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INTEGRATING SUPPLY CHAINS: AN INVESTIGATION OF COLLABORATIVE KNOWLEDGE TRANSFERS

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Abstract

This paper empirically investigates the impact on performance of explicit knowledge transfer in the integrated supply chain between a manufacturer and its external suppliers and customers. Literature-derived hypotheses were evaluated using International Manufacturing Strategy Survey data from 338 companies. Valid and reliable scales were created via confirmatory factor analysis, and effects on inventory performance tested via regression techniques. Whilst knowledge transfers from upstream and downstream directions were positively related to a manufacturer's performance, knowledge derived from customers was more powerful. Furthermore, integrated knowledge transfer – the combination of knowledge emanating from both suppliers and customers – had the strongest link to performance. The implications for practitioners are that integrating knowledge across supply chains could be more far-reaching than the exchange of assets, data and information usually considered in supply chain literature. Furthermore the current generalized approach to managing external knowledge is inadequate. This study expands on existing literature by including directional implications as to which knowledge inflows are most valuable. For academics, this paper supports and extends existing literature by considering the supplier-manufacturer-customer triad in unison. The focus goes beyond asset, data and information exchange towards the leveraging of external knowledge. Relevant perspectives and dimensions were adopted from the knowledge management stream in order to add conceptual depth. Several areas of knowledge-based supply chain research have been identified as potential opportunities for further investigation.

Keywords: Supply Chain, Knowledge Management, Empirical Research.

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INTEGRATING SUPPLY CHAINS: AN INVESTIGATION OF COLLABORATIVE KNOWLEDGE TRANSFERS

1. Introduction

Growing evidence suggests that companies must efficiently and effectively create, capture, and share knowledge in order to solve problems and exploit opportunities (Brown and Duguid, 1991; Kogut and Zander, 1992; Becker and Zirpoli, 2003; Giunipero, Hanfield, and Eltantawy, 2006). Unfortunately, most organizations find that successful knowledge management is an uphill struggle and its benefits elusive (Heibeler, 1996; Payne, 1996). Consequently, this field has become one of the most hotly debated yet least understood topics in business today (Hult et al., 2006), with companies demonstrating clear differences in terms of organizational readiness for knowledge management (Siemieniuch and Sinclair, 2004).

While theoretical work such as Nonaka (1994) has started unraveling the riddles of internally generated knowledge, our understanding of externally created knowledge is still relatively weak. There is an especially notable gap in the knowledge management literature from an integrated upstream and downstream supply chain perspective (Hult et al., 1999). Despite the apparent synergies between the areas, to date limited work has been carried out that applies relevant supply chain concepts to the field of knowledge management, and that which applies a knowledge perspective to the field of supply chain management (Bessant et al., 2003; Hult, 2003). Just as Bowersox et al. (2000) predicted, knowledge based learning is becoming a key to revolutionizing 21st century supply chains, and yet many questions still remain unanswered on the topic.

Investigation of external knowledge is especially important for two reasons. First, there is a need to develop a finer-grained understanding of the transfer processes involved in coordinating and sharing inter-organizational knowledge between external partners in the supply chain (Hult et al., 2000). Notably, a better understanding of the coordination of knowledge between suppliers and customers will extend previous work, such as Cohen and Levinthal (1990), Mowery et al. (1996), Ingram and Baum (1997), and Ahuja (2000), that considered the acquisition of 'generic' knowledge from somewhere in an organization's surrounding environment.

Second, the supplier-manufacturer-customer triad needs to be considered in unison, and the possible directional implications of knowledge transfer merit greater investigation. The limited work in this area has generally focused on knowledge transfer from either the supply side or the customer side of a manufacturer (Schonberger, 1990; Slater and Narver, 1995; Ulwick, 2002; Modi and Mabert, 2007) but rarely takes a more integrated supply chain perspective of simultaneous upstream and downstream flows. Hence, there is still the need to compare each of these knowledge transfer directions in a single piece of work. Frohlich and Westbrook (2001) raised the question "is it more important to link with suppliers, customers or both?" and this question has not yet been addressed from a knowledge perspective. Huber (1991), Gupta and Govindarajan (2000) and Molina et al. (2007) reference knowledge "richness" in terms of high quality information that is accurate, descriptive, timely and customized for the recipient. The dual concepts of knowledge-rich and richness relate to the extent of knowledge flows, 'bandwidth' of transmission channels, bandwidth of transmission channels or density of communication and the "comprehensiveness and accessibility of codified knowledge that is available to a firm" (Overby et al., 2006). Such rich knowledge can help managers to make appropriate and timely decisions (Glazer, 1991). Yet no research appears to have isolated the comparative richness of external explicit knowledge emanating from upstream versus downstream in the supply chain.

This study aims to make distinct theoretical contributions and identify managerial implications by linking the knowledge management and supply chain management streams. The knowledge management literature recognizes two forms of knowledge: explicit, codified knowledge, and tacit 'know-how' (Polyani, 1966; Brown and Duguid, 1991; Romer, 1995). Both explicit and tacit forms of knowledge are important and constitute the information, opinions and expertise present within organizations (Nonaka, 1994). Recent studies have investigated both explicit and tacit components of knowledge within organizations (e.g. Edmondson et al., 2003), but this investigation focuses on explicit knowledge since it plays an increasing role for modern organizations and is more precisely formulated and articulated, thus enabling accurate empirical analysis (Zack, 1999). Within a supply chain context, explicit knowledge incorporates, and goes beyond, the provision of operating data and information to suppliers and customers to include both "declarative" and "procedural" knowledge components (Kogut and Zander, 1992). Declarative explicit knowledge transfers between organizations include shared inventory and delivery information. Procedural explicit knowledge transfers include joint activities such as planning and forecasting, and shared methods such as Kanban.[1] Using manufacturers positioned between suppliers and customers as the unit of analysis, we developed a model that investigates the impact on performance of upstream and downstream explicit knowledge.

The next section of this paper reviews the literature on knowledge and supply chain management and develops specific hypotheses concerning their relationships. Subsequent sections describe the data and hypotheses tests, discuss the results, draw conclusions, and consider the managerial implications. The last section outlines suggestions for further research.

