.111		.042	
Age of presses	.033		.032	
Supplier base[4]	-.037			
Customer concentration[5]			-.030	
Supply Chain Integration		.032		.094**
Logistical integration	.174		-.323**	
Technological integration	-.190		.312**	
Green Supply Chain Practices		.004		.006
Environmental cooperation	.070		.035	
Environmental monitoring	-.082		-.111	
R^2	.088		.143	
F Statistics	0.739		1.225	
Number of observations	79		76	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01
† The standardized betas (β) are reported in the table.
1 Natural logarithm of the number of employees in the plant.
2 Natural logarithm of the number of employees in the parent company.
3 Percentage of annual sales invested in new equipment on average over the last two years.
4 Total number of suppliers divided by the number of employees at the plant.
5 The % of sales coming from the three largest customers.

6.3.3. Management Systems

The analysis for management systems is presented in Table 6.14. Environmental cooperation with suppliers was negatively related to the degree of allocation in management systems (Models 12a; $p < 0.05$). While not significant, a similar relation was found for environmental cooperation with customers. To a lesser extent, environmental monitoring of suppliers was found to have a positive relationship with management systems selection supporting hypothesis H4a (Model 12a; $p < 0.10$). There was no indication that GSCP with customers were linked to the selection of management systems.

Logistical integration with customers was positively linked to investment in management systems, giving some support to hypothesis H6c (Model 12b, $p < 0.10$). None of the other supply chain integration variables, whether upstream with the suppliers or downstream with the customers, was significant.

It is noteworthy that relative supply base size exhibits a negative relationship with management systems, complementing the results found in the pollution prevention analysis (Model 12a, $p < 0.05$). Also, parent company size was marginally significant and positively associated with management systems investments (Model 12b; $p < 0.10$).

Table 6.14 Green Supply Chain Practices and Management Systems Selection†

	GSCP with Suppliers Model 12a		GSCP with Customers Model 12b	
	Beta	**ΔR^2**	**Beta**	**ΔR^2**
Control Variables		.140**		.100
Plant size[1]	-.160		-.107	
Parent company size[2]	.140		.244*	
Reinvestment rate[3]	-.174		-.110	
Age of presses	.070		.089	
Supplier base[4]	-.262**			
Customer concentration[5]			-.025	
Supply Chain Integration		.031		.051
Logistical integration	.115		.247*	
Technological integration	-.170		-.148	
Green Supply Chain Practices		.055*		.032
Environmental cooperation	-.314**		-.244	
Environmental monitoring	.257*		.098	
R^2	.227**		.183	
F Statistics	2.248		1.638	
Number of observations	79		76	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

† The standardized betas (β) are reported in the table.

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The % of sales coming from the three largest customers.

6.3.4. Level of Investments in Environmental Technologies

The analysis for the level of investment in environmental technologies is presented in Table 6.15. The results provide support for hypotheses H3b and H4b as the change in the R-square associated with Green supply Chain Practices with suppliers (Model 13a, $p < 0.10$) and with customers (Model 13b, $p < 0.05$) were both significant. Furthermore, the coefficient estimates were all directionally consistent with hypotheses H3b and H4b.

Table 6.15 Green Supply Chain Practices and Level of Investment in Environmental Technologies†

	GSCP with Suppliers Model 13a		GSCP with Customers Model 13b	
	Beta	**ΔR^2**	**Beta**	**ΔR^2**
Control Variables		.052		.052
Plant size[1]	.105		.114	
Parent company size[2]	.005		-.019	
Reinvestment rate[3]	.022		.039	
Age of presses	.113		.107	
Supplier base[4]	.094			
Customer concentration[5]			-.083	
Supply Chain Integration		.003		.050
Logistical integration	-.018		-.234*	
Technological integration	-.133		-.204	
Green Supply Chain Practices		.067*		.113**
Environmental cooperation	.223		.214	
Environmental monitoring	.119		.215	
R^2	.122		.215**	
F Statistics	1.097		2.065	
Number of observations	81		78	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

† The standardized betas (β) are reported in the table.

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The % of sales coming from the three largest customers.

6.4. Environmental Technology Selection—Discussion

6.4.1. Green Supply Chain Practices

Stepping back to look at the findings of this section, it becomes apparent that the focal plant's allocation of resources to various forms of environmental technology in the last two years tended to be driven by more supplier-related interactions than customer-related interactions. That was particularly prevalent for GSCP. In particular, increased joint environmental planning and collaboration was related to more process- and product-based modifications within the focal plant. It is not clear why this came primarily at the expense of management systems, instead of at the expense of a *combination* of pollution control *and* management systems. Possibly, this occurred because some allocation toward pollution control had to be maintained to comply with specific air and waste regulations. For instance, several plants have built clean room (or total enclosure areas) to ensure a good recoup of the VOC emissions in the pressroom. In one plant visited, the clean room was a special requirement from pharmaceutical customers. Overall, however, the effects of joint environmental planning and collaboration with major customers were weaker than with suppliers, although they were directionally consistent.

The result related to upstream (suppliers) GSCP is consistent with Carter and Carter's (1998) work on environmental purchasing. They found that environmental purchasing, defined as the involvement of the purchasing department in life-cycle analysis, design for disassembly, and design for the environment (mainly all pollution prevention-related activities), was linked positively to vertical coordination, measured by the degree of partnership with the suppliers in environment-related projects.

Given that one plant's suppliers are another plant's customers, an interesting implication arises if more than two adjacent supply chain linkages are considered for cooperative practices. These results suggest that pollution prevention is likely to be more prevalent further downstream in the supply chain and, conversely, less prevalent upstream.

In contrast, because monitoring is not mutual, each member of the supply chain can make these decisions independently, with no necessity for a pattern to form along the supply chain. Moreover, monitoring by customers did not consistently encourage (or discourage, for that matter) greater allocation toward pollution prevention. As a result, a consistent, greater allocation toward management systems was only detected in the initiating plant.

It is also noteworthy that green supply chain practices downstream with the customers was positively associated with higher level of investment in environmental technologies but not on the allocation of such investment into different form of technologies (i.e., pollution prevention, pollution control or management systems). This can be an indication that customers are outcome- rather than process-oriented in the management of the supply chain. An interesting link to quality management can be made here. Customers often require and imposed quality related standards forcing their suppliers to invest resources. The attention is devoted to metrics such as incoming material defects or suppliers' delivery performance not particularly on the improvement of the suppliers' operations to attain the goals attached to such metrics.

6.4.2. Supply Chain Integration

Technological integration with suppliers was linked to more investment toward pollution prevention relative to pollution control and management systems, providing support to hypothesis H6a. Hence, tacit knowledge sharing and transfer taking place in activities pertaining to technological integration (i.e., technical training, site visits, and design collaboration) are associated with a plant's structural changes to prevent pollution.

These results are consistent with other findings in the literature. The study by Florida (1996) indicates that greater partnership with the supply network was associated with more structure-based initiatives such as process reengineering and design for the environment. A recent Canadian study suggests that advanced forms of environmental commitment and supplier relationships were positively linked (Roy et al. 2001).

The sign for the coefficient related to management systems was directionally consistent with Klassen and Vachon (forthcoming), but the shift of resources favored pollution control instead of pollution prevention. However, the coefficients relating technological integration with customers to pollution prevention and management systems were non-significant.

The fact that technological integration with customers was related to greater allocation toward pollution control in the focal plant was not expected. Technological integration may have increased the degree of visibility of the focal plant's environmental management to its customers (e.g., visits to the premises). As a result of increased interaction and visibility, plant managers might be more inclined to invest in easy-to-identify structural changes, i.e., pollution control devices.

6.5. *Green Supply Chain Practices—Analysis*

This section reports the result of the analysis on the linkages between GSCP and supply chain integration, both logistical and technological. The hypothesis related to this section is hypothesis H5, which proposes that logistical and technological integration are both positively related to environmental cooperation. Hypotheses were only developed for the relationship between supply chain integration and environmental cooperation. Overall in this section four models are run, one per type of green supply chain practices—environmental cooperation with suppliers, environmental monitoring of suppliers, environmental cooperation with customers, and environmental monitoring by customers.

