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The green bullwhip effect: Transferring environmental requirements along a supply chain

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ABSTRACT

The bullwhip effect has long been recognized as a critical factor that amplifies demand variability as customer orders pass upstream through successive tiers of a supply chain. Like customer demand, environmental requirements also change significantly at times, and are passed along the supply chain to varying degrees, suggestive of what we term, the "green bullwhip effect". Based on field cases exploring changes in three supply chains across three adjacent tiers, we find evidence that such a phenomenon exists. First, ratcheting demands for better environmental performance are passed upstream through successive tiers with significant variation. Second, a green bullwhip effect is created as time to comply with specifications is compressed. Four different managerial responses, namely replace, accommodate, negotiate and collaborate, were observed to amplify or attenuate a green bullwhip effect based on the nature of firm relationships and balance of environmental capabilities at each tier. Of particular interest, the green bullwhip effect can force positive change, triggering the development of new environmental capabilities at multiple tiers in a supply chain.

1. Introduction

Over the last decade, as regional manufacturing has evolved into global supply chains, customer concerns and regulatory changes have increasingly focused on environmental attributes implicitly embedded in raw materials, components and finished goods. These environmental concerns have been enacted into public policies that capture the broader life-cycle of products, and therefore, firms increasingly have faced a wide range of environmental risks linked to their supply chains (Handfield et al., 2005). For instance, the unfortunate position that Sony found itself in 2001 illustrates the complex interplay of factors when product-based regulations are introduced. At that time, Dutch customs agents stopped nearly 1.3 million PlayStation consoles being imported into Europe because the cables contained levels of cadmium that exceeded the Netherlands' new environmental regulations. Sony had to bear significant costs for replacing the parts, storing goods and repackaging the final products (Carlton, 2006). After this incident, Sony accelerated its Green Partnership program in order to integrate environmental considerations across its global supply chain. In a similar manner, original equipment manufacturers (OEMs) have introduced environmental criteria in their supplier selection process (Bai and Sarkis, 2010), required environmental audits and certification schemes (e.g., ISO14001) from suppliers, and provided them with environmental training, education and other support (Rao and Holt, 2005; Lee and Klassen, 2008).

As seen in Sony's case, significant changes that improve the environmental performance of products and suppliers – often initiated by regulation – flow back upstream in the supply chain with uncertain consequences. Moreover, the level of pressure can vary greatly from one tier in the supply chain to another (e.g., OEM, first-tier supplier and second-tier supplier). For example, while upstream suppliers usually face less intense scrutiny from consumers and governments, they are often under considerable pressure from indirect regulations that are conveyed by customer firms (Green et al., 2000). At this point, we have little understanding about how quickly and to what extent more stringent requirements from markets or product-based regulations affect the supply chains of materials, components and subassemblies.

A growing number of studies have examined operational approaches that address environmental issues in supply chains, termed green supply chain management (GSCM). This literature has identified management practices (e.g., Min and Galle, 2001; Vachon and Klassen, 2006), explored internal and external drivers

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of practice, and assessed performance outcomes (e.g., Rao and Holt, 2005; Sarkis et al., 2010; Wu et al., 2012; Zhu and Sarkis, 2004). However, this research has largely adopted a static view, whereby suppliers are simply expected to meet new requirements and improve their environmental performance as new demands are placed on them, possibly coincident with developmental support from next-tier customers (e.g., Lee et al., 1997a; Machuca and Barajas, 2004).

In contrast, the broader supply chain management literature has emphasized the behaviors of buyers and suppliers from a dynamic perspective. In particular, the bullwhip effect is well known to illustrate how and why orders or information change as they pass along a supply chain, and how multiple tiers in the supply chain respond to this distortion of information. By extension, it is conceivable that new insights might be gained by considering potential dynamic behaviors in the context of environmental or social issues.

Given this promise, our research explores several questions. How do focal firms manage their supply base in response to significant changes in environmental requirements? More specifically, how are environmental requirements of customers adjusted as they transfer upstream in supply chains? In addressing these questions, this paper makes three contributions. First, this study extends existing literature by synthesizing earlier research areas, namely environmental management and supply chain dynamics, to propose a dynamic phenomenon whereby environmental obligations flow back upstream in the supply chain with significant variation, termed the green bullwhip effect. Second, this research offers empirical evidence for such a phenomenon from case studies at multiple tiers in three different supply chains. Third, our case studies are combined with the previous literature to construct an integrative framework that illustrates both the dynamics and potential managerial responses to tightening environmental regulations in the supply chain. Thus, the challenges and management actions arising from the green bullwhip effect establish the groundwork for a set of research propositions.

2. Foundational literature and concept development

To explore the dynamic nature of environmental issues in the supply chain, two broad streams of research are particularly informative: green supply chain management and supply chain dynamics. Combined, the former explores how environmental issues are characterized in the supply chain and the latter provides a basis for understanding the green bullwhip effect.

2.1. Green supply chain management

With the emergence of environment issues as a legitimate business concern in supply chain management, research has examined a wide range of issues under the umbrella of green supply chain management (GSCM), including practices, drivers, and outcomes (Zhu and Sarkis, 2006). More specifically, previous literature has characterized various elements of GSCM practices, ranging from green purchasing (e.g., Min and Galle, 2001), to environmental integration with customers and suppliers (e.g., Vachon and Klassen, 2006, 2008), to a closed-loop supply management (e.g., Kleindorfer et al., 2005). For example, Bowen et al. (2001) distinguished between "practices that green the supply process" and "product-based green supply practices" by differentiating between managing supplier risk and performance, and supply chain integration for sustainable products, respectively. Vachon and Klassen (2006, 2008) addressed two broad sets of GSCM practices: monitoring and collaboration. Monitoring generally relates to supplier and material selection practices, whereas collaboration focuses more on building suppliers' environmental capabilities. Zhu and Sarkis (2004, 2006) proposed a broader perspective of practices, including internal environmental management, green purchasing, investment recovery, eco-design practices, and cooperation with supply chain partners.

Second, several drivers for the adoption of GSCM have been identified. While pressure from multiple stakeholders is important, two groups of stakeholders are of particular relevance: customers and governments (Seuring and Müller, 2008). Green et al. (2000) provided empirical evidence that regulations played the strongest role in influencing environmental improvement, followed by market pressures. Of course, not all firms are exposed to the same types of regulations or pressures. Large, high-profile firms tend to face considerable pressure to improve their environmental performance; in contrast, smaller suppliers or suppliers distant from the end-consumer, have few obvious incentives. Yet, environmental pressures still are often passed upstream to suppliers, including smaller firms, from buying firms (Hall, 2000).

Collectively, the literature on environmental issues and supply chain management clearly has identified that regulatory and customer demands prompt GSCM practices in a focal firm, although with little research into the underlying dynamics. Of note, Hill (1997) recognized the importance of supply chain dynamics and its linkage to environmental pressures. Hall (2000) pointed out that buyer–supplier relationships play a crucial role in transferring environmental pressure and stimulating environmental change within the supply chain.

Some evidence has emerged that both a focal firm's power within the supply chain and its technical capabilities are critical to diffuse the environmental innovation upstream when faced with stakeholder pressure to improve environmental performance. For example, Cousins et al. (2004) took a contingent perspective in characterizing GSCM strategies, and identified four generic strategies based on the level of perceived environmental risks and the resources available to the firm: "why bother", "no choice", "enthusiasts", and "go first". Their model assumed that the greater the level of perceived risks to the firm and available resources, the greater the likelihood that a firm will react in some way to minimize the expectation of the loss related to the risks. Of particular note, their study recognizes that GSCM strategy might be adjusted as circumstances change.

2.2. Bullwhip effect

Within operations and supply chain management, the demand-related bullwhip effect is well known: variability in customer demand often becomes amplified as orders pass upstream in a supply chain. In general, three characteristics are evident: oscillation, amplification and phase-lag (Forrester, 1961; Lee et al., 1997b). Oscillations and amplification occur as orders boom and bust over time, causing excessive inventories, and thus variance in order size increases as orders pass upstream in the supply chain. Phase lags indicate that inventory levels peak, potentially followed by backlogs, delayed to some extent at each subsequent tier in the supply chain. This phenomenon is costly because it causes excessive inventories, unsatisfactory customer service and uncertain production planning.