2. Explicit Knowledge in the Supply Chain

Zack (1999) explains and defines explicit knowledge as being distinct from data and information in that it "can be viewed both as a thing to be stored and manipulated and as a process of simultaneously knowing and acting - that is, applying expertise." When combined with the work of Kogut and Zander (1992) and Albino et al. (1999), Zack's (1999) definition suggests two dimensions to explicit knowledge in the supply chain. The first dimension

[1] Kanban (Japanese, meaning "signboard") is a JIT-production concept; a scheduling system for tracking what to produce, in what quantity, and when.

involves the "declarative" or "structural" elements of storing and sharing knowledge related to issues such as inventory levels, production plans and delivery frequencies. The second explicit knowledge dimension involves the "procedural" elements of coordinating, planning, and forecasting between partners in the supply chain, as well as shared techniques. Similarly, Handfield and Nichols (1999), Hill (2000) and Chase et al. (2001) note in their definitions of supply chain management that knowledge storing/sharing systems, procedural activities and application of combined expertise are integral to supply chain partnerships.

Further supply chain management literature identifies the importance of shared techniques such as Kanban pull signals in supply chain integration and collaboration mechanisms (Cagliano et al., 2006; Vereecke and Muylle, 2006). Therefore existing supply chain literature and knowledge management literature both suggest that declarative and procedural components of explicit knowledge within a supply chain context can be characterized in terms of shared knowledge and methods across issues such as inventory levels, production planning, demand forecasting, delivery frequencies and Kanban pull signals. Such components can form the basis for operationalization of empirical measures for explicit knowledge in the supply chain (see section 4).

Thus, from the literature it is clear that explicit knowledge is generated and transferred in supply chains and this knowledge needs to be effectively managed. Yet, while there is evidence in the literature that organizational knowledge is an important determinant of competitiveness (Brown and Duguid, 1991; Kogut and Zander, 1992; Davenport et al., 1996; Quinn et al., 1996) not all knowledge creation, capture, and distribution are equal, and some studies have demonstrated the value of looking beyond the boundaries of the organization in order to capture beneficial knowledge (Cohen and Levinthal, 1990; Hagedoorn and Schekenraad, 1994; Mowery et al., 1996; Hansen, 1999; Ahuja, 2000).

Others highlight the dangers of only searching inwards for beneficial knowledge. Brown and Duguid (1991) reported on the emergence of unified internal working, learning, and innovating practices that become a performance-limiting phenomenon. Ingram and Baum (1997) demonstrated that a firm can develop knowledge internally but that this internal knowledge is beneficial to its capacity to compete in a changing environment only up to a point. They state that firms initially benefit from internal knowledge but that, in the long run, it can become a constraint. As competencies are driven through the self-reinforcing nature of internal knowledge development, organizations become specialized to niches in which their competencies yield immediate advantage. But this process can remove a firm from other bases of experience and make them more vulnerable to changes in the environment as internal knowledge and old competencies inhibit efforts to change or improve. Similarly, Levinthal and March (1993) warned that an organization that does not look externally for new knowledge is in danger of becoming myopic and that, in the long run, this can lead to "competency traps" that diminish performance. Furthermore, over-exploiting internal knowledge can be self-destructive in the long run and lead to corporate "inertia" (Miller and Chen, 1994).

At the same time, the supply chain literature notes the benefits of sharing information with and coordinating activities between supply chain partners in order to overcome problems and improve performance (Fisher et al., 1994; Fisher, 1997; Lee et al., 1997a; Magretta, 1998; Sahin and Robinson 2002; Vereecke and Muylle, 2006). The importance of suppliers and customers as potential sources of beneficial knowledge becomes even more apparent when considering that, of all external organizations, these are usually the most aligned towards the mutual objectives of a manufacturer (Cagliano et al., 2006). Hence there is more chance of success in terms of knowledge adoption from these sources than from any others (Cohen and Levinthal, 1990; Almeida, 1996; Dussuage et al., 2000).

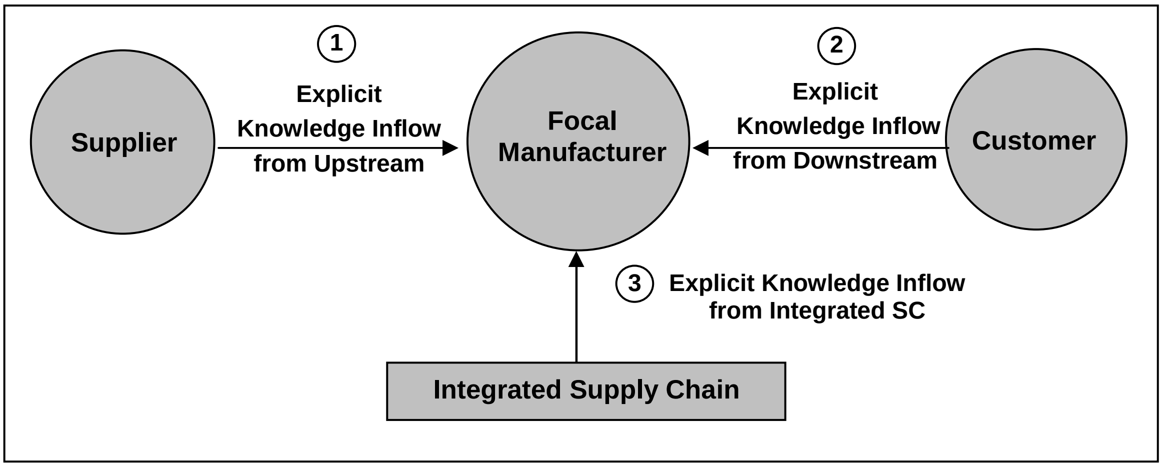
In summary, the knowledge management literature and supply chain literature parallel each other in the proposition that external, explicit, codified knowledge shared and coordinated between supply chain partners significantly benefits internal organizational efficiency. This proposition warrants further analysis of the links between external explicit knowledge in the supply chain and improved organizational efficiency. The next section, therefore, develops finer-tuned hypotheses regarding explicit knowledge sharing and coordination activities with specific upstream, downstream, and integrated supply chain sources.