Environmental Cooperation with Suppliers

Regressions pertaining to GSCP upstream are presented in Table 6.16. There is strong support for hypothesis H5, indicating a positive link between technological integration with suppliers and environmental cooperation (Model 14; $p < 0.05$). Similarly, logistical integration was also positively linked to environmental cooperation (Model 14; $p < 0.05$). It is also noteworthy that the relative size of the supply base was negatively related to environmental cooperation, which is coherent with the notion that supply chain partnership can hardly be achieved with a large supply base (Model 14; $p < 0.05$). The age of the presses was also positively associated with environmental cooperation with suppliers. That can be an indication that organizations having older equipment relies relatively more on suppliers to conduct their operations and to respond to environmental challenges hence developing more cooperative practices.

Table 6.16 Green Supply Chain Practices with Suppliers†

	Environmental Cooperation Model 14		Environmental Monitoring Model 15	
	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.116*		.117*
Plant size[1]	.080		.106	
Parent company size[2]	-.090		.179	
Reinvestment rate[3]	.117		.151	
Age of presses	.211**		.067	
Supply base[4]	-.207**		-.049	
Supply Chain Integration		.187***		.123***
Logistical integration	.235**		.217*	
Technological integration	.289**		.207*	
R^2	.303***		.239***	
F Statistics	4.658		3.369	
Number of observations	83		83	

Table 6.17 Green Supply Chain Practices with Customers†

	Environmental Cooperation Model 16		Environmental Monitoring Model 17	
	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.067		.128*
Plant size[1]	.005		.191*	
Parent company size[2]	-.028		-.037	
Reinvestment rate[3]	.116		.103	
Age of presses	.138		-.011	
Customers concentration[5]	-.007		.115	
Supply Chain Integration		.148***		.117***
Logistical integration	.054		.043	
Technological integration	.394***		.352***	
R^2	.215**		.245***	
F Statistics	2.819		3.337	
Number of observations	80		80	

† The standardized betas (β) are reported. *p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

1 Natural logarithm of the number of employees in the plant.

2 Natural logarithm of the number of employees in the parent company.

3 Percentage of annual sales invested in new equipment on average over the last two years.

4 Total number of suppliers divided by the number of employees at the plant.

5 The % of sales coming from the three largest customers.

Environmental Cooperation with Customers

The regression analysis (Table 6.17) suggests, again, strong support for hypothesis H5, with technological integration being positively linked to environmental cooperation (Model 16; $p < 0.01$). Overall, both logistical and technological integration have a significant impact on the variance explained in the regression. Change in the R-square was highly significant (Model 16; $p < 0.01$).

6.6. Green Supply Chain Practices—Discussion

The results of the regression analysis denote that, in general, a direct positive link exists between technological integration and environmental cooperation with both primary suppliers and major customers. This link was weaker for logistical integration. Hence, the integration related to strategic activities, such as product development and tacit knowledge transfer through technical training and premises visits, is linked with a higher propensity to collaborate in environmental planning, establishing common environmental goals and jointly addressing product- and process-related issues. At the tactical level, the extensive but low-level information sharing typical of logistical integration does have the same positive effect on the environmental cooperation. This result can indicate that environmental management is getting more strategic level attention in organizations' operations management and that it is increasingly viewed as a component of operations strategy rather than a constraint to the day-to-day operations (Angell and Klassen 1999).

Environmental monitoring by the customers was highly related to technological integration. This finding suggests that customers who are investing resources to develop suppliers through technical training and knowledge sharing are risk averse. They seek to protect their investment by increasing their evaluative activities and control of the environmental management behavior of their suppliers.

The result regarding environmental cooperation with suppliers is consistent with the study of Bowen et al. (2001), who suggest that supply management capability, which includes partnership with the suppliers, was associated with environment-based collaboration with suppliers. They also found a very weak relationship between supply management capability and control activities (e.g., environmental questionnaire, environmental scoring, and an EMS requirement), again consistent with the findings here.

It is also noteworthy that the supply base was negatively linked to environmental cooperation. This suggest that rationalization of the supply base might be an initial step toward more proactive green supply chain practices. In fact, this is consistent with the quality management (Latzko and Saunders 1995) and supply management (Agrawal and Nahmias 1997) literature.

6.7. Synthesis

The goal of this section is provide an overview of the results obtained from the analysis conducted throughout this chapter. In general, good support for hypotheses (list) was found while little or no support was found for hypotheses (list).

Table 6.18 Synthesis of the Results

Hypothesized Relations	Related Hypothesis	Support Upstream	Support Downstream
GSCP to Operational Performance			
Environmental cooperation to			
o Cost	H1a	√	
o Quality	H1b	√	√
o Delivery	H1c	√	√
o Flexibility	H1d	√	
o Environmental	H1e		√
Environmental monitoring to			
o Cost	H2a		
o Quality	H2b		
o Delivery	H2c	**X**	√
o Flexibility	H2d		
o Environmental	H2e	√	
GSCP to Environmental Technology			
Environmental cooperation to			
o Pollution prevention (form)	H3a	√	
o Level of investment (extent)	H3b		√
Environmental monitoring to			
o Pollution control (form)	H4a		
o Management systems (form)	H4a	√	
o Level of investment (extent)	H4b		√
Supply Chain Integration to GSCP			
Technological integration to			
o Environmental cooperation	H5	√	√
Logistical integration to			
o Environmental cooperation	H5	√	
Supply Chain Integration to Env. Technology			
Technological integration to			
o Pollution prevention (form)	H6a	√	
o Level of investment (extent)	H6b		
Logistical integration			
o Pollution control (form)	H6c		**X**
o Management systems (form)	H6c		√

√ = support for hypothesis **X = counter support for hypothesis**

7. CONCLUSION AND FUTURE RESEARCH

The primary goal of this dissertation was to gain a better understanding of the impact of inter-organizational activities on a plant's environmental technology selection and operational performance. Earlier case- and survey-based research remained vague on the influence of other organizations in the supply chain on environmental management practices and operational performance in a focal plant. Accordingly, the research objectives set in Chapter 1 of this dissertation makes the following contribution:

(i) The development of typology for green supply chain practices that was empirically validated.

(ii) The theoretical linkages between supply chain integration and green supply chain practices with environmental technology selection and investment within a focal plant. These linkages were empirically tested.

(iii) The theoretical linkages between green supply chain practices and operational performance with empirical assessment of such linkages.

(iv) The evaluation of the difference in the impact of green supply chain practices from both an upstream (suppliers) and downstream (customers) perspectives.

7.1. Overview of the Dissertation

In order to address the research questions a thorough review of the operations management literature related to supply chain and environmental management was performed. Particular attention also was given to studies pertaining to the natural resource-based view of the firm. The *Supply Chain Environmental Management* model was then conceptualized, linking green supply chain practices, environmental technology selection, and operational performance. Green supply chain practices were defined as comprising two categories of focal plant's activities whether with its supply network or its customer base. These two categories were *environmental cooperation* and *environmental monitoring.*

The *Supply Chain Environmental Management* model was tested with data collected through a single industry survey. The survey targeted the plant managers in the package printing industry in Canada and in the United States. A total of 84 responses were received, yielding a response rate of 23%. This response rate is judged appropriate given recent survey research in operations management. Overall the results can be categorized into three major sets:

(1) the linkage between GSCP and operational performance;

(2) the relationship between GSCP and environmental technology selection; and

(3) the impact of supply chain integration on GSCP and environmental technology selection.

The influence of GSCP on operational performance was highly significant, mainly on the delivery, flexibility, and environmental performance metrics. Environmental cooperation with suppliers was positively linked to perceptual scales regarding these three performance metrics as well as being marginally significant for cost and quality performance. Environmental cooperation with customers may improve quality performance, as the results indicated a positive link to the perceptual metric of quality performance and a negative link with the scrap rate. Hence, when considered together, the results indicate that **environmental cooperation with suppliers is more likely to yield better operational performance**.

It is noteworthy that environmental monitoring did not affect operational performance with the same consistency.

GSCP can also have an influence on the recent allocation of environmental investment toward different technologies, specifically, pollution prevention, pollution control, and management systems. In particular, environmental cooperation with suppliers positively influenced the allocation of resources into pollution prevention technology. In contrast, environmental cooperation with suppliers was negatively linked to the allocation of environmental investment in management systems. Therefore, **environmental cooperation with suppliers is related to a shift in the allocation of environmental investments from management systems to pollution prevention**.

Finally, general supply chain activities captured through logistical and technological integrations were assessed as antecedents to GSCP. The findings indicated that the **upstream (suppliers) technological integration was linked to environmental cooperation with suppliers**. Hence, the general integration of activities that permit the development of rich channels of communication and knowledge transfer is significantly correlated with the joint environmental planning and collaborative environmental solution finding. Similar results were found between **downstream (customers) technological integration and environmental cooperation with customers**.