Previous research on the bullwhip effect has explored both underlying causes and options for its alleviation. The underlying operational causes include the distortion of information, increasing batch size to reduce setup costs, rationing of inventory, and logistics delays (Lee et al., 1997a). Each cause can be complicated by a variety of managerial decision-making heuristics and bounded rationality (e.g., Sterman, 1989). For example, information transferred in the form of orders tends to become distorted as firms seek to protect themselves from demand uncertainty or shipping delays. Also, some members of the supply chain do not adequately account for time delays when ordering, expecting

faster shipment. However, others point out that the bullwhip effect is an outcome of the strategic interactions among rational supply chain members (e.g., Lee et al., 1997b). Uncertainty about the actions of other decision makers is also identified as a trigger for instability (Croson et al., 2014). Collectively, insufficient coordination between supply chain partners and the critical interaction between bounded rationality and rationing gaming have been revealed as the primary causes for the bullwhip effect.

Faced with this range of causes, a corresponding array of remedies for reducing and mitigating the bullwhip effect has been identified, including information sharing, integrated supply chain information system, joint planning, vendor-managed inventory, shorter lead times, and synchronized deliveries (e.g., Lee et al., 1997b; Larson and Kulchitsky, 2000; Disney and Towill, 2003; Machuca and Barajas, 2004). Frequent communication can facilitate the transparency of information flow from the market to the suppliers, and vice versa, thereby reducing uncertainty (Holweg et al., 2005). Enhancing visibility across the supply chain using information technology is also considered an effective means to alleviate the bullwhip effect; operational capabilities that enable timely response to customer demands across multiple tiers of the supply chain are another critical factor to mitigate the bullwhip effect (Lee et al., 1997b). Thus, remedies come in many forms with a common goal to create a transparent, visible demand pattern that paces the entire supply chain (Holweg et al., 2005), while contributing to better coordination and collaboration as learning is transferred along the supply chain (Arshinder et al., 2008; Wu and Katok, 2006).

2.3. Environmental requirements and the bullwhip effect

Green supply chain management has explored both strategic and tactical considerations. At a minimum, two critical aspects include greener design defined across a product's entire life-cycle (i.e., pre-manufacture, manufacture, distribution, use and end-of-life fate), and an extended view of a supply chain, encompassing the potential for remanufacturing and recycling (Srivastava, 2007; Klassen and Vachon, 2012). These aspects are quite consistent with recent efforts by government agencies to enact regulations that force manufacturers to "build in" better environmental performance, often through improved recyclability or the removal of toxic substances in the product. In general, original equipment manufacturers (OEMs) are the target of these product-based environmental regulations. Considering that society's environmental concerns often are eventually enacted into public policies, emerging product-based regulations often reflect consumer demands for environmentally friendlier products.

In general, how do such regulations affect upstream suppliers across multiple tiers? First, a level of stringency might be imposed somewhere between two possible extremes. At one extreme, firms might work collectively toward a single unified target that is implemented on the schedule dictated by regulation. Doing so would potentially reduce the total cost of compliance, and allow for maximum time to adjust and optimize supply processes and material selection. This is analogous to information sharing and synchronized delivery.

At the other extreme, OEMs could respond with behaviors that parallel those that trigger the classic demand-related bullwhip effect. Environmental obligations, as specified by customers and each successive tier in the supply chain, are conveyed upstream as buying specifications (Green et al., 2000). Most importantly, these obligations need not match the regulations. Thus, a focal firm might require more stringent environmental performance of their suppliers than that demanded by regulations, thereby imposing indirect "regulations". This is not unlike the strategies referred to by Lee et al. (1997a) as "rationing and shortage gaming," adopted to counteract opportunistic or ill-equipped suppliers. Conceivably, OEMs tighten the requirements or build-in a safety margin "just-in-case" the supplier misses the mark by some (uncertain) degree.

In addition to more stringent requirements, a focal firm might move aggressively ahead of the regulatory deadlines in order to create a time buffer. Recall that barriers to GSCM practices include poor supplier commitment, cost, and apparent legitimacy, to name a few (Walker et al., 2008). For example, powerful suppliers might withhold proprietary information, such as chemical composition necessary for product redesign (Dillon and Baram, 1993), industry-specific norms might slow the adoption of greener practices, customers might resist new concepts (Mollenkopf et al., 2010), and small suppliers might delay implementation because of limited capabilities (Lee and Klassen, 2008). Thus, a range of causes similar to those of the bullwhip effect (e.g., distortion of information, limited information sharing, delays ultimately due to bounded rationality of the actors) suggest that any changes will not be processed simultaneously along the supply chain. Given risk aversion to missing deadlines for regulatory compliance, firms must build in a buffer to adapt to uncertainty in suppliers' timing. More specifically, focal firms might adopt a phase-leading approach toward their suppliers, which shifts the deadline for compliance earlier at the next tier in the supply chain, analogous to the phase-lagging approach found in the bullwhip effect.

Thus, green supply chain management involves dynamic decisions with indirect and lagged feedback. Multiple tiers are involved in the process, whose environmental performance depends on the result of other supply chain members' decisions, and therefore is subject to coordination risk that can trigger instabilities in the supply chain system. This phenomenon is very consistent with that of the bullwhip effect. Given the uncertainty engendered by product-based regulations, it is reasonable to expect that any environmental specifications (and timing to comply) might be tightened (and shortened) as they are passed upstream, thus amplifying environmental stringency. We use the term "green bullwhip effect" to describe this dynamic set of responses to environmental issues in the supply chain.

Table 1
Dynamics of environmental issues in the supply chain: bullwhip effect.

	Classic bullwhip effect	Green bullwhip effect
General phenomenon	Customer orders oscillate; variability in orders amplify with each tier in the supply chain; delays also occur as orders pass upstream.	Customer environmental requirements (in the form of specifications) become tighter and more stringent as they pass upstream in a supply chain.
Contributing factors	Lead time (lag); processing of demand signals; order batching; price fluctuation; product rationing; and shortage gaming.	Response to product and process design (improvement) lead times; buffers for supplier and technology risk and uncertainty; amplification of environmental requirements.
Key differences	Customer demand-driven; short-term fluctuations (e.g., daily or quarterly); largely reactionary; and signal of managerial inefficiencies.	Event-driven, deliberate change (e.g., new regulatory policy); largely anticipatory; long-term tightening of specifications; and signal of customer expectations.

While we propose that the dynamic nature of environmental demands being transferred upstream in the supply chain is analogous to the bullwhip effect, it is helpful to compare and contrast the classic and green bullwhip effects (Table 1). First, the classic bullwhip effect is a continuous demand-related phenomenon, whereas the green bullwhip effect is an event-driven change in environmental requirements, such as the infrequent promulgation of new regulations (e.g., Reduction of Hazardous Substances (RoHS) in Europe), an industry's response to a high-profile negative incident (e.g., spills), or emergence of new customer concerns (e.g., Bisphenol A (BPA) in consumer goods). The sporadic nature of this event-driven change further compounds risk and uncertainty, as well as complicates any managerial planning and response. Second, the bullwhip effect is a systematic phenomenon that managers at each tier seek to attenuate; however, the green bullwhip effect is a deliberate phenomenon that the firm triggers via GSCM practices, specifically green procurement. Third, the bullwhip effect is a negative phenomenon that generates excessive inventories, unsatisfactory customer service, an uncertain production planning (Lee et al., 1997b). In contrast, from an environmental perspective, the green bullwhip effect might speed and expand the adoption of greener supply chain practices.

3. Methodology

Case-based research has been widely used to develop new insights and understand complex areas of management practice, thereby contributing to the advancement of theory (Yin, 1984). Interviews with managers at a small number of sites and firms frequently are instrumental in developing a deep understanding of the dynamics and relationships between different constructs (e.g., Tate et al., 2009), and have been encouraged as a means of providing rich descriptions of phenomena in a natural setting (Boyer and Swink, 2008). A multi-case approach improves the potential generalizability of any findings (Eisenhardt, 1989); to that end, five general methodological phases were employed, as is typical in operations management (Stuart et al., 2002; for a summary, see also Seuring, 2009). First, research questions are identified (described earlier); next, a basic interview instrument is developed; third, field and archival data are gathered; fourth, interviews are transcribed and analysis performed using coding schemes and cross-case comparisons; and finally, findings are disseminated to improve validity. Given the emergent and complex nature of this phenomenon, the case data from one supply chain was collected and analyzed before undertaking the final two cases some years later. Thus, a preliminary conceptualization from the first case (i.e., Samsung SDI, described later) provided the basis for further testing, elaboration and refinement as the series of case studies proceeded.