3. Conceptual Model and Hypotheses Development

The evolving supply chain literature, and some knowledge-based research, has taken the general 'external' viewpoint further. While showing that externally focused efforts can have dramatic effects on organizational efficiency and performance, it also demonstrates the need for refining research on explicit knowledge flows in specific parts and directions of the supply chain. In this regard, we used the conceptual framework in Figure 1 in order to develop more refined hypotheses. The framework is that of a manufacturing company located near the middle of a typical supply chain. This is a subtle but important issue – such companies can have both upstream and downstream business-to-business partners, unlike those at the very beginning or end of supply chains. And, by extension, potentially valuable, external, explicit knowledge can be acquired by the focal manufacturer from *either* their upstream suppliers *or* their downstream customers. That is, there is potential, positive, explicit knowledge inflow from upstream and downstream. As discussed above, while there are other external sources of potentially beneficial, explicit knowledge, these are likely to be the major ones since, arguably, the strongest external relationships that a typical manufacturing company has are with its immediate customers and suppliers, especially when it comes to sharing explicit knowledge.

Figure 1

Theoretical framework



In addition, the supply chain management literature provides strong support for the value of integrating information sharing and processing activities across different supply chain members (e.g. Stevens, 1989; Narasimhan and Jayaram, 1998; Frohlich and Westbrook, 2001). This suggests that if a manufacturer is in a position to do so, it can also benefit from explicit knowledge emanating from an 'integrated supply chain' (Reck and Long, 1988; Clinton and Closs, 1997; Bowersox et al., 2000).

By combining activities with external organizations in a supply chain in each of the structural and procedural dimensions of knowledge discussed above, explicit knowledge transfer will be achieved. More specifically, according to Cohen and Levinthal (1990) as long as the formal, codified, organizational routines are in place to ensure an adequate absorptive capacity, as well as sufficient motivational disposition and transmission channels (Gupta and Govindarajan, 2000), then explicit knowledge inflow into the focal manufacturer will take place.

3.1. Model 1: Explicit Knowledge Inflow from Upstream in the Supply Chain

Hult et al. (2000) found a positive effect of organizational learning antecedents on internal purchasing information processing and cycle time performance. This corresponds favorably to the supply side of our conceptualization, even though theirs was primarily an internal study. While the internal/external distinction is important, if sufficient efforts are made to share and coordinate explicit knowledge with external suppliers then this should also improve performance.

Conversely, if there is little or no explicit knowledge inflow from upstream, then a manufacturer will have to seek any improvements internally in its supply side (i.e., raw materials) inventory investment. Sooner or later such a manufacturer will run into performance limiting problems (Brown and Duguid, 1991), "competency traps" (Ingram and Baum, 1997), "myopia" (Levinthal and March, 1993), and over-exploitation of internal knowledge leading to "corporate inertia" (Miller and Chen, 1994). While these effects might not be fatal in the short term, they suggest that relying on upstream related knowledge from *within the organization* will not be effective at improving supply side inventory investment in the long run.

The supply chain literature supports this argument. Giunipero et al. (2006) discussed the need for collaborative arrangements and developing long-term partnerships with suppliers that surpass mere information sharing and move towards a common vision and cross-organizational actions and behaviors in order to reap the rewards of mutual risk and reward sharing. Handfield (1993) provides empirical evidence that greater information sharing and interaction with suppliers leads to improved upstream procedures. Narasimhan and Jayaram (1998) also provide empirical evidence that strategic sourcing interaction with suppliers positively influences manufacturing goal achievement. Finally, Krause (1999) demonstrates the importance of liaising and combining expertise in the development of suppliers to achieve the buying firm's supply needs.

The supply chain management literature as a whole treats low inventory investment as being synonymous with higher levels of organizational efficiency. Inkeeping with this perspective, low inventory investment is used in this paper as the desired outcome of explicit knowledge inflows. Accordingly, based on the existing knowledge and supply chain literature, we hypothesize the following:

H1: Explicit knowledge inflow from upstream in the supply chain will significantly impact inventory investment.

3.2. Model 2: Explicit Knowledge Inflow from Downstream in the Supply Chain

Hult et al. (1999) showed that facets of organizational learning have a positive influence on customer orientation and relationship commitment. In itself, this provides no firm evidence to expect improved organizational efficiency, yet it does lend knowledge-based support to Schonberger (1990), who suggested that effective firms have more profound long-term relationships with their external customers beyond a purely logistics concept. From a marketing knowledge perspective, Slater and Narver (1995) suggest that performance can be enhanced when a "market orientation" (i.e., customer focus) is combined with organizational learning. Thus, while the existing knowledge-based literature relating specifically to the customer side of the supply chain is limited, it does provide important theoretical evidence for downstream knowledge inflow that can potentially improve organizational efficiency.

If the reverse were true, and there were little or no knowledge inflow from downstream, then a manufacturing company would have to seek any improvements in its customer side (finished goods) inventory investment from within. As with the earlier argument in favor of upstream knowledge inflow, sooner or later, such a manufacturer would run into the same problems of performance limitations (Brown and Duguid, 1991), competency traps (Ingram and Baum, 1997), myopia (Levinthal and March, 1993), and corporate inertia (Miller and Chen, 1994). Therefore, with little or no knowledge inflow from downstream customers, it is likely there would be a corresponding undesirable increase in customer related inventory investment.

This argument is supported by the supply chain literature that considers downstream issues. Bowersox et al. (2000) point to downstream initiatives for establishing efficient, effective and relevant downstream inventory solutions by gaining an understanding of what drives customer purchase behavior. They declare that "success hinges on establishing intimate relationships with key customers" and also on sharing information with customers rather than anticipatory inventory planning. Evidence suggests that the stronger the downstream manufacturer/customer integration in a supply chain, the greater the benefits (Narasimhan and Jayaram, 1998; Johnson and Scudder, 1999). Downstream explicit knowledge integration with customers is therefore often crucial to a manufacturer's own supply chain performance (Bowersox et al., 2000; Stock et al., 2000). Blackburn (1991), Daugherty (1999) and Waller et al. (1999) linked distribution programs such as automatic replenishment programs and JIT II to improved performance. Conversely, there are inherent hazards of not fully coordinating with downstream partners in the supply chain (Lee and Billington, 1996; Armistead and Mapes, 1993). Therefore, based on the existing knowledge and supply chain literature, we hypothesize the following:

H2: Explicit knowledge inflow from downstream in the supply chain will significantly impact inventory investment.