7.2. Green Supply Chain Practices

The first contribution of the dissertation, in line with its first research objective, is the development of a typology of environment-related activities taking place in a supply chain. Grounded in the externalization/internalization framework from the international business literature (Buckley and Casson 1976), and particularly referring to its recent application to supplier development programs (Krause et al. 2000), two types of activities were proposed, namely *environmental cooperation* and *environmental monitoring*.

Environmental cooperation consists of activities taking place between a focal plant and its supply network or its customers base that are related to joint environmental planning and collaboration in solving environmental problems. Environmental monitoring pertains to control and evaluative activities (questionnaires, audits, EMS requirements) that a focal plant exercises over its supply network or that are imposed on the focal plant by its customers. These categories are not just grounded in theory but map closely to the activities reported in the practitioner and scientific literatures (Gavaghan et al. 1998; Krut and Karasin 1999; Min and Galle 1997; Walton et al. 1998).

Conceptualizing this typology is different than what is proposed in the literature with regards to green supply chain. First, previous research focused on an organization's purchasing function when studying the green supply chain (Bowen et al. 2001; Carter and Carter 1998; Carter et al. 1998). Therefore, these studies have limited their scope to upstream interactions. This dissertation asserts that green supply chain practices also refer to an interaction that can and must take place downstream with customers. While only one linkage upstream and one linkage downstream was examined, future empirical research will need to consider multiple linkages and increase the scope to include more of a network approach rather than a linear supply chain design (Choi et al. 2001; Fine 1998).

Secondly, the literature at this point had not organized the activities in a theoretically grounded manner, as pointed out in a recent and thorough review of environmental purchasing literature (Zsidisin and Siferd 2001). By considering a dichotomy of green supply chain practices into environmental cooperation and environmental monitoring, a better understanding of the influence of inter-organization activities concerning the natural environment can be gained.

The results of this study suggest that environmental monitoring is not highly desirable from an operational performance perspective. The recent literature associating lean production and environmental management (King and Lenox 2001; Rothenberg et al. 2001) provide another perspective to the general results regarding environmental monitoring. The diffusion of lean production systems in the supply network through supplier development and suppliers evaluation has been the topic of several studies. Macduffie and Helper (1997) cautioned against relying solely on supplier development programs and suggested that: "Customers who want their suppliers to improve must balance the need to monitor the suppliers existing performance while encouraging them to learn new skills, which in short term might disrupt that performance." The entanglement of environmental monitoring and environmental cooperation found in the operational performance regressions of this dissertation might suggest that Macduffie and Helper (1997) are right. Both sets of green supply chain practices are needed to achieve sound environmental management throughout the supply chain. This balance between evaluative activities (monitoring) and direct involvement (cooperation) is also discussed in the supplier development literature (Krause et al. 2000). Hence, monitoring suppliers can remain an important feature of supply chain management despite the merits of environmental cooperation displayed in this dissertation.

7.2.1. Scale Development and Empirical Validation

The development of scales and items to evaluate the extent of green supply chain practices exercised by a manufacturing organization constitutes a empirical contribution. Five items for each segment of green supply chain practices—environmental cooperation with suppliers, environmental monitoring of suppliers, environmental cooperation with customers, and environmental monitoring by customers—were developed using the logistics (Ellinger et al. 2000) and the green operations literature (Bowen et al. 2001; Gavaghan et al. 1998; Min and Galle 1997; Noci 1997; Walton et al. 1998). The scales achieved a high level of reliability and construct validity. Therefore, theses scales can be replicated, for the use in other studies, as they capture the essence of the concepts of environmental cooperation and environmental monitoring.

7.3. Supply Chain Environmental Model

Another contribution is the conceptual and theoretical development of the linkages between green supply chain practices and other constructs of interest, namely environmental technology selection and operational performance. The *Supply Chain Environmental Management* model was developed, and the relationships between green supply chain practices and operational performance was elaborated in two phases. First, environmental cooperation with both suppliers and customers was hypothesized to positively influence operational performance. This link was grounded in the natural resource-based view of the firm (Hart 1995; Russo and Fouts 1997). Second, it was argued that environmental monitoring increases the degree of formalization in the supply chain. As such, environmental monitoring had a different influence depending on the dimension of operational performance studied.

The relationship between environmental cooperation and operational performance is of particular interest. The argument is that environmental cooperation, with its joint environmental planning and collaboration to find solutions to environmental challenges, provides a strategic resource that is difficult for competitors to replicate. This is a new facet of the natural resource-based view of the firm since most of the previous studies focus on internal processes and product changes (e.g., Christmann 2000; Klassen and Whybark 1999b). This dissertation is one of the first studies to integrate external resources with the natural resource-based view of the firm.

The argument that environmental cooperation leads to improved performance is predicated on the ability of an organization to integrate its own resources with the tacit knowledge and technologies of the suppliers' and customers' organizations. As such, environmental cooperation can be viewed as a capability that triggers the combination of internal and external resources (taking the form of knowledge and technologies) leading to the creation of a new resource that provides a competitive advantage (Germain et al. 2001; Grant 1996b). This perspective, using inter-organizational activities to create resources, is also known as the relational view of the firm (Dyer and Singh 1998) and was applied to plant performance in a recent study on manufacturing strategy (Schroeder et al. 2002). Therefore, this dissertation also extends the previous work in the supply chain by incorporating environmental issues to the relational view and inter-organizational learning.

Besides testing the natural resource-based view of the firm, assessing the link between green supply chain practices and environmental technology selection was another empirical contribution. Some evidence from large-scale surveys linking supply chain collaboration to environmental technology has already appeared in the literature (Klassen and Vachon, forthcoming), as several case studies reported that the suppliers and customers could be key in the selection of cleaner technologies (Ashford 1993; Bonifant et al. 1995; Kemp 1993). However, this dissertation is the first attempt to link green supply chain practices to environmental technology selection.

7.4. Future Research Avenues

Two broad topics are discussed in this section: the influence of stakeholders, other than the suppliers and the customers, and the application of environmental management in the service sector.

7.4.1. Stakeholder Pressures

Recent studies suggest that different stakeholders groups have an influence on the development of corporate environmental strategy (Delmas 2001; Henriques and Sadorsky 1999). However, these studies focus on business policy and the development of environmental plans and systems at the corporate level. The influence of different stakeholders groups on operations management remains largely unexplored. For instance, this dissertation portrays customer (a stakeholder) pressure, which took the form of environmental monitoring. The results indicate that customer-driven actions like environmental audits, special standard requirements, and evaluative activities were not affecting the allocation of resources to different environmental technologies. Is pressure coming from suppliers, local communities, regulatory agencies, or internal stakeholders (e.g., employees or shareholders) expected to have a similar impact?

The argument here is that pollution control devices attract more attention, as they can be more visible than fundamental process changes or material substitution. Therefore, local community and lobby group pressure might cause managers to opt for pollution control devices rather than seeking more long term, sustainable pollution preventive options not entirely visible to outsiders. Similarly, employees' issues that would be related to health and safety matters might push management to consider product substitution, hence pollution prevention options. The disentanglement of the influence of different stakeholders groups on the operations management decisions regarding the environment constitutes an interesting research avenue.

7.4.2. Shifting the Paradigm Toward the Service Sector

The greater part of environmental management research has been concentrated in the manufacturing sector, with special emphasis on industries with a high environmental impact such as the chemical (Christmann 2000), furniture (Klassen 1995), electronics (Krut and Karasin 1999), and automotive (Geffen and Rothenberg 2000) industries. While the service sector represents more than 75% of the industrialized economy it has not attracted much attention in the environmental management literature (Salzman 2000). Some studies based on anecdotal evidence in the hospitality industry (Enz and Siguaw 1999) and in the health care industry (Messelbeck and Whalley 1999) start to build the recognition that service operations can be harmful to the environment. However, theoretical and conceptual development is practically nonexistent in the literature.

Research on environmental management in the service sector can be challenging for several reasons. The first set of reasons pertains to the characteristics of several industries in the sector. For instance, the process design of several organizations in the service sector requires large brick-and-mortar investments, hardly reversible, for which day-to-day operations are labor intensive (e.g., restaurants, hotels, resorts, health care, education, and airlines). Such design makes structural changes very time consuming and costly, as they require extensive investments to retrofit the equipments (e.g., changing an engine on an aircraft) or buildings (e.g., energy savings in lighting systems). However, some service organizations engage in a more advanced form of environmental investments that involve structural changes. An example of such an initiative is the Aspen Ski Company, which undertook several structural projects such as retrofitting garages and lighting systems and designing *green buildings* (Schendler 2001). This was also true for Scandic hotels, which reduced the mirror size in their rooms in order to minimize the amount of mercury that needed to be disposed when the room is redesigned. Would it, therefore, be possible to develop a typology of environmental initiatives in the service industry similar to the three environmental technologies used in this dissertation?