3.1. Case selection

To identify firm-specific supply chains, three criteria were used to capture a diverse set of factors. First, the focus was on international supply chains that extend into developing countries, which in turn present challenges with product-based regulations. Second, at least two industries were sought to explore the range of factors that might affect any green bullwhip effect, management responses, and potential generalizability of the green bullwhip effect (beyond our initial observations in the electronics industry). Third, it was important to obtain clear first-hand or archival data to understand interactions between three adjacent levels in the supply chain. While more tiers would certainly be preferable, this scope was viewed as representative at this exploratory stage of theory development.

Two contrasting industries were identified, namely electronics and fashion apparel (textile), to empirically study the potential for increasing environmental demands in stringency, compressed timelines, and variability. These industries are informative for several reasons. First, they serve global markets that are subject to both international regulations and environmental pressures from multiple stakeholders, e.g., customers and non-governmental organizations (Carlton, 2006; Wu et al., 2012). Each industry's markets also are highly interdependent and a firm must consider and manage both sourcing from multiple regions and sales into multiple markets. Countries in which suppliers operate might have very different environmental regulatory limits and timelines, relative to those imposed in customer markets. Thus, firms must be both responsive to compliance while maintaining competitiveness. Second, these two industries are somewhat fragmented with multiple tiers, comprising firms of different sizes, operational strategies, and environmental management capabilities. Finally, both industries have large markets in the European Union where multiple product-based regulations have been (and continue to be) implemented. Of course, given the nature of case research, we must be cautious about broad generalizations from examining a small number of firm-specific supply chains; however, it is important to keep in mind that our research objective was to identify and explore the nature and dynamic form of any bullwhip-like effects for environmental specifications with the intent of motivating further research.

Determining the ideal number of firms to target for case study research is not an exact science. Ideally, information gathering continues until the incremental gains become small, given the initial research objectives and availability of resources (Miles and Huberman, 1994). In many studies, depending on the research objectives, a small number of firms are reasonable. Here, three different supply chains, comprising three tiers in each, were targeted using one firm as a key informant. Collectively, the intent was to explore similarities and differences, both within and between industries (i.e., electronics vs. fashion apparel). While the unit of analysis was a three-tier portion of three supply chains (OEM combined with the first two tiers of suppliers), a particular focus was on the dynamics that occur between tiers in a supplier chain. The intent was not to explore all possible dyadic relationships within these three tiers, but rather to understand how a variety of dyadic relationships and new environmental regulatory requirements interact. Overall, the three supply chains were treated as a series of studies that details, confirms and enhances our understanding of emerging conceptual insights (Yin, 1984).

Considering that the green bullwhip effect is an event-driven phenomenon that is observed intermittently over a long-term time span, comparing three supply chains also can explore similarities across at least two regulatory deadlines and specifications. Here, the event for the first case study was the promulgation of RoHS regulations in the European Union (EU). This regulation bans the use of six harmful materials – cadmium, lead, hexavalent chrome, mercury, poly-brominated biphenyls (PBB), and poly-brominated diphenyl ethers (PBDB) – in electronic and electrical equipment (with some exceptions). While adopted in February 2003, RoHS was initially enforced in July 2006.

As a result, the initial investigation in Samsung SDI (Korea) began in 2003–2004. As a major first-tier supplier, Samsung SDI provided electrical and electronic components, such as plasma display panel (PDP), liquid crystal display (LCD), and rechargeable batteries to global electronics firms, including Samsung Electronics, Sony, and Matsushita. As a buyer, the firm sourced from over 400 suppliers (i.e., second-tier suppliers), thereby providing insight into how environmental requirements are transferred upstream in the supply chain.

More recently, the EU introduced Registration, Evaluation, Authorization and Restriction of Chemicals (REACH); this complex

Table 2
Supply chain data collection.

Regulatory change	Timing	Supply chain (industry)	Supply chain stage		
			2nd-Tier	1st-Tier	OEM
RoHS	2003–2004	Samsung SDI (electronics)	Key suppliers[c]	Samsung SDI[a]	Branded products[b,c]
REACH	2011–2012	Benetton SpA (apparel)	Tunisian printing shops[c]	Benetton's suppliers[c]	Benetton[a]
REACH	2011–2012	Moncler SpA (apparel)	Key suppliers[c]	Limonta[a,b]	Moncler Group[a,b]

[a] Interview data was collected from management interviews by the research team.
[b] Archival data (either public or internal) was collected from printed or published reports.
[c] Data was collected indirectly by interviewing managers in other firms in the same supply chain.

regulation established reporting obligations in 2008, followed by phased reductions in specific chemicals in 2015. Regardless of industry, all firms that sell products *containing* chemicals in Europe (either produced domestically or imported) are subject to REACH regulations. The effects of this second event on the supply chains of two Italian apparel firms, namely Benetton and Moncler Group, were explored (2010–2012).

Benetton's supply chain provided a second case study. This global firm, with approximately 6400 retail stores, has invested heavily in R&D, and has focused on style, along with new materials and production technologies. Benetton directly manufactures about half of its volume (150 million items), with facilities located in Europe, India and Asia, where it focused on dyeing, weaving, and quality controls (some labor-intensive steps are outsourced to smaller suppliers). The remaining production was completely outsourced from countries like China, India, Thailand, and Turkey.

For the third case, Moncler Group's supply chain provided an interesting comparison. The firm was somewhat smaller (€610 million in 2012), encompassed a range of disparate brands (e.g., Moncler, Henry Cottons, Marina Yachting, Coast Weber & Ahaus), and outsourced all of its production of roughly four million items. For about 60% of production, the firm maintained tight control over the supply chain, as it purchased raw materials and coordinated a network of subcontractors in Italy and Eastern Europe.

3.2. Data sources and collection

Data was collected using interviews, archival materials capturing longitudinal information (not publicly available), and published documents. Interviews with managers at a small number of sites and firms have been frequently used in developing a deep understanding of the dynamics and relationships between different constructs (e.g., Klassen and Vereecke, 2012; Tate et al., 2009). At multiple tiers, interviews were conducted with one or more managers in a firm (combined with objective data) to assess environmental stringency and implementation timelines, as well as management practices that respond to environmental regulations.

Given the long-term development and implementation of these regulatory policies, our case studies were carried out over an extended period of time. In 2003, an interview protocol was originally developed comprising both open-ended and directed questions that explored how Samsung SDI was responding internally and externally to the compliance demands of OEM customers regarding RoHS. One research team member participated in a project that established a green supply chain management system at Samsung SDI. Later, seven managers – in such areas as quality assurance, environmental management, R&D, production technology management, and procurement – were interviewed to investigate the firm's response to customers' RoHS requirements. These interviews were designed to explore the following questions: (1) what were the requirements of the firm's customers regarding RoHS regulations? (2) How did the managers view these requirements and respond to them? and (3) How did any response extend to its suppliers? In addition to these interviews, Samsung SDI's internal and public archival documents, along with public documents of some of its customers, were reviewed dating back as far as 1999.

This initial case seeded much discussion and thinking, and the open-ended, structured interview protocol later was slightly modified to reflect REACH and the apparel industry for use with our case studies of the supply chains of Benetton and Moncler Group (Appendix A). For Benetton, interviews were conducted with managers of R&D for raw materials, as well as safety and environmental managers. For Moncler Group, five managers were interviewed with a particular focus on REACH regulations: chief operations officer (COO), purchasing, planning and control, logistics and quality control. Three aspects were explored: (1) aims, peculiarities and details of REACH; (2) internal actions adopted by the firms to comply with REACH, such as internal deadlines and thresholds, development of formal organizational structures and roles within the firms, and internal routines and procedures; and (3) external actions adopted, including thresholds and deadlines for suppliers and supply chain improvement initiatives. With Moncler Group, additional interviews were conducted directly with two managers at a major supplier, Limonta (Table 2).