3.3. Model 3: Explicit Knowledge Inflow from an Integrated Supply Chain

Zack (1999) reasoned that the "integration of [explicit] knowledge across different contexts opens an organization to new insights… increasing the scope and value of that knowledge. By being able to combine experiences… the scope of experience is broadened, as is the ability to learn from those experiences." Adding to this, Hult et al. (2000) took a rare organizational learning view of the entire customer-to-supplier supply chain, and found that learning facets have a positive correlation with general supply chain relationships. No conclusions are drawn for specific performance improvements from these studies in the knowledge management field. Nevertheless, it would seem reasonable to infer that if the integration of explicit knowledge and improvement of relations across the supply chain allow for more, and better, organizational learning across the supply chain, then the ability for combined problem solving and opportunity exploitation will increase. Hence, explicit knowledge inflow from an integrated supply chain is likely to result in improved abilities to deal with functional problems such as excessive inventory investment.

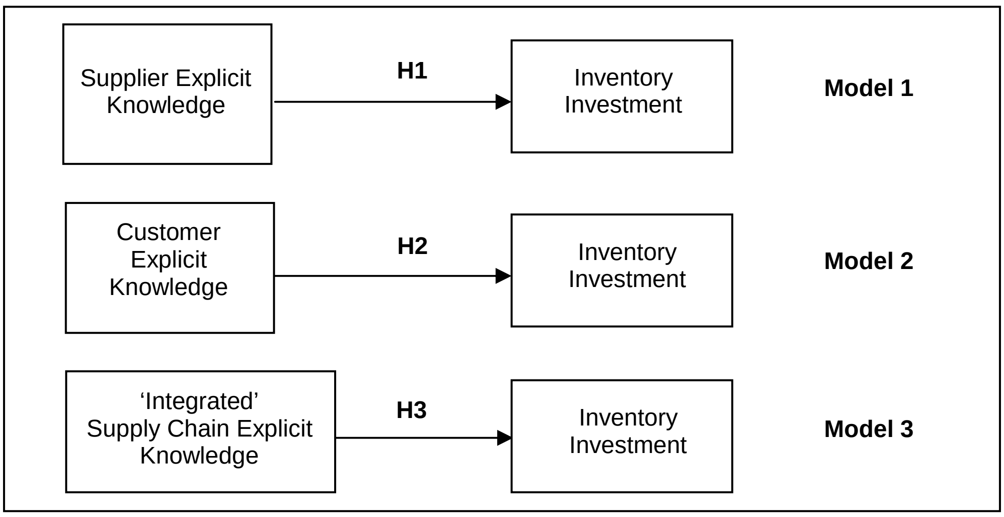
The supply chain management literature provides strong empirical support for this argument. According to Vachon and Klassen (2006) "supply chain integration offers one means by which uncertainty can be moderated or reduced for operations, whether on the demand or supply-side of the supply chain." An integrated supply chain involves both upstream and downstream partners in activities such as exchanging information, making decisions, and sharing benefits in what have come to be called "outward-facing organizations" (Frohlich and Westbrook, 2001) with processes "transcending the company's boundaries and extending back to suppliers and forwards to customers" (Hammer, 2007). Along those lines, there is growing evidence of the positive impact of integration on performance in terms of coordinating and sharing supply chain information and aligning organizational goals to improve overall supply chain efficiency. Frohlich and Westbrook (2001) showed that an integrated supply chain approach leads to performance improvements, reasoning that "better coordination in the supply chain reduces uncertainty throughout the manufacturing networks," and that "tighter coordination helps eliminate any non-value-adding activities from internal and external production processes." Stock et al. (2000) looked at optimizing the coordination of knowledge across an entire integrated supply chain, and reasoned that the level of organizational performance is dependent upon integrated information sharing from supplier to customer. One of the more important of the 'mega-trends' that will revolutionize supply chain logistics is the move from information hoarding to information sharing and "the open deployment of information across the supply chain is the catalyst that enables effective integration" (Bowersox et al., 2000). Therefore, based on the existing knowledge management and supply chain literature, we hypothesize the following:

H3: Explicit knowledge inflow from an integrated supply chain will significantly impact inventory investment.

The above three hypotheses are summarized in Figure 2.

Figure 2

Hypotheses



4. Methods

The hypotheses were tested using data from the 2001 International Manufacturing Strategy Survey (IMSS), which was designed to explore and identify the philosophies, strategies and practices of manufacturing firms around the world, and is oriented to single plants or business units within the company. Respondents were typically manufacturing VPs and therefore had ready access to all of the upstream and downstream knowledge and performance measures used in this paper. In order to control for regional variations, this study analyzed companies from Denmark, Germany, Hungary, Ireland, Italy, Norway, Spain and the United Kingdom. The IMSS sampling frame included between 20 and 60 manufacturers from each of the eight countries. The original IMSS questionnaire was in English but, to ensure a higher reliability of the answers for companies in their respective countries, full-time OM professors familiar with manufacturing strategy translated the original English version into various languages. Back-translation was not necessary since the survey response data was essentially numerical in nature. The methodology for survey administration was a mail survey, and data was treated as anonymous. A second wave of questionnaires was sent if the target number of companies in the sample was not reached. Before the final release of the IMSS data, several phases of data quality checks were carried out: non-respondent bias was checked, missing answers were limited as much as possible, and incomplete questionnaires were returned to companies in order to gain more information or discarded if more than 40% of the answers were missing. The total sample used for this analysis was 338 manufacturers and the response rate was approximately 20%.

The IMSS sampled from single plants or business units within manufacturing companies belonging to the population as defined by ISIC Division 38: Manufacture of Fabricated Metal Products, Machinery and Equipment. A balanced number of surveys were gathered in each of the sub-industry sectors as seen in Table 1. The average company size was 1079 employees and the mean market share was 41%.

Table 1

ISIC division 38 sub-divisions represented in the 2001 IMSS data

International Standard Industrial Classification of Economic Activities (ISIC- 1968)	
Major Division 3.	Manufacturing
Division 38.	Manufacture of Fabricated Metal Products, Machinery and Equipment

ISIC	**Count**	**Percent**	**Definition**
381	93	27.5	Manufacture of metal products, except machinery and equipment.
382	89	26.3	Manufacture of machinery, except electrical.
383	76	22.5	Manufacture of electrical equipment apparatus, appliances and supplies.
384	32	9.5	Manufacture of transportation equipment.
385	23	6.8	Manufacture of professional and scientific and measuring and controlling equipment not elsewhere classified, and of photographic and optical goods.
-	25	7.4	Missing/not identified.