A second set of challenges with studying environmental management in the service sector is the small amount of empirical knowledge regarding the service sector environmental performance. This is symptomatic of the lack of environmental performance and management metrics in the service sector (Salzman 2000). Without such metrics, managers have difficulties establishing environmental programs and assessing their evolution; the lack of metrics also renders the research tasks more complicated. For instance, with the exception of the transportation industry, pollution emission streams—whether by air, water, or soil—are diffused and not easily identifiable. Hence, how can a researcher design a good project when environmental metrics and the environmental challenge are not well defined?

However, the little research done so far suggests that the supply chain will be key in the development of sustainability in the service sector. On the one hand, the customers, often an integral part of the service process, become critical to successfully implementing environmental programs (Foster et al. 2000). On the other hand, suppliers of goods and service play an important role helping services organizations to redesign the service process and the structural elements used to deliver the service. On this last point it has been recognized that, in order for American Hospitals to fulfill their goal of a 50% waste reduction by 2010, they will need work collaboratively with the suppliers of health care goods to find sustainable solutions (Messelbeck and Whalley 1999).

The predominance of the service sector will increase in this information age. If no attention is given to the environmental consequences and to ways of addressing environmental challenges in that sector, the beautiful promises of a better lifestyle associated with the information age will be tarnished by the poor quality of our essential commodities—clean air, clear water, and pristine soils.

APPENDIX A INTERVIEW PROTOCOL PLANT MANAGERS

General Plant Operations

1. What are the major product lines produced in this plant?
2. How large is the plant?
3. What is the average age of the equipment in the plant?

General Environmental Issues

1. What type of environmental issues do you see affecting the package printing industry now? ... in the future?
2. What forces are driving these changes (customers, competition, regulation)?
3. How do you think production managers like yourself in the industry should be responding or planning for these issues?
4. Will the response to these issues affect the way the industry as a whole can print package (material, prepress, pressroom, and post-press operations)?

Specific Plant Issues

1. What are the most critical environmental issues specifically for your plant? Do you have any performance metrics to monitor your environmental performance?
2. Will environmental issues affect the way your plant can manufacture your product?
3. How do you plan for or respond to these issues for your plant (equipment, training...)? Is it different than what would be the general practice in the industry?
4. Specifically, what types of changes are occurring in your plant related to the environment?
5. Are they beneficial from an operations standpoint? Are they detrimental from an operations standpoint? Both? (cost, quality, speed and flexibility)

6. Are you limited (or helped) by your plant's particular situation (incompatibility of the equipment, insufficient financial resources, inflexibility)?

7. Do you have an environmental management system in place?

8. Besides for environmental issues, what other programs and technology have you been devoting time and money to over the last two years?

9. What is your major area of emphasis to improve your plant's position in the marketplace (cost, quality, speed, flexibility)

Supply Chain Management

1. To what extent do you share operational information (inventory, production plan, forecasting…) with your suppliers? Are your information systems partially "linked" with your suppliers? Would you say it is generally the practice in the industry?

2. Are your primary suppliers responsive in facing unforeseen events? (rush order, disruption, energy shortage…)

3. How do environmental issues impact purchasing?

4. Are environmental criteria used to evaluate potential suppliers?

5. To what extent do suppliers assist you in managing environmental issues within your plant? Have any suppliers (or equipment vendors) actively participated in your environmental effort?

6. Do your major customers request environmental-responsible products?

7. Do your major customers monitor your environmental management performance? (questionnaires, audits)

8. Do your major customers consult your plant prior any major design changes or for promotional packages?

APPENDIX B SURVEY INSTRUMENT

Date

To: **«Salutation» «First_Name_Two» «Last_Name_Two»**
«Company_Name»

Fax: **«Fax_II»**

From: **Stephan Vachon**
Richard Ivey School of Business
University of Western Ontario

Dear «Salutation» «Last_Name_Two»

Supply chain management has received greater attention as firms increasingly rely on their supply network to handle more complex technologies and higher customer expectations. Similarly, the importance of environmental issues increased with the growing involvement of several stakeholders which resulted in greater pressures to comply with regulation and new customers' requirements with respect to the management of the natural environment. The purpose of my research is to better understand the relationship between supply chain management, environmental issues and operational performance in the package printing industry. I will use the data collected in this study for my doctoral dissertation research.

Included with this fax is a questionnaire that asks about your package printing supply chain and environmental practices. The questionnaire is straightforward and should take no more than 30 minutes of your time. I ensure that all responses given are **strictly confidential**. Neither you nor your institution will be identified: only aggregate results will be published. If after reading through the enclosed material you feel that you are not the appropriate questionnaire respondent for your plant, please pass this package of material to the individual most informed to respond for your plant and let us know to whom the package has been given. Your participation is entirely voluntary as no consequences or repercussions are tied to your decision.

The results may provide you with insights on how to improve your plant supply chain and environmental practices. In appreciation for your assistance, you will also receive a summary report of the results providing benchmark information. In recognition of your participation, I will **donate $5 to "Médecins Sans Frontières / Doctors Without Borders (MSF)"** for each completed survey. Funds raised will help provide medical assistance to populations in danger around the world. Therefore, it is important that you also complete the participant form (blue sheet), which will be used to collect the company address so a copy of the results can be sent to you.

Please return the completed questionnaire and participant form by April 30th, 2002 by fax to Stephan Vachon at (519) 661-3959 or by mail at the address indicated at the last page of the survey. If you have any questions, please contact me at (519) 661-2111 (ext. 85138) or through e-mail at svachon@ivey.uwo.ca. Thank you in advance for your participation and generous support of this doctoral dissertation research study. I look forward to hearing from you.

Sincerely,

Stephan Vachon
Ph.D. Student – Operations Management

Richard Ivey School of Business
The University of Western Ontario

IVEY

Package Printing Industry

Manufacturing Competitiveness
The Role of Supply Chain and Environmental Practices

QUESTIONNAIRE DIRECTIONS

Please respond to each question/statement carefully and candidly. It is your opinion and perception as a manager knowledgeable about your plant's practices that are important! Your plant specific information will be kept **strictly confidential**. Only aggregate summaries will be reported. We recommend that you keep a copy of your completed questionnaire so you can compare your own organization's results with those of others in your industry.

A. Supplier Management

This section examines the type of supplier management practices and development activities. Please circle the number that best describes your plant's practices.

A1. The following statements relate to your plant's **communication** activities with your primary suppliers (inks, substrates, equipment). ***Our plant...***

		never		*sometimes*				*always*
a.	provides information to help our primary suppliers improve	1	2	3	4	5	6	7
b.	exchanges operational and logistical information with primary suppliers	1	2	3	4	5	6	7
c.	exchanges information informally with primary suppliers without pre-specific agreements	1	2	3	4	5	6	7
d.	informs our primary suppliers about events or changes that may affect them	1	2	3	4	5	6	7
e.	has face-to-face communication with primary suppliers for planning purpose	1	2	3	4	5	6	7

A2. The following statements relate to your primary suppliers' **commitment** to your plant. ***Our primary suppliers...***

		never		*sometimes*				*always*
a.	visit our premises to help us to improve our performance	1	2	3	4	5	6	7
b.	dedicate people and resources to make us a satisfied customer	1	2	3	4	5	6	7
c.	sell us capabilities, not just their products	1	2	3	4	5	6	7
d.	provide training on their products	1	2	3	4	5	6	7
e.	help us in process improvement activities (e.g., value analysis, cost reduction, problem solving)	1	2	3	4	5	6	7
f.	make efforts with us to improve the quality of the product we order from them	1	2	3	4	5	6	7
g.	collaborate in the design of new products or new product lines to be introduced at our plant	1	2	3	4	5	6	7

A3. The following statements relate to the **degree of flexibility** characterizing the logistical transactions with your primary suppliers. ***Our primary suppliers...***

		never		*sometimes*				*always*
a.	advise us of shipment (delivery) problems	1	2	3	4	5	6	7
b.	are willing to respond to special requests	1	2	3	4	5	6	7
c.	allow us to make blanket orders	1	2	3	4	5	6	7
d.	provide us with emergency delivery	1	2	3	4	5	6	7
e.	take back obsolete or damaged inputs/materials	1	2	3	4	5	6	7

A4. Please indicate the number of suppliers that your plant has for each of the following:

a.	Substrates (all of them)..	_____ suppliers
b.	Inks	_____ suppliers
c.	All other suppliers (maintenance, equipment, transportation)................	_____ suppliers

B. Customer Involvement

This section examines the degree of interaction between your plant and major customers. Please circle the number that best describes your plant's practices.