In addition to managerial interviews, which were transcribed for analysis, multiple sources of evidence, including published and/or unpublished archival documents and websites, triangulated the responses and comments obtained during the interviews (Table 2). Generally, good agreement and consistency were found in the responses from multiple managers within each firm about how other firms within their supply chain were addressing environmental issues. We then followed techniques for cross-case analysis and tabular displays (Miles and Huberman, 1994), which denoted the differences and similarities in the synthesis of the cases. Data was coded using a theoretic frame driven by the underlying research questions, i.e., what is the nature and form of a green bullwhip effect, what are the management responses, and what are the implications (Section 4). This analysis, in turn, provided the basis for developing an integrative framework and further propositions (Section 5).

4. Case results and development of propositions

Based on our conceptual framework of the green bullwhip effect and the cross-case analysis of the three supply chains, we separated the findings into three areas: stringency of environmental specifications; timeline for compliance; and management response to ensure compliance.

4.1. Increasingly tighter limits imposed

Each of these three supply chains experienced, to a greater or lesser degree, increasingly stringent environmental requirements being demanded by each tier from its direct suppliers. Looking first at Samsung SDI (first-tier), the firm undertook an assessment

Table 3
Initial levels of stringency applied by each tier on its suppliers for Samsung SDI (RoHS).

Supply chain tier	Firm	Substance limits (ppm) demanded from suppliers					
		Cadmium	Lead	Hexavalent chrome	Mercury	Poly-brominated biphenyls	Poly-brominated diphenyl ethers
Regulation	RoHS directive	100	1000	1000	1000	1000	1000
OEM	Sony	5	nd[a], 1000[b]	100	5[d], 100[c]	nd	nd
	Samsung Electronics	5	100	100	100	100	100
	LG	10	100	100	100	100	100
	HP	100	100[c], 1000[a]	100[c], 1000[a]	100[c], nd[a]	nd	nd
1st Tier	Samsung SDI	5	100–1000	100	100	nd	nd

Notes: All levels are reported in parts per million (ppm). nd = not detectable. Lower levels are more stringent.
For example, Samsung SDI demanded that second-tier suppliers have less than 5 ppm of cadmium in all materials and components.
Some firms had two different limits for different materials:

[a] All components.
[b] Soldering.
[c] Packaging.
[d] Sony allowed 5 mg per florescent tube.

Table 4
Initial levels of stringency applied by each tier on its suppliers for Benetton and Moncler Group (REACH).

Supply chain tier	Firm	Substance limits (ppm) demanded from suppliers				
		Azo dyes	Organo-stannic compounds	Lead	Cadmium	Pentachloro-phenols
Regulation	REACH directive	30	1000	na	100	1000
OEM	Benetton	20	1–2	90	40	0.5
	Moncler Group	30	1000	1	100	0
1st Tier	Limonta	30	1000	0	0	0

Note: na = not provided for clothing.

of the implications of EU's newly promulgated RoHS directive. At that time, the firm was receiving requests from major OEMs, such as Matsushita, Samsung Electronics, Nokia, Motorola and other Chinese electronic manufacturers, to report what materials were being used and the quantities of specific substances in its components. Further complicating the problem, these OEM customers were starting to impose varying levels of stringency, differing both by customer and by restricted substance, many being lower than the regulatory requirement (and possibly consumer expectations too) (Table 3).

After analyzing the composition of its components, such as LCDs, PDPs, CRTs and rechargeable batteries, managers realized that a quarter of Samsung SDI's products, representing revenues of €1.5 billion, could be excluded from EU markets by 2006 if business continued unchanged. In fact, more than 18% of parts, or 30% of annual purchases of €910 million, contained restricted materials. Thus, internal changes were far from sufficient; consequently, 431 suppliers (i.e., second-tier) required checking, auditing and monitoring. In response to tighter customer demands, Samsung SDI developed new detailed requirements and communicated these to its suppliers. The requirements imposed on second-tier suppliers tended to mirror the most stringent levels enforced by Samsung SDI's customers (last row in Table 3), often substantially much stricter than the RoHS regulation (i.e., fewer parts per million).

Benetton, facing the recent regulatory requirements of REACH, adopted a similar approach with its first-tier supply base in 2008. After developing a chemical "blacklist," Benetton's more stringent limits ranged from 1/2000th of REACH's legal limits for pentachlorophenols (PCPs), to entirely new limits for other substances that did not have specific regulatory limits, such as 90 ppm for lead. In a similar fashion, Moncler Group also planned to impose greater stringency on its supply chain. For some substances, the limits on its first-tier suppliers were more stringent than Benetton's, such as lead (1 ppm) and PCPs (not detectable) (Table 4). This variation mirrored the differences between OEMs in the electronics industry (Table 3).

Limonta, one of the most important suppliers for Moncler Group, adopted even more stringent requirements for some chemical substances. This supplier of special fabrics for clothing, leather goods, and footwear was one of the few European products with in-house production lines for coating, flocking, resin impregnation and coagulation, as well as a wide range of textile finishing processes. Limonta demanded the complete elimination of some substances such as lead, cadmium and PCP by its suppliers (second-tier for Moncler Group) (see last row in Table 4).

Proposition 1. *The stringency of product- and material-based environmental requirements tends to increase as they pass upstream in the supply chain.*

4.2. Increasingly shorter timelines imposed

More stringent limits were not the only change that fostered a green bullwhip effect. Recall that the RoHS regulatory compliance deadline for Samsung SDI was June 2006. However, customers imposed much more aggressive timelines that varied considerably by substance (Fig. 1). In fact, the most lenient deadline allowed by any OEM customer was 15 months prior to the regulation coming into force (March 2005), whereas the most aggressive customer imposed a deadline of 27 months (March 2004). In response, Samsung SDI initiated a new chemical substance survey of its

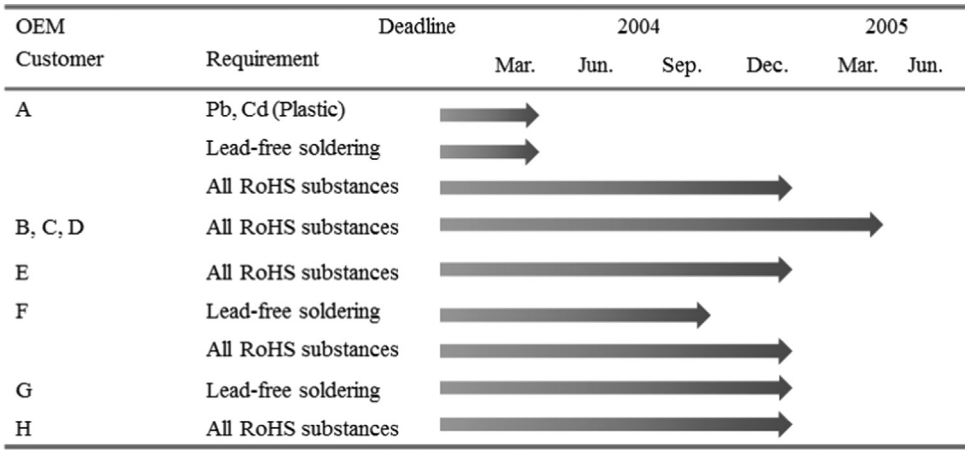

Fig. 1. Deadlines imposed on Samsung SDI to reduce RoHS substances by OEM customers.