The dependent variable *inventory investment* was constructed using object measures. As previously discussed, the supply chain management literature treats low levels of inventory investment as synonymous with high levels of organizational efficiency. For example, Lee et al. (1997b) argued that excessive inventory investment was a signal of "tremendous" organizational inefficiency. Therefore, in order to best capture the magnitude of a manufacturer's inventory investment reflecting the upstream and downstream nature of the supply chain, a multi-item scale was constructed using factor analysis from three objective measures: days of raw materials; days of work-in-process; and days of finished goods inventory. Factor analysis is a statistical approach for identifying interrelationships between variables and explaining these variables in terms of an underlying dimension. The objective is to condense several variables into a factor with a minimum loss of information. Factor analysis is an established method for creating valid and reliable scales for subsequent analysis (Hair et al., 1998; Cohen et al., 2003). The data were checked for normality and outliers before creating the final scale. Confirmatory Factor Analysis was used to check the scale's uni-dimensionality and the Kaiser-Meyer-Olkin measure of sampling accuracy was 0.66. The Cronbach alpha for this scale was 0.72, and the mean inventory investment was a total of 74.86 days.

An extended supply chain consists of a series of suppliers and customers, where every customer is a supplier to another customer. We used the conceptual framework, showed in Figure 1, where a manufacturing company is located near the middle of a typical symmetrical supply chain, where any company can be both a supplier and customer at the same time. The same structural knowledge sharing and procedural mechanisms are likely to be in place upstream and downstream in the supply chain. Therefore it makes sense for the supplier and customer explicit knowledge scales (SEK, CEK) to be equivalent. To ensure that derived factors of our proposed model would be generalizable, the specific items of SEK and CEK were defined to form parsimonious, symmetrical, interpretable and reliable factors.

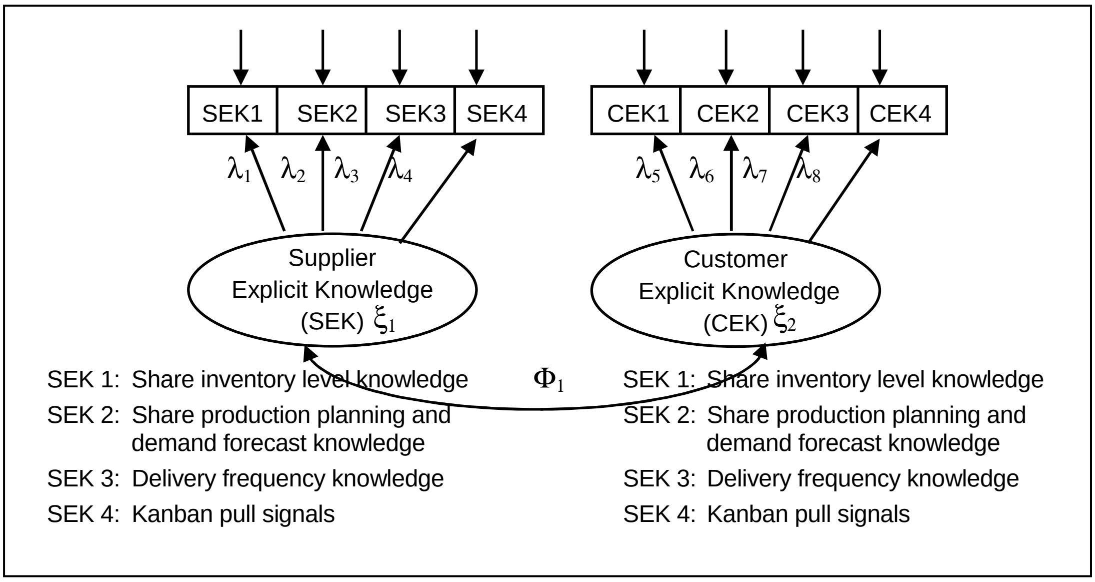
The independent variables, supplier's explicit knowledge (SEK) and customer's explicit knowledge (CEK), were based on identical multi-item scales shown in the Figure 3. Both scales were grounded in the literature and gauged a manufacturer's effort to integrate explicit knowledge with its suppliers and customers in terms of inventory levels, production plans and demand forecasts, delivery frequencies from suppliers/and to customers, and Kanban signals. As discussed in section 2, these measures thus correspond to both declarative and procedural dimensions of explicit knowledge, storing/sharing systems and procedural activities across supply chain partnerships (e.g. Zack, 1999; Chase et al., 2001). Each item was measured on 1-5 Likert scales indicating their relative levels of knowledge sharing (1 = none, 5 = high). Knowledge sharing is a collaborative two-way process, and the IMSS questionnaire items are designed to measure manufacturers' efforts to collaboratively share and coordinate explicit knowledge with suppliers and customers. The more effort a manufacturer makes towards this two-way knowledge sharing, the greater the knowledge transfers/inflows to the manufacturer from the supplier and customer. This paper considers the impact of knowledge inflows from suppliers and customers.

When theory drives a study, an appropriate approach for assessing scale reliability is confirmatory factor analyses (CFA) (Kim and Mueller, 1978). In order to evaluate each scale's reliability we examined their standardized residuals, comparative goodness of fit index (CFI), normed fit indices (NFI), magnitude of modification indices, chi-square with corresponding degrees of freedom, and overall interpretability. These reliable four-item scales are summarized in Table 2 for SEK and CEK. The Cronbach alphas for SEK and CEK were 0.68 and 0.76 respectively.

In order to gauge the level of explicit knowledge inflow from the integrated supply chain, a new independent variable (Integrated explicit knowledge, IEK) was formed. The literature states that supply chain integration involves both upstream and downstream partners in coordinated activities of knowledge sharing, extending simultaneously backwards to suppliers and forwards to customers, creating a unified whole of the entire supply chain (Frohlich and Westbrook, 2001). In line with this concept, the IEK variable was formed by combining the SEK and CEK variables into a single integrated variable.

Figure 3

Two-factor oblique measurement model of supply chain explicit knowledge



Since only one respondent rated supplier and customer explicit knowledge and performance, this might have led to common method bias. We checked for this using Harman's one factor test (Podsakoff and Organ, 1986). All of the 11 measures in this study were included in this test (SEK 1,2,3,4; CEK 1,2,3,4; days of raw materials, days of work-in-process, days of finished goods inventory). In the Harman's one-factor test, 7 principal components with eigenvalues greater than 1 were extracted and these accounted for 68% of the variance. Given that a single principal component did not emerge and thus one factor did not account for most of the variance, this suggested that the results were not due to common method bias.