B1. Please consider the **involvement** of your major customers in the operations of your plant. In general, ***our major customers...***

		never		*sometimes*				*always*
a.	provide our personnel with training	1	2	3	4	5	6	7
b.	visit our premises to help us improve our performance..	1	2	3	4	5	6	7
c.	invite us to their premises in order for us to increase our awareness on how our product is used...........................	1	2	3	4	5	6	7
d.	participate in the proofing process and assist us in first runs of the prints	1	2	3	4	5	6	7

B2. The following statements relate to the degree of **communication** and **flexibility** found in the interaction with your major customers. In general, ***our major customers...***

		never		*sometimes*				*always*
a.	involve us in the design of new packages or package lines..	1	2	3	4	5	6	7
b.	provide us information that might help our operations...	1	2	3	4	5	6	7
c.	discuss with us production issues related to major design changes in existing packaging (e.g., colors, size)	1	2	3	4	5	6	7
d.	share information informally with us without specific agreements	1	2	3	4	5	6	7
e.	have face-to-face communication with us for planning purpose..	1	2	3	4	5	6	7
f.	are willing to make cooperative changes	1	2	3	4	5	6	7
g.	allow some flexibility in their requirements regarding product delivery	1	2	3	4	5	6	7
h.	understand and comprehend unforeseen situations that might cause late deliveries	1	2	3	4	5	6	7

B3. Please indicate the percentage of your plant's total sales represented by your three largest customers .... _______% of sales

B4. Considering that a normal month of demand is indexed at 100

a. what would be the level of demand for a "peak" month (e.g., 20 % more than normal = 120)? .... _______

b. what would be the level of demand for a "trough" month (e.g., 30 % less than normal = 70)? .... _______

B5. On what percentage of orders do

a. changes in customers promised delivery time occur? .... _______% of orders

b. *last minute* design changes occur? .... _______% of orders

c. initial ordered quantities change?.. _______% of orders

C. Plant Operations Strategy

This section examines your plant's operations strategy in regards to competitive priorities such as cost, quality, delivery and flexibility. Please circle the number that best describes your plant's practices.

C1. Please indicate the importance of the following characteristics in selling the products that comprises a major portion of your plant total sales.

		not important		*quite important*			*extremely important*	
a.	High product resistance (e.g., color fading, ink adherence)	1	2	3	4	5	6	7
b.	High durability (e.g., structural properties of the substrate)	1	2	3	4	5	6	7
c.	High production capabilities (e.g., high tolerance to spec.)	1	2	3	4	5	6	7
d.	Short time delivery	1	2	3	4	5	6	7
e.	Delivery on due time	1	2	3	4	5	6	7
f.	Large number of product features or options	1	2	3	4	5	6	7

C2. Please indicate the importance given to each item in your plant.

		not important		*quite important*			*extremely important*	
a.	Production cost	1	2	3	4	5	6	7
b.	Labor productivity	1	2	3	4	5	6	7
c.	Capacity utilization	1	2	3	4	5	6	7
d.	Conformance of final product to design specification	1	2	3	4	5	6	7
e.	Ability to introduce new products into production quickly	1	2	3	4	5	6	7
f.	Ability to adjust capacity rapidly within a short time period	1	2	3	4	5	6	7
g.	Ability to make product design changes in the product after the production has started	1	2	3	4	5	6	7
h.	Reducing inventory	1	2	3	4	5	6	7

C3. Please indicate the importance given to each criterion in evaluating manufacturing management performance at your plant.

		not important		*quite important*			*extremely important*	
a.	Cost	1	2	3	4	5	6	7
b.	Delivery (timely and completeness)	1	2	3	4	5	6	7
c.	Quality (conformance to specs, low scrap rates)	1	2	3	4	5	6	7
d.	Flexibility (e.g., quantity, specifications)	1	2	3	4	5	6	7

C4. Over the last two years, to what extent has the plant invested resources (money, time and/or people) in programs in the following areas?

		not at all		*moderate*			*great extent*	
a.	Color management systems (e.g., densitometer)	1	2	3	4	5	6	7
b.	Press automation (e.g., rolls auto-cleaner)	1	2	3	4	5	6	7
c.	Press job throughput time reduction (speed)	1	2	3	4	5	6	7
d.	Press setup time reduction (make-ready)	1	2	3	4	5	6	7

D. Green Supply Management

This section examines the degree of cooperation between your plant and your primary suppliers to address environmental challenges in the package printing industry. Please circle the number that best describes your plant's practices.

D1. The following statements relate to your plant's **environmental activities** with your primary suppliers (inks, substrates, equipment). Over the last two years, ***our primary suppliers...***

		not at all		*moderately*				*great extent*
a.	share their know-how and expertise in environmental management and technologies......................................	1	2	3	4	5	6	7
b.	are involved in the implementation of new environmentally-sound processes in our plant	1	2	3	4	5	6	7
c.	help us during the transition phase toward more environmentally friendly materials (e.g., ink change, water-based adhesive)	1	2	3	4	5	6	7
d.	co-operate with us to reduce waste in logistics and material management (e.g., reusable containers)	1	2	3	4	5	6	7

D2. During the past two years, to what extent did your plant engage in the following **environmental activities** with your primary suppliers (inks, substrates, equipment)?

		not at all		*moderately*				*great extent*
a.	Achieving environmental goals collectively	1	2	3	4	5	6	7
b.	Developing a mutual understanding of responsibilities regarding environmental performance..........................	1	2	3	4	5	6	7
c.	Working together to reduce environmental impact of our activities	1	2	3	4	5	6	7
d.	Conducting joint planning to anticipate and resolve environmental-related problems..................................	1	2	3	4	5	6	7
e.	Making joint decisions about ways to reduce overall environmental impact of our products..........................	1	2	3	4	5	6	7

D3. During the past two years, to what extent did your plant engage in the following **control and monitoring** activities with your primary suppliers (inks, substrates, equipment)?

		not at all			*moderately*			*great extent*
a.	Including environmental considerations in selection criteria for suppliers	1	2	3	4	5	6	7
b.	Providing suppliers with written environmental requirements	1	2	3	4	5	6	7
c.	Sending environmental questionnaires to suppliers in order to monitor their compliance	1	2	3	4	5	6	7
d.	Requiring that suppliers have an implemented environmental management system (e.g., ISO 14000)	1	2	3	4	5	6	7
e.	Asking suppliers to commit to waste reduction goals	1	2	3	4	5	6	7

E. Customers Green Practices

This section examines the degree of cooperation between your plant and your major customers in order to improve environmental practices. Please circle the number that best describes your plant's practices.

E1. The following statements relate to joint **environmental activities** and **initiatives** between your plant and its major customers. Over the last two years, ***our major customers...***

		not at all			*moderately*			*great extent*
a.	share their know-how and expertise in environmental management and technologies	1	2	3	4	5	6	7
b.	provide their expertise during environmentally-sound process modifications	1	2	3	4	5	6	7
c.	provide their expertise during environmentally-sound material adoption (e.g., input substitution)	1	2	3	4	5	6	7
d.	co-operate with us to reduce waste in logistics and material management (e.g., reusable logistics material)	1	2	3	4	5	6	7

E2. During the past two years, to what extent did your plant engage in the following **environmental activities** with your major customers?

		not at all			*moderately*			*great extent*
a.	Achieving environmental goals collectively	1	2	3	4	5	6	7
b.	Developing a mutual understanding of responsibilities regarding environmental performance	1	2	3	4	5	6	7
c.	Working together to reduce the environmental impact of our activities	1	2	3	4	5	6	7
d.	Conducting joint planning to anticipate and resolve environmental-related problems	1	2	3	4	5	6	7
e.	Making joint decisions about ways to reduce the environmental impact of our products	1	2	3	4	5	6	7

E3. The following statements relate to your major customers' **control and monitoring** of environmental-related activities of your plant. During the past two years, ***our major customers***...

		not at all			moderately			great extent
a.	incorporate environmental considerations in selecting their suppliers	1	2	3	4	5	6	7
b.	request information to assure our environmental compliance	1	2	3	4	5	6	7
c.	prefer us to have an implemented environmental management system	1	2	3	4	5	6	7
d.	request us to fulfill waste reduction goals	1	2	3	4	5	6	7
e.	provide us with detailed, written environmental requirements (e.g., % of recycled content in substrate).	1	2	3	4	5	6	7

F. Plant Environmental Management

This section examines the characteristics of the environmental management practices in place within your plant. Please indicate what best describes your plant's situation.