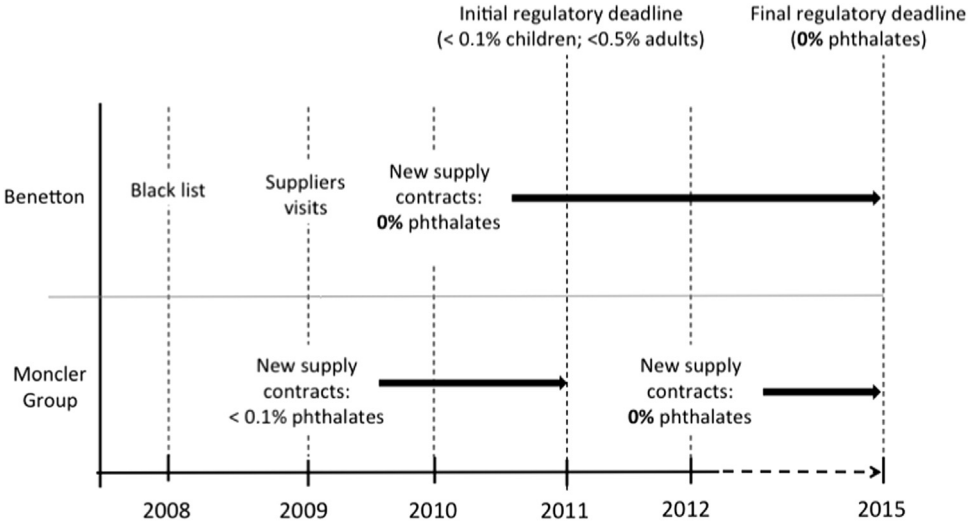

Fig. 2. Deadlines imposed on suppliers to reduce phthalates by Benetton and Moncler Group.

suppliers (i.e., second-tier) in early 2003, and then required each supplier to provide assurance that their third-tier suppliers did not ship banned substances.

A similar compression in timing was pushed by Benetton and Moncler Group. We explored in more detail one hazardous chemical, e.g. phthalates, which illustrated both the complexity of supply chain dynamics, as well as responses that Benetton and Industries employed. Phthalates are organic compounds that are used to soften plastics and other materials to make them easier to be processed; they are persistent, bioaccumulative and toxic. REACH set a limit of 0.1% and 0.5% by weight for products, for children (≤ 3 years old) and adults, respectively. Companies were required to be compliant by January 1, 2011. Subsequently, phthalates were to be eliminated completely by February 2015.

In 2008, Benetton initially set the limit of 0.1% for all customers globally, and following further review, decided to completely eliminate the use of phthalates. The zero tolerance for phthalates partly resulted from pressure exerted by Greenpeace, an environmental non-governmental organization that was perceived to greatly influence public opinion worldwide. Within the Benetton's supply chain, for example, phthalates were used by Tunisian print shops. The firm's managers maintained tight control over and directly coordinated these second-tier suppliers. Printing shops tended to be small firms serving multiple customers, although Benetton might account for up to 80% of their business. In January 2009, inspections were made of about 10 Tunisian printing shops, and auditors compiled a list of all materials (such as glues and colorants) that contained phthalates. Based on this inspection, Benetton imposed a deadline of January 1, 2010 for printing shops to eliminate the phthalates, *five years* ahead of the REACH deadline.

Moncler Group's concerns about the growing emphasis on green criteria in the marketplace prompted the firm to become more proactive on environmental issues. Starting in 2009, Moncler Group imposed a limit of 0.1% for phthalates on its suppliers (i.e., first-tier), setting a limit more stringent than REACH and requiring conformance to this lower limit two years ahead of the 2011 deadline. Subsequently, in 2012, the firm incorporated the new requirement for zero-phthalates in the supply contracts for the upcoming 2013–2014 fall-winter season, two years ahead of 2015 REACH regulatory deadline for zero phthalates. Like Samsung and Benetton, the firm created a temporal buffer that will allow it fix tardiness by or implementation shortcomings of first-tier suppliers. Fig. 2 summarizes the timeline for eliminating phthalates within Benetton's and Moncler Group's supply chains. The two black-bolded arrows measure the extent to which the two firms moved ahead the REACH deadlines.

Returning to the electronics industry, public documents such as environmental and sustainability reports indicate that this timeline compression for RoHS extended beyond our case of Samsung SDI (Fig. 3). For example, a number of OEM companies rushed to declare aggressive timelines (Phase III), along with interim compliance

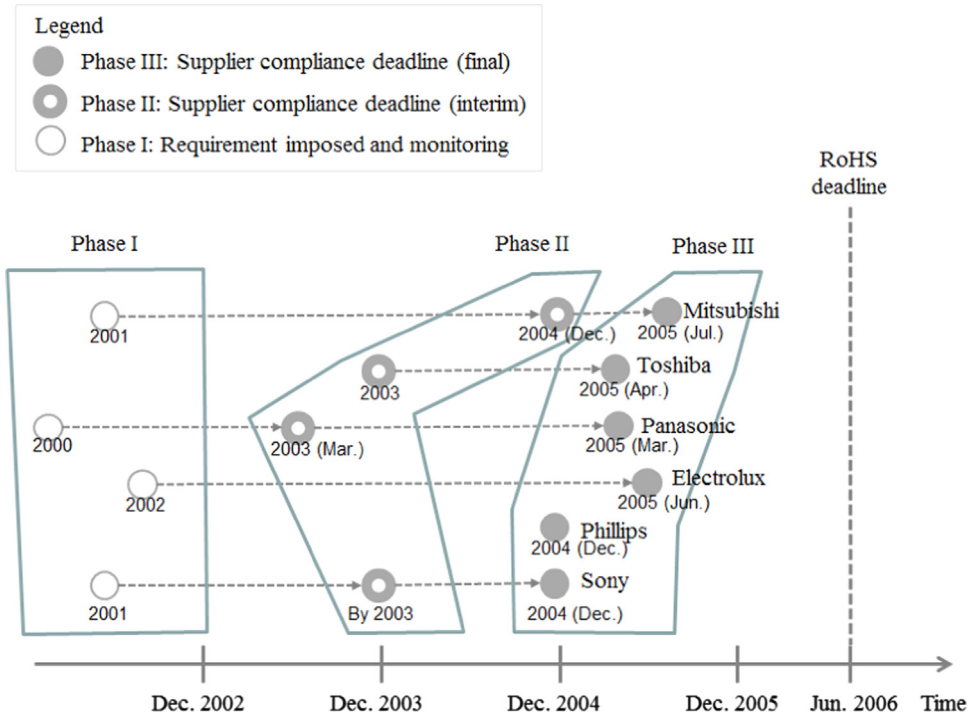

Fig. 3. Timelines imposed by major OEMs in electronics industry: first-tier supplier compliance with RoHS.
Sources: Mitsubishi Electric Group's Environmental Sustainability Reports 2002 and 2004; Toshiba's Environmental Report 2003 and Corporate Social Responsibility Report 2005; Matsushita Electric Group's Environmental Report 2000 and Sustainability Report 2003; Electrolux's Sustainability Report 2004; Phillips's Sustainability Report 2004; Sony's Social and Environmental Report 2002

deadlines for some substances (Phase II), such as lead. Furthermore, these deadlines were accompanied with the requirements being clearly communicated, and additional monitoring being introduced (Phase I). As a result, focal firms adopted a phase-leading approach of having preparatory phases to comply with the deadline using a phased, accelerated approach (Fig. 3).

Proposition 2. *The timeline for product-based environmental requirements tends to compress with each successive upstream tier in the supply chain.*

4.3. Management actions in response to the green bullwhip effect

Across the three supply chains studied, managers reported a variety of different practices driven by the need to comply with regulatory and customer environmental requirements. Initially, our case study OEMs in electronics and fashion goods attempted to influence their supply chains by imposing stringent environmental standards using a compressed timeline. However, this approach was forced to evolve over time as the firms attempted to effectively manage suppliers. As detailed below, further examination and follow-up questioning pointed toward four basic managerial responses: replace, negotiate, accommodate, and collaborate. Collectively, these responses reflect outcome-based and behavioral approaches for managing supply chain risk, consistent with the agency theory (Zu and Kaynak, 2012). However, it is important to note that each firm often employed multiple approaches with different suppliers for a variety of reasons.

The first response, namely *replace*, was observed in Samsung SDI's procurement policy of 'meet-or-give-up' (Table 5). Samsung SDI classified the relative importance of its suppliers into four categories, S/A/B/C, with "S" being the most important (i.e., strategic), ranging to "C" being commodity providers. Generally, the limit imposed on its suppliers mirrored the lowest, most stringent limit enforced by its customers (with some notable exceptions, e.g., lead, discussed later). In response, its suppliers had to provide assurance that all materials, parts and components did not contain restricted materials; otherwise, they could be replaced. Benetton identified a chemical "blacklist" of toxics to eliminate, and pushed first-tier suppliers to comply. Furthermore, this firm imposed on all tiers an aggressive timeline to phase out phthalates. When one printing shop resisted Benetton's direction, the firm replaced the supplier. This 'replace' response is consistent with GSCM practices that simplistically focus on controlling outputs relative to particular performance criteria.