The reliability and validity of each scale and objective measure were further analyzed following the example of Flynn et al. (1995). Construct validity was established by testing whether the items in a scale all loaded on a common factor when within-scale factor analysis was run. All three independent and dependent scales passed this test, which supports each scale's uni-dimensionality. Divergent or discriminant validity was tested three ways. First, bivariate correlations were checked between each of the scale measures and other potentially confounding variables, such as market share and a make to stock strategy, which could be considered as alternative measures of business performance or operations strategy (Table 3). There were no significant correlations ($p < 0.05$), which helped establish that the scales were not measuring other unintended constructs. Second, we compared the average interscale correlations in Table 3 to the Cronbach alphas. Acceptable divergent validity is shown when the alphas are greater that the average interscale correlations. Finally, the average correlations between scale and nonscale items were lower than between scale and scale items which helped support discriminant validity.

Table 2

Confirmatory factor analysis statistics for supply chain knowledge items

ξ_1 Supplier Explicit Knowledge (SEK): What is your level of adoption with suppliers?

	None				High	Loading	*t*-score
SEK 1: Share inventory level knowledge	1	2	3	4	5	$\lambda_1 = .75$	13.52 [a]
SEK 2: Share production planning and demand forecast knowledge	1	2	3	4	5	$\lambda_2 = .70$	12.61 [a]
SEK 3: Delivery frequency knowledge	1	2	3	4	5	$\lambda_3 = .61$	10.99 [a]
SEK 4: Kanban pull signals	1	2	3	4	5	$\lambda_4 = .77$	9.18 [a]

ξ_2 Customer Explicit Knowledge (CEK): What is your level of adoption with customers?

	None				High	Loading	*t*-score
CEK 1: Share inventory level knowledge	1	2	3	4	5	$\lambda_5 = .77$	13.95 [a]
CEK 2: Share production planning and demand forecast knowledge	1	2	3	4	5	$\lambda_6 = .73$	12.24 [a]
CEK 3: Delivery frequency knowledge	1	2	3	4	5	$\lambda_7 = .61$	10.87 [a]
CEK 4: Kanban pull signals	1	2	3	4	5	$\lambda_8 = .68$	11.84 [a]

Goodness of Fit Statistic	2-Factor Model (df = 6)
χ^2	2.59 (p < 0.86) [b]
χ^2/df	0.43 (≤ 2.00) [b]
GFI	1.00 (> 0.90) [b]
AGFI	0.99 (> 0.90) [b]
RMSR	0.01 (< 0.10) [b]
NNFI	1.01 (~ 1.00) [b]
NFI	1.00 (> 0.90) [b]
Hotelling's Critical N	2186 (> 200) [b]

Covariance between supplier and customer explicit knowledge

$\Phi_1 = .68$

t-score = 14.65 [a]

[a] t-scores significant at p < 0.001.

[b] Critical values for concluding "good" fit of model to data (Bollen, 1989; Hoyle, 1995; Marcoulides and Schumacker, 1996).

Table 3

Measurement analysis: Explicit knowledge and performance scales

	Correlations [a] Between Measures and Other Implementation-related Variables				Average Item Total Corr.	
Multi-item Scale	**Cronbach's Alpha**	**Average Interscale Correlate**	**Market Share [b]**	**Make to Stock [c]**	**Non-scale Items**	**Scale Items**
1. Supplier Explicit Knowledge	.68	.13	-.07	.05	.15	.50
2. Customer Explicit Knowledge	.76	.10	-.01	.04	.13	.57
3. Inventory Investment [d]	.72	.35	.09	.09	.26	.63

[a] No correlations significant at p < 0.05; [b] Market share = average percentage of market(s) served by the business unit products; [c] Make to stock percent = proportion of customer orders produced to stock; [d] Inventory investment scale objective measures: days of raw materials, days of work-in-process and days of finished goods inventory.

Based on the literature and industry observations, we included a set of control variables in the regression model. These control variables represented a baseline against which to assess the effect of adding the relevant explanatory variables to test the hypotheses of this study. The variables used were: 1. Company control: total number of employees (Cagliano et al., 2006); 2. Competition controls: product focus versus customer service (Froehle and Roth, 2004; Droge et al., 2004); 3. Fluctuating controls: outsourcing (Becker and Zirpoli, 2003) and temporary workers (Kosnik et al., 2006); 4. Operational controls: select supplier on price (Chen and Huang, 2007), push versus pull production (Razmi et al., 1998) and percentage of dedicated lines versus jobshop/cellular layout (Jonsson et al., 2004).

5. Results

Table 4 shows the baseline regression model, containing only the control variables, as well as the three subsequent hypothesis tests. To varying degrees, all three hypotheses were supported. The regression models were of the following form:

Model 1 (H_1): y = *control variables* + β_1 SEK + ε_1

Model 2 (H_2): y = *control variables* + β_2 CEK + ε_2

Model 3 (H_3): y = *control variables* + β_3 IEK + ε_3

Hypothesis 1 – that explicit knowledge inflow from upstream in the supply chain will lead to reduced inventory investment – was weakly supported. While the relationship of explicit supplier knowledge (SEK) was in the expected negative direction, it was significant at only the $p < 0.10$ level. The resultant increase in adjusted R^2 showed slightly greater explanatory power in comparison to the baseline model and the F statistic remained highly significant ($p < 0.001$). The Durbin-Watson Test indicated no autocorrelation, and the statistical power of 99% was well above the 80% suggested threshold (Cohen, 1988).

Hypothesis 2 – that explicit knowledge inflow from downstream in the supply chain will lead to reduced inventory investment – was strongly supported. The expected relationship between high customer explicit knowledge (CEK) and low inventory investment stayed in the expected negative direction while Model 1b's adjusted R^2 increased. Similarly, the F statistic remained highly significant ($p < 0.001$), and the Durbin-Watson Test indicated no autocorrelation and the statistical power was 99%.