F1. Please think about **all** of your plant's projects, investments and operating costs over the last two years that have benefited the natural environment in any way. A benefit is defined as reducing any negative impact of manufacturing operations on the environment or improving the state of nature. **Assign a percent to the five project categories below based on their use of resources** (e.g., capital, operating costs and people). *(Total must equal 100%).*

a. Remediation projects – cleaning up crises or past practices such as cleaning up an environmental spill, remove soil contaminated by chemicals or environmental fines .... _______ %

b. Pollution control technologies – installing equipment at the end of a process, air emission collection or effluent pipes (e.g., permanent total enclosure or oxidizer) .... _______ %

c. Management systems – the way the business is managed or people work such as environmental training for employees to minimize spills, environmental audit programs, or operating procedures and practices that reduce environmental impacts .... _______ %

d. Product adaptation – introducing a new product or modifying an existing product's design leading to an increased use of recycled materials or material substitution (e.g., different ink systems). Material reduction projects are also included here. .... _______ %

e. Process adaptation – changing the material acquisition, production system or delivery process such as enclosed doctor blade systems or process adaptation needed for material substitution. Energy conservation technologies are also included in this category. .... _______ %

100 %

F2. On average over the past two years, what percentage of the annual operating costs was allocated to environmental control and improvement activities? (circle one)

<1% 2% 4% 6% 8% 10% 12% other: ______%

F3. On average over the past two years, what percentage of the plant's total capital budget was allocated to investments in environmental projects? (circle one)

<1% 2% 4% 6% 8% 10% 12% other: ______%

F4. Think about **all** of your plant's projects, investments and operating costs over the last two years that have benefited the natural environment in any way. **Allocate to the five stakeholder groups the relative percentage of pressure each places on your plant to select these environmental projects and expenditures** (investment and operating costs). *(Total must equal 100%).*

a. Downstream supply chain – from your plant to the end-consumers (e.g., demand for higher recycle content, ISO 14001 requirement, imposed use of less harmful inks and chemicals)........ _______ %

b. Upstream supply chain – equipment manufacturers, raw material providers and their suppliers (e.g., introduction of UV curable ink, modification of the chemicals of some inputs, in-line coating technologies)........ _______ %

c. Internal stakeholders – Shareholders or owners, department, or employees (e.g., risk mitigation and cost-efficiency, competitive imperatives, employees concerns with health and safety)........ _______ %

d. Special interest groups and general population (e.g., complaints about fumes, corporate image)........ _______ %

e. Government – federal, state and local (e.g., VOC reporting, water usage restrictions, solid waste disposal)........ _______ %

100 %

G. Manufacturing and Operational Performance

This section explores the manufacturing performance of your plant. The importance of your completed response cannot be overemphasized.

G1. For each of the items listed below, how does the plant compare relative to your primary competitors?

		far worse than competitors		*about the same as competitors*			*far better than competitors*	
a.	Production costs	1	2	3	4	5	6	7
b.	Total product costs	1	2	3	4	5	6	7
c.	Labor productivity	1	2	3	4	5	6	7
d.	Conformance to design (e.g., color intensity/structural property)	1	2	3	4	5	6	7
e.	Product durability (e.g., color fading, substrate resistance)	1	2	3	4	5	6	7
f.	Perceived overall product quality	1	2	3	4	5	6	7
g.	Promptness in solving customer complaints	1	2	3	4	5	6	7
h.	Order fulfillment speed	1	2	3	4	5	6	7
i.	Manufacturing throughput time	1	2	3	4	5	6	7
j.	Meeting delivery due date	1	2	3	4	5	6	7
k.	Ability to change delivery date	1	2	3	4	5	6	7
l.	Ability to change output volume	1	2	3	4	5	6	7
m.	Ability to change product mix	1	2	3	4	5	6	7
n.	Solid waste disposal	1	2	3	4	5	6	7
o.	Air emissions	1	2	3	4	5	6	7
p.	Water emissions	1	2	3	4	5	6	7

G2. What percentage of customer orders is delivered accurately (e.g., quantity and specifications) at the time promised?

a. two years ago (2000) ______ % on time b. now (2002) _____ % on time

G3. For a typical job, about how much time elapses from the start of the first operation until a batch of products is finished (including imaging, pre-press and post-press operations if any)?

a. two years ago (2000) _____ days b. now (2002) ______ days

G4. On average, approximately how much time does it take to make a changeover on the press (i.e., set-up time or make ready time)?

a. two years ago (2000) _____ hours   b. now (2002) ______ hours

G5. What percentage of *production* does not meet specifications resulting in scrap or returns from customers
(also known as *spoilage* or *first-pass* scrap rate):

a. two years ago (2000) _____ % scrap   b. now (2002) ______ % scrap

G6. How many days of production do you carry of the following inventory?

a. inputs _____ days   b. finished goods ______ days

H. Plant Description and Background Information

This section explores the characteristics of your plant. Please indicate what best describes your plant's situation.

H1. As of the beginning of January 2002, how many employees (full-time equivalent) work at your plant? .... _____ employees

H2. As of the beginning of January 2002, how many employees work in the entire organization (parent company) including your plant? .... _____ employees

H3. For the past year, what was the shop-floor worker annual turnover rate? .... _____ %

H4. What percentage of the plant's products is print-to-order? .... _____ %

H5. Is your plant ISO 9000 certified? (circle one) Yes No Year of registration: ______

H6. Is your plant ISO 14000 certified? (circle one) Yes No Year of registration: ______

H7. Please indicate your estimate of the probability that this plant will be operating at or above its current production level. (Circle the probability for each horizon)

	no chance					*moderate probability*					*with certainty*
next year	0	10	20	30	40	50	60	70	80	90	100
in five (5) years	0	10	20	30	40	50	60	70	80	90	100

H8. Please address the following questions as of the beginning of January 2002. Please indicate what best describes your plant's situation by checking the most appropriate category for:

total assets (fixed and current)		total annual sales	
less than $20 million	☐	less than $20 million	☐
over $20 million to $40 million	☐	over $20 million to $50 million	☐
over $40 million to $60 million	☐	over $50 million to $75 million	☐
over $60 million to $80 million	☐	over $75 million to $100 million	☐
over $80 million	☐	over $100 million	☐

H9. On **average**, over the last two years, about what percent of annual sales has been invested in new manufacturing equipment? ..... _____ % of sales

H10. What percentage of your plant's sales is generated by the following printing process? *(Total must equal 100%)*

Flexography ________ % of sales Lithography ______ % of sales

Gravure ________ % of sales Other ______ % of sales

H11. What is the plant's average capacity utilization rate for its presses? ..... _____ % utilization

H12. What is the **average** age of the presses? ..... _____ years

H13. How many presses does your plant have? ..... _____ presses

H14. How many different types of presses does your plant have? ..... _____ presses

H15. What is the profile of the substrate used in your pressroom operations? (Total must equal 100%)

a. Paper/Paperboard _____ % b. Film ____ % c. Others ____ %

H16. Excluding unusual orders, what is the number of colors to be printed for an order

H16_a. On average colors

H16_b. Minimum colors

H16_c. Maximum colors

H17. Please indicate the percent of activities that your plant outsources (production made outside the plant or activities conducted by a third party) for the following:

a. Imaging and design _____ % c. Platemaking ______ %

b. Post press operations _____ % d. Ink room management _____ %

H18. What is the primary industry segment for your plant? *(Please check one)*

Folding carton .... ☐ Flexible package .... ☐ Labels and tags........... ☐

H19. What is the primary market segment for your plant? *(Please check one)*

Food and beverage .... ☐ Pharmaceutical... ☐
General consumer products.............. ☐ General industrial products .... ☐

Comments

Are there any important issues that you feel have been left out? If so, please comment here or on the separate information sheet.