The second response, *negotiate*, allowed for some adjustment from the initial level of stringency imposed by downstream customers. For example, Samsung SDI initially received environmental requirements with varying levels of stringency and timelines, differing both by OEM customer and substance (see Table 3). The costs for Samsung SDI to meet both the most stringent limit and aggressive timeline were onerous. Instead, the firm leveraged the variation between customers to convince the most aggressive customers to relax their deadlines, as long as progress continued. Such negotiation was possible because Samsung SDI had a relatively high power within the supply chain, based both on its size and capabilities. Yet, despite this apparent power, customers still imposed more stringent limits than dictated by regulation (e.g., hexavalent chrome).

The third response, termed *accommodate*, was reported in the Moncler Group case. Relative to Benetton, this firm attempted to impose even more stringent limits for two substances, lead (1 ppm) and PCPs (not detectable). Much like many firms, Moncler Group classified the relative importance of its suppliers into A/B/C categories, with "A" being the most critical for its product portfolio. However, unlike either Samsung SDI or Benetton, supplier pushback was very strong. While the majority of A-category suppliers indicated their willingness to comply with Moncler Group's more stringent limits, this response was far from universal, with 20% rejecting these more stringent limits outright (Table 6). Moreover, the proportion rejecting more stringent limits grew larger with each lower category of supplier. Managers at

Table 5
Supply chain responses.

Case	Response			
	Replace	Accommodate	Negotiate	Collaborate
Samsung SDI	Suppliers in B/C categories were replaced if they could not meet the requirements.	–	Different customers required varying limits for the same toxic substances. Openly discussing differences that provided convergence around a "compromise" limit and deadline.	Suppliers S/A were offered training and education. Joint development was also undertaken as need, e.g., lead-free soldering.
Benetton	A Tunisian printing shop resisted Benetton's proposed limits.	–	–	Tunisian printing shops are offered consultation, encouragement and technological expertise.
Moncler Group	–	Powerful suppliers dictated their terms to customers based on maximum allowable legal requirements.	Looked at tighter limits over longer term, with more time for some suppliers to adjust. Supplier (Limonta) adjustments could be made if volumes were sufficient.	–
Rationale	Impose the lowest limit of downstream customers. Generally, customers have much greater power. Substitute suppliers that are readily available, and transition costs are modest.	Powerful suppliers counteract customer demands, and dictate their offering based on allowable legal requirements.	A combination of playing within a single tier (e.g., customers) against each other, and finding a basis for collective agreement.	Limited supplier capabilities require specific investment by customer. These suppliers might be critical; few alternatives might exist, or are strategic in nature.

Table 6
Supplier response to more stringent limits imposed by Moncler Group.

Category of suppliers	Supplier response		
	Accepted (%)	Revised (%)	Rejected (%)
A	67	13	20
B	42	21	37
C	32	18	50

Note: All suppliers were willing to meet the basic REACH regulatory limits.

Moncler Group attributed this resistance to the firm's lack of market influence with their European suppliers.

Follow-up interviews with an illustrative supplier (Category A), Limonta, corroborated Moncler Group' perceptions. Limonta was one of the most critical suppliers to Moncler Group. Managers here indicated that their products had complied with REACH limits since 2008. However, more stringent requirements from individual customers were considered within the broader context of that customer's importance and bargaining power. For Moncler Group, Limonta's management refused the more stringent contract because the estimated additional costs of fulfilling more stringent requirements were not offset by sufficient sales volume. In the end, Moncler Group abandoned its initial efforts to impose stricter requirements; instead, REACH limits were explicitly incorporated into new contracts (2013–2014 season) globally.

Upstream, Limonta reacted similarly, at least in part. The firm forced its suppliers (i.e., second-tier) to comply with REACH limits well ahead any pressure from its customers (since 2008). Every six months Limonta updated its blacklist of chemicals, and conducted in-house and external monitoring. Managers considered a supplier's capability to be compliant with REACH standards to be a critical factor in vendor selection and rating. Those suppliers that do not comply with REACH were eliminated from the vendor list and alternative suppliers are sought.

The fourth response, "collaborate," combines some elements of both accommodate and negotiate responses; however the key difference is active investment to develop new capabilities in the supplier, consistent with the GSCM literature. For example, Samsung SDI decided to pursue collaboration based on the combination of supplier criticality and size. For the combined S+A categories, small- and medium-sized suppliers accounted for 81% of these 111 suppliers. Management recognized their limited capabilities in environmental management, and rather than force suppliers to achieve RoHS compliance on their own, technical and managerial assistance was offered. Initiatives included environmental training, education, and technical support for analyzing material composition. Joint development also was undertaken with soldering vendors to develop lead-free soldering processes. As a result, Samsung SDI and its supply chain met the environmental demand from OEM customers and markets one year in advance of the actual regulation deadline (albeit a small delay from the original planned timeline for compliance).

Benetton reported a similar response. In January 2009, the firm inspected Tunisian printing shops – second-tier suppliers – that were required to eliminate phthalates from glues and colorants. Not surprisingly, some suppliers were entirely unaware of this requirement. Multiple suppliers faced an even more complex problem: phthalates are highly volatile and could easily migrate from one product to another. For example, contaminants could migrate from another customer's printed products to Benetton's when they were cured in the same oven at different times. And duplicating large capital equipment, such as curing ovens, proved too costly for these suppliers. Thus, these printing shops were forced to gradually eliminate phthalates from all products across their entire customer portfolio. Those printing shops that were willing to collaborate were assisted by Benetton to change their production processes to handle phthalate-free materials. Those that did not were replaced.

In summary, firms and their multiple tiers of suppliers responded in a number of ways the complex implications of green bullwhip effect. Buyer–supplier relationships, reflecting power, supplier substitutability, and interdependency can influence which response is adopted.

Proposition 3. *Supply chain responses to the green bullwhip effect vary, as the characteristics of buyer–supplier relationships differ.*

5. Discussion

5.1. An integrative model

Collectively, as the research team tried to structure the cross-case analysis, a conceptual model emerged, as depicted in Fig. 4.

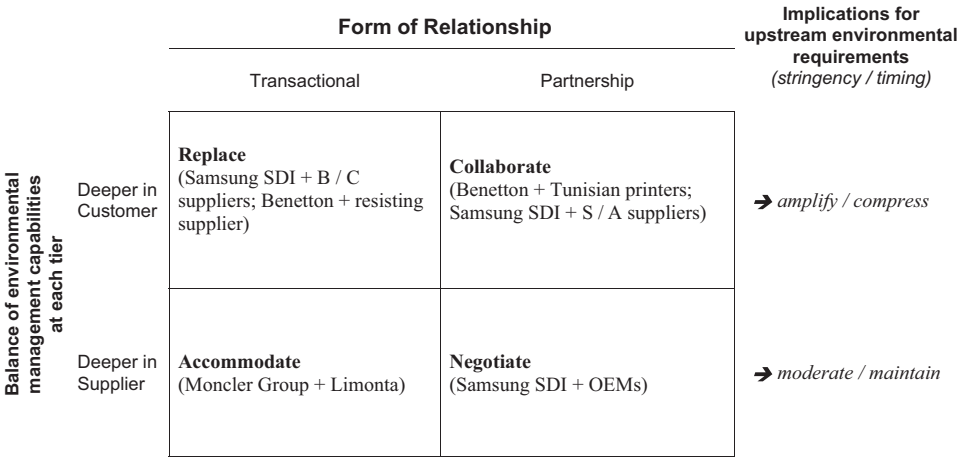

Fig. 4. The green bullwhip effect: expected responses and implications based on the nature of dyadic supply chain relationships and environment capabilities.

This general framework differentiates among the four management responses based on the form of the supply chain relationship and the relative balance of environmental management capabilities (i.e., which firm has the stronger set of environmental capabilities). It should be stressed that this vertical axis must be assessed separately for dyadic pairs at each tier in the supply chain, and may also differ by the specific nature of the environmental requirement (e.g., lead vs. phthalates). This conceptual model is not meant to be definitive, but rather interpretive of the synthesis of our finding. More research is needed to explore whether other factors explain the management responses, or additional responses might be possible.