Hypothesis 3 – that explicit knowledge inflow from an *integrated* supply chain will lead to a reduction in inventory investment – was tested by forming a new variable (Integrated explicit knowledge, IEK). Conceptually, an integrated supply chain combines upstream and downstream knowledge to form a unified whole. We thus combined explicit supplier knowledge (SEK) with customer explicit knowledge (CEK) to form the new integrated explicit knowledge variable. This hypothesis was strongly supported. Again, the *'integrated explicit knowledge'* (IEK) variable had the expected negative relationship with performance and the adjusted R^2 increased over the baseline model. The Durbin-Watson Test indicated no autocorrelation and the statistical power was greater than 99%.

Table 4

Hypothesis test results

Control Variables	Baseline Model	Model 1 Supplier Explicit Knowledge SEK (H1)	Model 2 Customer Explicit Knowledge CEK (H2)	Model 3 Integrated Explicit Knowledge IEK (H3)
Company Control				
Total Employees	-0.079 (0.003)	*-0.065* (0.003)	*-0.066* (0.003)	*-0.063* (0.003)
Competition Controls				
Product Focus	0.127 (4.025)	0.146* (4.066)	0.146* (4.135)	0.168* (4.160)
Customer Focus	0.149* (4.029)	0.164** (4.042)	0.118 (4.299)	0.137 (4.182)
Fluctuating Controls				
Outsourcing	0.283*** (3.540)	0.274*** (3.585)	0.271** (3.869)	0.271** (3.840)
Temporary Workers	-0.272*** (3.178)	-0.269*** (3.176)	-0.274** (3.339)	-0.272*** (3.309)
Operational Controls				
Select Supplier on Price	-0.108 (3.981)	-0.103 (3.998)	-0.128 (4.213)	-0.126 (4.182)
Push vs. Pull Production	-0.011 (3.530)	0.060 (3.928)	0.041 (3.858)	0.073 (3.956)
Dedicated Lines	-0.134* (0.127)	-0.129 (0.128)	-0.111 (0.135)	-0.113 (0.134)
Direction of Explicit Knowledge Inflow (SEK, CEK or IEK)	–	**-0.154*** **(1.515)**	**-0.184**** **(1.307)**	**-0.223**** **(0.066)**
R^2	**.223**	**.243**	**.250**	**.261**
Adjusted R^2	**.175**	**.188**	**.190**	**.202**
F Statistic	**4.624*** **	**4.484*** **	**4.155*** **	**4.403*** **
Statistical Power(α = .01)	–	**99%**	**99%**	**99+%**

Table gives Standardized Beta Coefficients. Standard Errors in Parenthesis

*p<0.10, **p<0.05, ***p<0.001 for two tailed test, n =338

Model 1 (H_1): y = *control variables* + β_l SEK + ε_l

Model 2 (H_2): y = *control variables* + β_2 CEK + ε_2

Model 3 (H_3): y = *control variables* + β_3 IEK + ε_3

The statistical support for all three hypotheses supports and extends previous theory. Equally interesting, however, is that the results suggest other important trends. When comparing the hierarchical effects of adding the SEK, CEK and IEK variables in turn to the control model, the adjusted R^2 values increase and the magnitude and significance of the standardized beta coefficients increase. This indicates that IEK is more influential than either SEK or CEK on their own and suggests that integrating knowledge from both customer and supplier is the best approach. By extension, Model 2 – the integrated supply chain – is the most powerful model in terms of explaining inventory-related performance. It is also worth noting that CEK has a more influential and important effect on reducing inventory investment than SEK. This suggests that the direction from which knowledge comes in the supply chain might also be crucial.

6. Discussion

This research was conducted with three overall objectives. First, the study sought to empirically replicate the general notion that explicit knowledge inflows from outside the organization have a beneficial effect on that organization's performance. Second, the study aimed to add to existing literature through a finer-grained analysis of this external explicit knowledge. A specific objective of the study was to find out whether such explicit knowledge inflows from suppliers and customers in the external supply chain contributed to improved performance. Finally, consideration was given as to whether the existing literature could be expanded by ascertaining whether the richness of explicit knowledge depends on whether it comes from the upstream or downstream direction, or from an integrated supply chain. In accordance with knowledge management literature, explicit knowledge flows between supply chain partners have been characterized in terms of i) shared declarative knowledge elements related to inventory levels, production plans and delivery frequencies, and ii) shared procedural knowledge elements of coordinating, planning, and forecasting between supply chain partners and shared practices such as Kanban.

The support for all the stated hypotheses adds empirical weight to concepts found in the knowledge-based and supply chain management literatures outlined in previous sections of this essay. The empirical results lend support to the general notion that inflows of external explicit knowledge are beneficial to performance. More specifically, it would appear that particular explicit knowledge inflows emanating from upstream and downstream supply chain partners are beneficial in terms of the objective performance measure of inventory investment. Thus the first two objectives of this research have been met.

Regarding the third objective of this research, the results of the hierarchical regression indicate two possible new insights to the literature. First, when considered independently, explicit knowledge inflow from downstream appears to be more powerful in terms of reducing inventory investment than explicit knowledge inflow from upstream. Therefore, the direction from which a knowledge inflow emanates could be important. Second, the results indicate that, of all explicit knowledge inflows considered, the inflow from an integrated supply chain has the most powerful beneficial effects on inventory management. Thus, integrating explicit knowledge from both supplier and customer would appear to result in the richest explicit knowledge.

What theoretical mechanisms are behind these phenomena? The existing knowledge management literature cannot fully explain either, since it makes little direct comparisons between the richness of knowledge inflows from different directions. Possible explanations can be found in the supply chain literature though. One possible explanation of why knowledge inflow from the downstream customer side could be richer than that from upstream is provided by the "bullwhip effect" concept (Lee et al., 1997b), whereby demand variance is amplified when moving upstream in a supply chain setting similar to our conceptual model. Thus, useful ordering information from the customer could become distorted as it passes upstream. As Lee et al. (1997b) state: "distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies – excessive inventory investment." The empirical results indicate that explicit knowledge from upstream is less rich in helping to reduce inventory investment, which suggests that it might well be more distorted than knowledge from downstream. Hence the bullwhip effect might also be prevalent beyond the data/informational level at which it has been researched to date. In fact, the measures that Lee et al. (1997b) propose to counter the undesirable bullwhip effect (i.e., avoiding multiple demand forecast updates, breaking order batches, stabilizing prices, eliminating gaming in shortage situations) all require declarative explicit knowledge sharing and procedural explicit knowledge coordination with supply chain partners - in particular those providing explicit knowledge inflows from downstream.