Thank you for your participation.
Results and findings will be sent to all participants
as soon as they are available

Please return the questionnaire to

Stephan Vachon
Ph.D. Student
Richard Ivey School of Business
The University of Western Ontario
London, Ontario, Canada, N6A 3K7
Fax: 519-661-3959

Participant Form

Manufacturing Competitiveness: The Role of Supply Chain and Environmental Practices

(This page enables us to provide the results to you and will be separated from the data)

NAME OF PLANT ____

NAME OF THE PARENT COMPANY ____________________________

Would you like to receive the results of this study? ☐ ***Yes*** ☐ ***No***

If yes, please indicate, below, the name and address of the person responsible for coordinating the completion of the survey in your plant (or attach a calling card).

SURVEY COORDINATOR

Name ____

Title/Function ____

Mailing Address ____

____

____

____

Phone Number ____

Fax Number ____

E-mail ____

APPENDIX C ETHICS APPROVAL LETTER

APPENDIX D MISSING VALUE ESTIMATIONS

This appendix presents the results pertaining to the estimation of missing value (ref. Section 5.2.3.). Five missing values were estimated using the stochastic regression imputation technique (Little and Rubin 1987).

Table D1 Missing Value Estimation – A2e (Case ID 392)

Independent Variable	Coefficients	Response (ID 392)	Product
Constant	-0.759	1	-0.759
A2a	0.044	6	0.264
A2b	0.223	5	1.115
A2c	-0.063	4	-0.252
A2d	0.272	3	0.816
A2f	0.250	4	1.000
A2g	0.359	4	1.436
R^2	63.6%		
		Predited value	3.620
		Random error	0.785
		Imputed value	**4.405**

The residuals were assumed to be normal (Shapiro-Wilk p-value = 0.155, n = 82). The residual mean was 0 with variance of 0.774. Using the random generation of normal data in the spreadsheet the random error was generated. The value inputted in the database was 4.4.

Table D2 Missing Value Estimation – A2g (Case ID 352)

Independent Variable	Coefficients	Response (ID 352)	Product
Constant	1.104	1	1.104
A2a	0.266	4	1.064
A2b	-0.523	6	-3.138
A2c	0.340	4	1.360
A2d	-0.146	5	-0.730
A2e	0.446	4	1.784
A2f	0.368	6	2.208
R^2	51.5%		
		Predited value	3.652
		Random error	0.134
		Imputed value	**3.786**

The residuals were assumed to be normal (Shapiro-Wilk p-value = 0.063, n = 82). The residual mean was 0 with variance of 0.961. Using the random generation of normal data in the spreadsheet the random error was generated. The value inputted in the database was 3.8.

Table D3 Missing Value Estimation – B2g (Case ID 354)

Independent Variable	Coefficients	Response (ID 354)	Product
Constant	2.481	1	2.481
B2a	-0.012	6	-0.070
B2b	0.027	5	0.137
B2c	0.118	6	0.708
B2d	-0.050	6	-0.301
B2e	0.042	6	0.253
B2f	0.285	6	1.710
R^2	11.5%		
		Predited value	4.918
		Random error	-0.349
		Imputed value	**4.569**

The residuals were assumed to be normal (Shapiro-Wilk p-value = 0.229, n = 83). The residual mean was 0 with variance of 1.049. Using the random generation of normal data in the spreadsheet the random error was generated. The value inputted in the database was 4.6.

Table D4	Missing Value Estimation – B2h (Case ID 354)		
Independent Variable	**Coefficients**	**Response (ID 354)**	**Product**
Constant	1.592	1	1.592
B2a	0.153	6	0.918
B2b	0.015	5	0.074
B2c	0.061	6	0.367
B2d	-0.057	6	-0.343
B2e	-0.052	6	-0.311
B2f	0.380	6	2.280
R^2	14.7%		
		Predited value	4.578
		Random error	1.299
		Imputed value	**5.877**

The residuals were assumed to be normal despite a significant Shapiro-Wilk statistics (p-value = 0.006, n = 83). The Kolmogorov-Smirnov was only marginally significant with p-value = 0.040. The residual mean was 0 with variance of 1.252. Using the random generation of normal data in the spreadsheet the random error was generated. The value inputted in the database was 5.9.

Table D5	Missing Value Estimation – D3a (Case ID 391)		
Independent Variable	**Coefficients**	**Response (ID 391)**	**Product**
Constant	1.058	1	1.058
D3b	0.468	2	0.936
D3c	0.223	2	0.446
D3d	0.125	2	0.250
D3e	0.095	2	0.191
R^2	60.1%		
		Predited value	2.881
		Random error	-1.527
		Imputed value	**1.354**

The residuals were assumed to be normal (Shapiro-Wilk p-value = 0.029, n = 83). The residual mean was –0.026 with variance of 1.330. Using the random generation of normal data in the spreadsheet the random error was generated. The value inputted in the database was 1.4.

Appendix E Descriptive Statistics

Table E1 Descriptive Statistics for Operational Performance Metrics*

Construct or variable	Mean	Standard deviation	Min	Max
Perceptual cost (83)	4.8	0.8	3.0	6.7
Perceptual quality (83)	5.6	0.7	4.0	6.8
Perceptual delivery (83)	5.6	0.8	3.7	7.0
Perceptual flexibility (82)	5.5	0.8	2.7	7.0
Perceptual environment (81)	5.2	1.0	3.0	7.0
On-time delivery—2002 (83)	94.8	4.7	75.0	100.0
On-time delivery—2000 (83)	88.0	9.7	60.0	100.0
Cycle time in days—2002 (83)	11.7	9.1	1	45
Cycle time in days—2000 (83)	17.0	11.5	2	60
Setup time in hours—2002 (83)	3.1	3.5	1	30
Setup time in hours—2000 (83)	4.3	5.1	1	45
Scrap rate (2002) (82)	6.0	6.3	0.0	35.0
Scrap rate (2000) (82)	8.4	8.4	0.0	50.0

*Number of observations in parenthesis.

Table E2 Descriptive Statistics for Supply Chain Environmental Management*

Construct or variable	Mean	Standard deviation	Min	Max
Environmental technology selection				
Investments in environmental technology (82)	4.0	5.3	0.0	32.0
Pollution prevention index (80)	47.2	25.9	0.0	100.0
Pollution control index (80)	19.8	21.2	0.0	75.0
Management systems index (80)	33.0	24.3	0.0	100.0
Green supply chain with suppliers				
Environmental cooperation (84)	3.4	1.5	1.0	7.0
Environmental monitoring (84)	2.8	1.5	1.0	6.8
Green supply chain with customers				
Environmental cooperation (84)	2.8	1.4	1.0	7.0
Environmental monitoring (84)	2.9	1.3	1.0	6.2

*Number of observations in parenthesis.

Table E3 Descriptive Statistics for Supply Chain Integration and Other Control Variables*

Construct or variable	Mean	Standard deviation	Min	Max
Supply chain integration with suppliers				
Logistical integration (84)	5.4	0.8	2.6	7.0
Technological integration (84)	4.8	1.1	2.0	7.0
Supply chain integration with customers				
Logistical integration (84)	4.6	0.9	2.5	6.3
Technological integration (84)	4.1	1.0	1.8	6.5
Control variables				
Plant size[1] (84)	4.9	0.6	3.1	6.4
Parent company size[2] (84)	7.0	2.2	3.5	15.4
Reinvestment rate[3] (83)	7.5	8.0	0.0	40.0
Age of presses (84)	11.3	6.7	2.0	30.0
Supply base[4] (84)	0.7	1.4	0.0	10.4
Customer concentration[5] (81)	0.5	0.2	0.0	1.0

* Number of observations in parenthesis.
1 Natural logarithm of the number of employees in the plant.
2 Natural logarithm of the number of employees in the parent company.
3 Percentage of annual sales invested in new equipment on average over the last two years.
4 Total number of suppliers divided by the number of employees at the plant.
5 The percentage of sales coming from the three largest customers.

APPENDIX F COMPLEMENTARY ANALYSES

This appendix presents the detailed results of complementary analyses conducted to gain further understanding from the regressions presented in Chapter 6 of this dissertation. A total of four complementary analyses were conducted respectively for perceptual quality performance, perceptual delivery performance, on-time delivery, and perceptual flexibility performance.

Perceptual Quality Performance

Table F1 presents the results for Models 2c and 2d of Table 6.3 in Chapter 6. The goal of this complementary analysis is to assess the contribution of environmental cooperation with customers and environmental monitoring by customers, in order to explain the variance in quality performance.