The horizontal axis is defined by the manner in which adjacent tiers of the supply chain interact. At two extremes of a spectrum, buyer–supplier relationships are often characterized as transactional vs. partnership-based. While a relationship entails many characteristics, an aggregate measure is reflected in a supplier category rating system (e.g., Samsung SDI's S/A/B/C and Moncler Group's A/B/C). A transactional relationship seeks to control outputs based on particular performance criteria with little mutual adjustment (Williamson, 1985); both buyers and suppliers can observe outcomes, and buyers reward or penalize suppliers based on measured performance (Ekanayake, 2004). In contrast, a partnership-based relationship emphasizes the value of building each party's capabilities toward common objectives rather than specific short-term outcomes. This relationship is built on communication, mutual trust, commitment, and inter-dependency that can be achieved through asset-specific investment between a small number of customers and suppliers. Behavior-based management mechanisms, involving the direct interaction of the focal firm with its supply chain partners, jointly improve the performance of each party (Eisenhardt, 1989; Zu and Kaynak, 2012).

The vertical axis characterizes whether the customer or supplier in each dyadic relationship *at each tier*, on balance, is likely to be more skillful in dealing new environmental requirements, to have greater underlying technical capabilities, and to have more available resources (Parmigiani et al., 2011). In general, if the customer is perceived as more capable, the environmental requirements are more likely to be amplified as those requirements are passed upstream between that particular dyad. For example, Benetton's strict restrictions and compressed timelines prevailed with its small suppliers that often poorly understood both the regulatory demands, and the technical means by which those demands might be met. Similar challenges arose with Samsung SDI and the elimination of lead in solder. In contrast, if the supplier has stronger environmental capabilities, the stringency and timing of new environmental requirements are likely to be moderated. Examples include suppliers refusing the greater stringency of Moncler Group (with the customer having little technical recourse), and Samsung SDI's negotiation with its OEM customers toward some middle ground.

This framework provides a clearer explanation about why and how firms differ in responding to a given specific change, all else being equal. First, under circumstances in which the customer has a stronger set of environmental capabilities and their relationships are transactional (i.e., upper-right cell), a customer can attempt to impose more stringent environmental requirements with a threat of replacing an uncooperative supplier. In part, the customer can assess the risk that a supplier might fail to comply, combined with any expected losses that could occur, and compare that to the costs of bringing in an alternative supplier (Cousins et al., 2004). To avoid such risks, customers begin by imposing stricter limits on these high-risk suppliers, i.e., amplifying environmental requirements; transactional relationships also allow the customer to seek substitute suppliers with relatively low transition costs. Samsung SDI and its B/C category suppliers ("transactional relationships") are an example for this 'impose, then replace if needed' response. Facing varying environmental demands from OEM customers, Samsung SDI imposed the most stringent requirement onto its suppliers; however, the manner in which such environmental criteria were satisfied was left to suppliers in the B/C categories.

Second, when a supply chain has a transactional relationship in which the supplier holds the balance of environmental capabilities, then the environmental requirements are likely to moderate or attenuate under an "accommodate" response (lower-right cell). Under these circumstances, the environmental demands and threat of supplier replacement by the customer are less credible. As a result, the supplier can refuse any overly burdensome requirements from customers, as long as it complies with the basic legal requirements. Moreover, if one or more powerful suppliers counteract customer demands, and dictate their offering based on allowable legal requirements or another internal standard, the buyer must adjust. As discussed earlier, Moncler Group and its suppliers provide one such example; after the firm attempted to impose greater stringency, accommodation was made for Limonta.

Third, when supply chain partners are partnership-based at a particular tier, and the supplier has greater environmental capabilities, the supplier and customer are more likely to evolve toward a negotiate response (i.e., lower-left cell). Partnership indicates mutual commitment, possibly based on a long-term contract, which also can engender higher transaction costs if supplier substitution were considered. Moreover, the strong environmental capabilities of the supplier help customers to understand (from a trusted source) the costs of a more stringent

environmental requirement. As a result, both parties engage in a collaborative negotiation that can moderate or attenuate the requirements of the customers, as we observed with Samsung SDI and its OEM customers. As a dominant and reliable display panel provider, this supplier had built deep relationships with international brands. Based partly on customers' confidence in Samsung SDI's environmental capabilities, some customers relaxed their initial environmental limits and deadlines.

Finally, a collaborative response is likely to be utilized by supply chain partners when a customer holds the greater balance of environmental capabilities (upper-left cell). However, the perceived risk of a suppliers' inability to comply (even with collaboration) prompts amplification of either the level of stringency, a more aggressive timeline, or both. Thus, the partnership relationship pre-empts potential supplier substitution, except as a last resort. Ideally, the partners come to jointly develop new technologies, products and/or processes in order to meet the environmental demands. Samsung SDI and its S/A-category suppliers pursued this approach to eliminate lead. However, with very limited competitive or environmental capabilities, as illustrated by Benetton and its second-tier suppliers (i.e., Tunisian printing shops), the customer might bear most of this collaborative burden.

One might ask why Benetton did not simply replace the small Tunisian suppliers? Here one must consider that the relational nature of a dyadic relationship need not arise from only the strategic, potential irreplaceable nature of a supplier. Instead, upgrading a supplier's environmental capabilities in a developing economy can be viewed as contributing to the buying firm's social bottom line, and enhance the long-term commitment of small supplier.

Collectively, the green bullwhip effect is a dynamic phenomenon, illustrating that as periodic, significant changes in environmental regulation occur, these demands flow upstream in the supply chain with varying consequences. Thus, product-based environmental regulations prompt significant improvement, and firms such as HP (or other OEM customers of Samsung SDI), Benetton, and Moncler Group are initially targeted by tougher regulations. Supplier uncertainty prompts these firms to impose more stringent requirements – tightened specifications and a shortened compliance deadline – on their suppliers in order to create 'capability' and 'time' buffers. Moreover, the multiplicity of management responses, determined over an extended period of time as supplier capabilities become clearer, creates further uncertainty and variability. Thus, the green bullwhip effect and the green supply chain responses result, in part, from iterative interactions between buyers and suppliers. For example, a buyer's initial decision about how to transfer new environmental pressures upstream stimulates supplier change; the supplier's initial response whether to accept or refuse to comply with more stringent requirements; the buyer's response whether to replace the supplier, accommodate a supplier's refusal, or help the supplier meet more stringent requirements; the supplier's response whether to offer a counter proposal; and other responses across multiple suppliers.

5.2. Managerial implications

The findings of this research provide at least five implications for managerial practice. First, stepping back, one must acknowledge that OEMs face a time-consuming set of tasks to appraise the environmental risks transferred through each tier in the supply chain. The complexity of many tiers, along with many materials, parts and subassemblies, must be combined with an incomplete and uncertain understanding about suppliers' intentions and capabilities (Speier et al., 2011). Managers rationally build in buffers, both for more stringent limits on chemical substances, and for meeting early deadlines for compliance. These buffers, much like the quantity and time buffers of the classic bullwhip effect, are perceived by managers to reduce any risks of non-compliance.

Not dissimilar from the "cost of quality," buffers implicitly reflect the uncertainties and subsequent costs in three categories: appraisal, failure-recovery and prevention. Appraisal takes time, often involving hundreds of suppliers, over roughly a year for both Samsung SDI and Benetton. Moreover, if suppliers prove incapable of meeting the requirements, or refuse to do so, time must be available to look for other suppliers or for negotiations (i.e., failure-recovery). In other situations, suppliers require time to re-engineer the equipment, seek alternative materials and assess their performance and/or pass requirements upstream to yet another tier (i.e., prevention). Managers should understand the characteristics of their supply chain, the nature of buyer–supplier relationships, and ultimately, the most effective response to push environmental requirements upstream in the supply chain.

Second, given the challenges and uncertainty surrounding environmental issues in the supply chain, managers must foster the development of environmental capabilities across multiple tiers in their supply chain. As environmental requirements in many industries move upstream with more stringent limits and tighter timelines, these amplified requirements rapidly impinge on SME suppliers operating in developing countries. Yet, SMEs are the least likely to have the technical capabilities to meet very stringent limits and tight timelines. OEMs and first-tier suppliers must account for the time needed for collaboration, including education, training, technical study, and managerial assistance, and if necessary, co-development of new technologies.