Similarly, the work by Frohlich and Westbrook (2001) provide possible reasons as to why integrated explicit knowledge from supplier and customer could be the richest. Their work compared different supply chain strategies and demonstrated that the greatest degree (or 'arc') of integration was strongly associated with higher performance levels. They explained that better coordination in the supply chain reduces uncertainty throughout manufacturing networks and eliminates excessive inventory investment. Extending this explanation to the knowledge perspective of this research could explain why the explicit knowledge inflow from an integrated supply chain appears to be the richer in helping reduce inventory investment.

7. Theoretical Conclusions and Managerial Implications

While there are clear limitations relating to the lack of sophistication of findings and limited precision of conclusions that can be drawn from such an exploratory survey-based study, this investigation has identified relevant perspectives from the knowledge management literature that could prove valuable in extending the supply chain literature, from a focus on the exchange of assets, data and information, towards the integration and leverage of expertise and knowledge. In this regard, the investigation leads to three broad knowledge-based conclusions. First, the empirical results appear to support existing knowledge management and supply chain management theory in that inflows of declarative and procedural explicit knowledge from outside the organization apparently do have a beneficial effect on performance. More specifically, declarative and procedural explicit knowledge inflows from all of the considered supplier, customer and integrated supply chain partnership sources appear to have a beneficial effect on inventory investment reduction.

Second, the results suggest that there are directional implications as to which explicit knowledge inflows are most beneficial in reducing inventory investment. Explicit knowledge inflows emanating from downstream would appear to be more valuable in reducing inventory investment than those from upstream. This might be due to a "bullwhip effect," or similar phenomenon, resulting in distortion of upstream explicit knowledge.

Third, the richest inflow of declarative and procedural explicit knowledge seems to come from the integrated supply chain. The results suggest that this inflow, which integrates explicit knowledge from both suppliers and customers, is the most powerful in terms of reducing inventory investment. This is possibly due to a combination of reduced uncertainty and elimination of non-value adding activities, as a result of better overall supply chain coordination.

These findings potentially have some important implications for managerial theory and practice. In terms of theory, it might no longer be enough to consider a generalized approach to external explicit knowledge. The results indicate that all explicit knowledge outside the organization is not equal. Further research could continue combining knowledge-based and supply chain perspectives in further investigations of these potential inequalities. In addition, the implications of integrating explicit knowledge across supply chains could be more far reaching than the integration of data and information considered in the supply chain literature to date. Thus, continued knowledge-based research into supply chains is suggested as possibly offering new conceptual depth. Yet such increased depth might also pose challenges, especially when considering its application to research into increasingly complex supply chain mega-trends (e.g. 'adversarial to collaborative,' 'information hoarding to sharing,' etc.; Bowersox et al., 2000).

In terms of managerial implications, the results from this study indicate that, in real operational terms, benefits might result from explicit knowledge obtained outside the company, and specifically by integrating with supply chain partners. This study supports recent managerial literature, indicating that those companies that work together with their external supply chain partners could be the most likely to make significant operational performance improvements. While the results of this study suggest that external explicit knowledge inflows do improve operating characteristics of manufacturing companies, they go further in proposing that limited resources might be best focused in certain directions in order to maximize return on effort.

Ideally, if resources and competitive context permit, a manufacturer would share and coordinate explicit knowledge with both upstream and downstream supply chain partners. Working towards an integrated supply chain appears to be justified from a knowledge-based perspective. However, with limited resources, competitive implications, bargaining power losses and so forth, many practitioners might not be in a position to adopt this ideal option. Therefore, this refinement of existing knowledge provides some guidance as to where the most valuable explicit knowledge could potentially come from. The results indicate that, for manufacturing companies looking to reduce investment in inventory, knowledge-acquiring activities with downstream customer partnerships are potentially more likely to yield benefits, *ceteris paribus*, than similar activities with upstream supplier partnerships.

8. Future Research

Our findings suggest that the following areas of knowledge-based supply chain research might provide good opportunities for further investigation, and it is hoped that other researchers will be attracted to these areas.

1. This study draws on data from fabricated metal products, machinery and equipment manufacturers. There might be characteristics particular to these companies that do not apply to other operational sectors and contexts. For example, would these conclusions hold true in service supply chains? Context specific studies will potentially yield different results. Nevertheless, in conducting comparisons between different supply chain contexts, efforts will need to be made to ensure compatibility of empirical data.

2. The broad nature of the knowledge flow constructs in this study, while supporting and extending current supply chain and knowledge management literature, could perhaps be more precisely defined in terms of established knowledge related supply chain management constructs, such as "purchasing competence" (Narasimhan et al., 2001). Making use of such constructs might yield different insights.

3. Although this research proposes and uses inventory investment as a performance measure of explicit knowledge transfer, additional studies considering other additional performance measures could enhance current and future findings.

4. This study makes no mention of the routes companies have taken towards supply chain integration or the relative levels of evolution or maturity. Different experiences, methodologies and maturity levels are likely to have implications on the nature and extent of knowledge flows. Thus, interesting opportunities exist to compare the early adopters of supply chain knowledge and practices with the laggards. Perhaps the best areas for studying this are the newer supply chain contexts, such as services, where there is probably a greater spread in maturity than in relatively mature traditional manufacturing supply chain contexts.

5. While the "bullwhip effect" found in supply chain literature provides a strong theory for directional implications of information flow, very little work has been done to provide empirical evidence from a knowledge-based perspective. Confirmatory research to verify the bullwhip effect at the knowledge level would be useful.

6. Our research has focused on explicit knowledge transfer, yet we also recognize that future investigation of tacit knowledge mechanisms is also likely to be fruitful. For example, supply chain "collaboration" clearly goes beyond the pure sharing of data and information in explicit codified form towards the exchange of tacit knowledge elements, such as experience and know-how. Mechanisms for sharing tacit expertise and know-how could include the exchange of engineering personnel, joint training programs, combined research projects, etc.

7. The role of the internet in supply chain integration has been profound. Cagliano et al. (2005) state that "the efficiency of information transfer, the timeliness of information availability, [and] the openness and transparency of relevant business information are only a few of the benefits provided by the internet to support supply chain integration." They find a close empirical link between the use of internet tools and the level of integration with customers and suppliers. Further research of "virtual integration" and similar developments from a knowledge perspective is likely to add insights to the existing literature.

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