The regressions were re-run, with an additional step created by sequentially entering the two GSCP variables. Individually, the coefficients assigned to environmental cooperation with customers and environmental monitoring by customers were both significant at the 5% level. The total R^2 for model 2c' was .248. The total R^2 for the whole Model 2c (Table 6.3) was .254, indicating that environmental monitoring by customers was contributing only .006 (p = 0.47) by itself. Similarly, environmental cooperation with customers was contributing .026 (p = 0.14).[13] Hence most of the variance explained by GSCP in Model 2c is common to the two variables (.087 - .006 - .026 = .055).

[13] Total R^2 of Model 2c (Table 6.3) minus Total R^2 of Model 2c' (Table F1a): .254 -.228 = .026.

Table F1a Complementary Analysis for Quality Performance†

	GSCP with customers			
	Model 2c'		Model 2c''	
	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.157**		.157**
Environmental Technology Selection		.011		.011
Green Supply Chain Practices		.081***		.060**
Environmental cooperation	.306***			
Environmental monitoring			.278**	
R^2	.248**		.228**	
F Statistics	2.682		2.401	
Number of observations	74		74	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01
† Standardized betas reported.

Table F1b Complementary Analysis for Quality Performance†

	GSCP with customers			
	Model 2d'		Model 2d''	
	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.157**		.157**
Environmental Technology Selection		.023		.023
Green Supply Chain Practices		.084***		.057**
Environmental cooperation	.312***			
Environmental monitoring			.271**	
R^2	.264**		.237**	
F Statistics	2.549		2.212	
Number of observations	74		74	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01
† Standardized betas reported.

Analogically for Model 2d, environmental monitoring by customers contributed .004 (p = 0.56).[14] However, the contribution of environmental cooperation was marginally significant, with a unique variance explained of .031 (p = 0.11).[15]

[14] Total R^2 of Model 2d (Table 6.3) minus Total R^2 of Model 2d' (Table F1b): .268 - .264 = .004.
[15] Total R^2 of Model 2d (Table 6.3) minus Total R^2 of Model 2d'' (Table F1b): .268 - .237 = .031.

Perceptual Delivery Performance

The regressions results in Table 6.5 (Model 4a and 4b) can raise some concerns for the adverse effect of the high correlation among the independent variables in the regressions. For instance, the ΔR^2 for the environmental technology selection was not significant, while the coefficients for pollution prevention and management systems were significant at the 5% level. The models were re-run with a set of regressions replicating Models 4a and 4b but the pollution prevention index and management systems index were entered as the last regressor in the model. The results are presented in Table F2. It shows that both variables contribute significantly to the model total R^2, with a contribution of .045 (p = .04) for the pollution prevention index[16] and .058 (p = .01) for the management systems index[17].

Table F2 Complementary Analysis for Delivery Performance†

	GSCP with customers			
	Model 4a'		Model 4b'	
	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.072		.072
Environmental Technology Selection		.001		.001
Investments in environmental technology	-.018		-.090	
Pollution prevention index	**entered last**			
Pollution control index			.126	
Management system index			**entered last**	
Green Supply Chain Practices		.198***		.198***
Environmental cooperation	.688***		.713***	
Environmental monitoring	-.377***		-.404***	
R^2	.270***		.271***	
F Statistics	2.682		2.401	
Number of observations	74		74	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

† Standardized betas reported.

[16] Total R^2 of Model 4a (Table 6.5) minus Total R^2 of Model 4a' (Table F2): .315 - .270 = .045.

[17] Total R^2 of Model 4b (Table 6.5) minus Total R^2 of Model 4b' (Table F2): .329 - .271 = .058.

On-Time Delivery Performance

Table F3 presents the results for Models 5a and 5b of Table 6.6 in Chapter 6. The goal of this complementary analysis is to assess the contribution of environmental cooperation with suppliers and environmental monitoring of suppliers in explaining the variance of on-time delivery.

Again, the regressions were re-run, with an additional step created by sequentially entering the two GSCP variables. Individually, the coefficients assigned to environmental cooperation with suppliers and environmental monitoring of suppliers were both significant at the 10% level. The total R^2 for Model 5a' was .452. The total R^2 for the whole Model 5a was .468, indicating that environmental monitoring of suppliers was contributing only .016 ($p = .17$) by itself. Similarly, environmental cooperation with suppliers was contributing .004 ($p = .46$). Hence most of the variance explained by GSCP in Model 5a is common to both variables (.048 - .016 - .004 = .028).

Analogically for Model 5b, environmental monitoring by customers was contributing for .009 ($p = .29$)[18], and the contribution of environmental cooperation with suppliers was of .008 ($p = .30$).[19] Again, most of the variance explained was shared between the variables.

[18] Total R^2 of Model 5b (Table 6.6) minus Total R^2 of Model 5b' (Table F1b): .503 - .494 = .009.
[19] Total R^2 of Model 5b (Table 6.6) minus Total R^2 of Model 5b'' (Table F1b): .503 - .495 = .008.

Table F3a Complementary Analysis for On-Time Delivery†

	GSCP with suppliers			
	Model 5a'		Model 5a"	
	Beta	ΔR^2	Beta	ΔR^2
Past Performance		.341***		.341***
Control Variables		.057		.057
Environmental Technology Selection		.021		.021
Green Supply Chain Practices		.033**		.037**
Environmental cooperation	.204**			
Environmental monitoring			.231**	
R^2	.452***		.463***	
F Statistics	6.144		6.428	
Number of observations	77		77	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

† Standardized betas reported.

Table F3b Complementary Analysis for On-Time Delivery†

	GSCP with suppliers			
	Model 5b'		Model 5b"	
	Beta	ΔR^2	Beta	ΔR^2
Past Performance		.341***		.341***
Control Variables		.057		.057
Environmental Technology Selection		.060*		.060*
Green Supply Chain Practices		.037**		.037**
Environmental cooperation	.216**			
Environmental monitoring			.212**	
R^2	.494***		.495***	
F Statistics	6.453		6.458	
Number of observations	77		77	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01

† Standardized betas reported.

Perceptual Flexibility Performance

Table F4 presents the results for Models 7c and 7d of Table 6.8 in Chapter 6. The goal of this complementary analysis is to assess the impact of environmental cooperation with customers and environmental monitoring by customers on flexibility performance.

Again, the regressions were re-run, with an additional step created by sequentially entering the two GSCP variables. Individually, the coefficients assigned to environmental cooperation with customers and environmental monitoring by customers were both significant at the 5% level. The total R^2 for Model 7c' was .140. The total R^2 for the whole Model 7c was .156, indicating that environmental monitoring by customers was contributing only .016 (p = .29) by itself. Similarly, environmental cooperation with customers was contributing .011 (p = .37)[20]. Hence most of the variance explained by GSCP in Model 7c is common to both variables (.075 - .016 - .011 = .048).

Analogically for Model 7d, environmental monitoring by customers was contributing .015 (p = .27)[21] and the contribution of environmental cooperation with customers was of .031 (p = .11).[22] Again, most of the variance explained was shared between the variables.

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[20] Total R^2 of Model 7c (Table 6.8) minus Total R^2 of Model 7c'' (Table F3a): .156 - .145 = .011.
[21] Total R^2 of Model 7d (Table 6.8) minus Total R^2 of Model 7d' (Table F3b): .156 - .141 = .015.
[22] Total R^2 of Model 7d (Table 6.8) minus Total R^2 of Model 7d'' (Table F3b): .158 - .148 = .010.

Table F4a Complementary Analysis for Flexibility Performance†

	GSCP with customers			
	Model 7c'		Model 7c''	
	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.078		.078
Environmental Technology Selection		.003		.003
Green Supply Chain Practices		.059**		.064**
Environmental cooperation	.262**			
Environmental monitoring			.286**	
R^2	.140		.145	
F Statistics	1.326		1.377	
Number of observations	74		74	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01
† Standardized betas reported.

Table F4b Complementary Analysis for Flexibility Performance†

	GSCP with suppliers			
	Model 7d'		Model 7d''	
	Beta	ΔR^2	Beta	ΔR^2
Control Variables		.078		.078
Environmental Technology Selection		.005		.005
Green Supply Chain Practices		.059**		.066**
Environmental cooperation	.261**			
Environmental monitoring			.291**	
R^2	.141		.148	
F Statistics	1.170		1.239	
Number of observations	74		74	

* p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01
† Standardized betas reported.

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NON-REFEREED CONFERENCE PRESENTATIONS

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Working Papers under Journal Review

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