Third, firms must consider the value of information (i.e., visibility) about suppliers' environmental capabilities and performance. The less information available – conversely, the greater the uncertainty – about supplier capabilities, the greater the buffers needed to manage the risk. By way of analogy from the classic bullwhip effect, greater demand visibility serves as an effective antidote (Lee et al., 1997a). For managers, evolving customer and regulatory demands require ongoing attention to ensure that accurate information is quickly captured, and then translated into the appropriate limits and timelines. Suppliers at multiple tiers also need to be quickly informed of expected changes while they remain under study, without necessarily waiting until final regulations are promulgated.

Fourth, the green bullwhip might encourage OEMs to develop stronger supply chains with deeper relationships (Camuffo et al., 2007), which in turn can respond with greater certainty, thus reducing the need for buffers such as greater stringency and compressed timeline. Partnership-based relationships facilitate coordination, collaboration, knowledge transfer and adaptation across the supply chain (Krause et al., 2007). Moreover, collaboration can strengthen the environmental capabilities of multiple tiers (Vachon and Klassen, 2008), and can assist with adapting to future, additional environmental regulations.

One final point should be raised for further consideration: the classic bullwhip effect is typically viewed negatively, creating waste, reducing responsiveness and hurting customer service. In contrast, the green bullwhip effect is not necessarily a negative phenomenon, and might create positive value that exceeds direct costs. For example, reducing or eliminating phthalates ahead of regulations provides customers with a product that is greener and/or safer.

Moreover, the green bullwhip effect has potential spillover effects in communities upstream in the supply chain that are far removed from the regulated point-of-sale. From a public policy perspective, new limits on hazardous substances tend to be often imposed initially by regulators or customers in developed countries. Yet, many first- and second-tier suppliers are located in developing countries where regulators do not necessarily directly impose the same limits. Combined, these tendencies suggest that at times, as was the case with Benetton, the increasingly stringent limits will be implemented sooner in SME suppliers. These suppliers are pushed to move ahead of any regulations in their local markets, yielding positive benefits for local

customers, as well as worker safety and community health (Klassen and Vereecke, 2012).

5.3. Limitations and future research

Several limitations of this research suggest potential directions for future research. First, the findings and implications are based on case research with only a small number of firms at each tier of three supply chains. While one of the major advantages of the case research is the depth of the information that can be collected, a major concern is the extent to which the conclusions can be broadly generalized. To expand generalizability, our propositions should be tested with extended and/or repeated case studies applied to a variety of industries and product-based regulatory events. Second, the range of constructs considered in the framework explaining different responses of our case firms and their consequences was exploratory in nature. This suggested framework should be extended, first by considering additional factors, such as the levels of pre-existing institutional environmental pressures (Reid and Toffel, 2009), and second, by explicitly capturing the evolution of practices over time at the supply chain level, rather than at the firm level (Zadek, 2004).

Third, the data for our case studies focused on the requirements that OEMs (i.e., Benetton and Moncler Group) and first-tier suppliers (i.e., Samsung SDI and Limonta) placed on adjacent suppliers, relative to regulations. Further studies could examine the environmental requirements imposed by tiers further upstream on their suppliers (i.e., second-, third-, and higher-tiered suppliers). Fourth, the dynamics of environmental issues in the supply chain might vary from country to country since contextual differences can matter. For instance, corporate environmental management differs depending on the policies and culture of countries (e.g., Klassen and Angell, 1998; Jeswani et al., 2008). Thus, future research should investigate how institutional differences cause differences in the green bullwhip effect. Finally, beyond the legal environmental requirements, the importance of managing social and/or sustainability issues is becoming the focus of increasing attention by end-consumers and NGOs, among others (Seuring and Müller, 2008; Klassen and Vereecke, 2012). It is unclear how this phenomenon might extend to other aspects of sustainability, as reflected in the similarities and differences between environmental and social issues in the supply chain.

6. Conclusions

Firms are increasingly being required to meet new product-based environmental requirements driven by ratcheting customer expectations, urgent NGO demands or more stringent government regulations. However, managers find it challenging to ensure that all purchased materials and components meet these new requirements in timely manner. In response to these issues, our study of three firm-specific supply chains in the electronics and apparel industries identified three critical aspects that pointed to the concept of a green bullwhip effect. First, the need to assure full regulatory compliance prompted managers to establish buffers, in terms of greater stringency and compressed timelines, to adjust for and mitigate both foreseen and unforeseen risks. Furthermore, first-tier suppliers seek to apply the same logic to second-tier suppliers, albeit now derived from OEM requirements, thereby often creating even more stringent limits or more aggressive timelines – a green bullwhip effect.

Second, our study revealed four generic management responses that contributed to the green bullwhip effect to varying degrees: replace, collaborate, accommodate and negotiate. These responses were not applied universally at every tier in the supply chain, but instead varied based on the nature of buyer–supplier relationship at each tier, the balance of environmental capabilities between buyer and supplier at each tier, and the networking of suppliers and customers (i.e., different buyers might use the same supplier or vice versa). Moreover, the use of the first two responses, namely replace and collaborate, stimulated amplification from increased stringency, tighter timelines, or both. In contrast, the latter two responses, namely accommodation and negotiation, modified or attenuated initial demands for greater environmental stringency or tighter deadlines (while still complying with regulatory requirements).

Finally, while the classic bullwhip effect creates negative consequences from high levels of inventory and poor customer service, the environmental bullwhip has more subtle implications. Yes, short-term costs likely increase as OEMs are forced to reduce the use of less expensive (but toxic) substances. However, for smaller suppliers located in developing countries, collaboration with customers that possess strong environmental capabilities can foster the development of upgraded supplier capabilities. Thus, these suppliers move ahead of any regulations in their local markets, yielding spillover benefits for local customers, workers and communities. Thus, the broader network of stakeholders might benefit to a greater degree than customers from a green bullwhip effect.

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Appendix A. Interview instrument

Questions on general information and management of the relationships

(1) Describe firm background: history, products, # of employees, and annual sales (total and regional).
(2) If the firm is a buyer (e.g., OEM): describe the characteristics of suppliers (# of suppliers, demographic of suppliers, and major suppliers); describe the relationships between the firm and its suppliers, including contract type, long-term partnership, bargaining power, and inter-dependency.
(3) If the firm is a supplier: describe the characteristics of customers (# of customers and demographic of customers and major customers); describe the relationships between the firm and its customers, including contract type, long-term partnership, bargaining power, and inter-dependency.

Questions on environmental management

(1) Describe the firm's environmental management practices, including environmental management systems (e.g., ISO 14001), formal and informal organizational structures to deal with environmental issues, the firm's environmental investment, and the firm's general stance towards environmental issues.
(2) Describe the changes in the abovementioned environmental management of the firm over time.

Questions on response to environmental regulations for firms as a customer

(1) Describe when and how the firm recognized the environmental regulations (RoHS and/or REACH).

(2) Describe what the firm's initial reactions to the regulations were.
(3) Describe what internal actions adopted by the firm to comply with the regulations were, including thresholds, formal organizational structures and roles within the firm, and internal routines and procedures.
(4) Describe any changes in those internal actions over time.
(5) Describe what external actions adopted by the firm to comply with the regulations were, including the thresholds and deadlines for suppliers and supply chain improvement initiatives.
(6) Describe any changes in those external actions over time.

Questions on response to environmental requirements as a supplier

(1) Describe what the requirements of the firm's customers regarding the RoHS and/or REACH regulations were. Describe any differences among customers, if they were.
(2) When did the firm's customers place such requirements? Describe any differences among customers, if they were.
(3) What was the firm's initial reaction to such customers' requirements?
(4) Describe what internal actions adopted by the firm to comply with the requirements were, including thresholds, formal organizational structures and roles within the firm, and internal routines and procedures.
(5) Describe any changes in those internal actions over time.
(6) Describe what external actions adopted by the firm to comply with the regulations were, including the thresholds and deadlines for suppliers and supply chain improvement initiatives.
(7) Describe any changes in those external actions over time.

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