Retrieving and Transferring Embodied Data: Implications for the Management of Interdependence Within Organizations

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This research helps to link theories of sticky information with organizational design and governance. It suggests that information embodied in process material can allow downstream tasks to uncover information about upstream tasks. It shows that downstream operators can use this information to negotiate interdependence problems with upstream operators. Data presented in this article begin to uncover when such information retrieval and exchange occurs, and how managers can encourage it. Finally, the article discusses implications for theories of operational design and governance.
(*Information Transfer*; *Sticky Information*; *Organizational Design and Governance*; *Task Interdependence*; *Negotiated Solutions*)

Introduction

Past research in economics and operations management has emphasized the active role of managers and principals in mitigating problems caused by interdependent processes within firms. This article contends that the existing literature underestimates the potential for direct negotiation between agents responsible for these processes. Such negotiation is facilitated, the paper argues, by the ability of downstream agents to acquire information useful to upstream processes. These agents have this ability because information about upstream processes can become embodied in products and byproducts and thereby passed to downstream operations. If downstream agents retrieve this information, they can use it to barter for solutions to problems of interdependence.

This paper argues that downstream agents can retrieve embodied information because this information is less sticky in the context of the downstream task. The stickiness of information is a measure of the cost to retrieve and transfer information, and scholars now argue that this cost depends on numerous contextual factors (Arrow 1974, Kogut and Zander 1992, von Hippel 1994, Szulanski 1996). Recently, scholars have begun to argue that the stickiness of information may influence the locus of learning and the structure of organizations (von Hippel 1994, Szulanski 1996, Tyre and von Hippel 1997).

This article extends the existing empirical literature by showing that the "stickiness" of information may vary along a production process, thereby allowing downstream acquisition of information useful to upstream processes. It explores the conditions that affect the transfer and use of this information. Finally, it shows the transfer of this information can allow the direct negotiation of problems of interdependence, and that this negotiation may change the locus of learning and the structure of organizations.

This article also has import for several broad debates in management. It provides new perspective on the recent debate among advocates of conflicting theories of the firm on how firm structure encourages or discourages the transfer and use of information.

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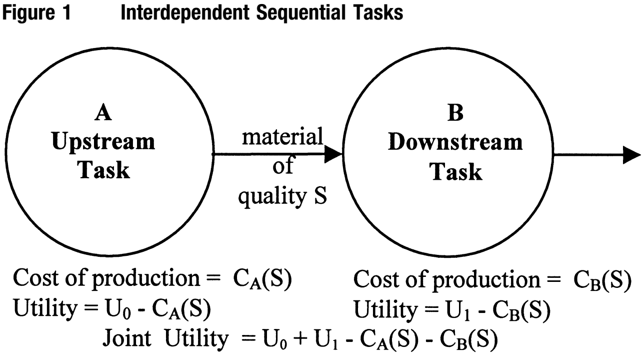
This research also suggests an amendment to organizational design theories that encourage the creation of independent tasks (Thompson 1967, von Hippel 1990, Hammer and Champy 1993). It proposes that in some case the negative effects of interdependence can be mitigated by increased extraction and transfer of embodied information.

The plan for this article is as follows. Since the article considers how sticky data might influence the governance of interdependent tasks, the paper begins with a review of governance issues. It then discusses how downstream agents could retrieve embodied sticky information and use this information to directly negotiate problems of interdependence. The article then presents a model that predicts (1) that such embodied data is retrieved by downstream agents, (2) when agents will extract and transfer this information, and (3) how this information will be used. It tests this model with qualitative and quantitative data from one segment of the electronics industry. Finally, it presents some implications of the research for the governance of interdependent tasks.

Review of Theory

Tasks can be interdependent in a number of ways. Commonly, tasks are sequentially interdependent—the output of one task is the input to the next. Such interdependence often causes problems of coordination or moral hazard (Thompson 1967, Galbraith 1977, Mas-Colell, et al. 1995). The simple model shown in Figure 1 illustrates this. The two tasks are sequentially connected, and the cost functions (C_A, C_B) of the two tasks both depend on the quality of the output of the upstream task (S). Principals desire that upstream agents produce the S^* that minimizes total cost, but upstream agents may seek to maximize their local benefit by skimping on quality ($U_A = U_0 - C_A(S)$). For example, at one automobile assembly plant, unloaders of car frames often failed to check if the vendor had installed a seat bolt. Such inspection required that the operators expend the effort to walk around each car frame as they unloaded it. Failure to conduct the inspection forced downstream seat installers to discover the problem, remove the car from the assembly line, tear up the newly installed car flooring, and install the missing seat bolt.

Figure 1 Interdependent Sequential Tasks



Managing Interdependence Within a Firm

Several means for managing organizations to reduce such costly coordination problems have been suggested, but each has limited applicability and each can be expensive.

Managers can invest in reduced interdependency. For example, they can invest in robust technology to make the downstream task independent of upstream actions (i.e., reduce $C_B(S)$). Alternatively, they can invest in a filter or buffer between the upstream and the downstream (Thompson 1967, Galbraith 1977). Economists and management scholars have long argued that managers should partition tasks to reduce interdependencies (minimize $C_B(S)$) (Thompson 1967, Eppinger et al. 1994; and for examples from economics see Barbier 1989). However, technology, the availability of data, the location of problem solving skills, and the potential for free-riding all may impede perfect partitioning (von Hippel 1994).

Managers can reduce moral hazard. Managers can specify standards of quality and penalize or reward workers based on conformance to these standards. In some cases, managers can use their power over technological decisions to prevent or restrict opportunistic behavior by agents (Grossman and Hart 1986). However, the managerial costs of such techniques may be great. There may be numerous criteria to consider, and the choice of technology or performance standards may be contingent on numerous local factors (Milgrom and Roberts 1990, McMillan 1992). Even within the firm it may be difficult to structure contracts that solve problems of interdependence and moral hazard (Williamson 1985, Milgrom and Roberts 1990, McMillan 1992).

Finally, managers can directly and dynamically control interdependent tasks. Indeed, theory suggests that firms occur in part because it is difficult to make contracts that cover all contingencies, and thus a principal is required who can determine and direct the action of agents as unforeseen conditions arise (Grossman and Hart 1986, Williamson and Winter 1991). However, directly controlling action often requires expenditure of expensive managerial labor.

Unmanaged Negotiation of Solutions to Interdependence

Given that managing solutions to problems of interdependence can be difficult and costly, can the problem be solved directly by the agents? Indeed it can, Galbraith (1977) argues, if managers (1) reward collaborative behavior, (2) use the "the vertical process" to support direct negotiations, and (3) provide mechanisms to integrate and manage direct negotiation. More generally, Coase (1960) argues that direct negotiation to solve the problem does not require active support or direction by a governing authority. His analysis suggests that regardless of how task rights and responsibilities are initially allocated, agents in charge of interdependent tasks can bargain to their mutual benefit (and to the benefit of the firm), *so long as bargaining costs are low*.

Although firms may exist in part to allow better management of interdependence, negotiation among agents within a firm can still be costly. Bargaining within a firm is often impeded by rules against side payments and subcontracts; that is, operators of downstream tasks may have no way to pay for changes in upstream behavior. The management rights doctrine stipulates that unless otherwise restricted, management maintains the right to direct the work (Masten 1991). Unless explicitly allowed, subcontracts and side payments among employees are superseded and invalidated by the employment contract (Williston 1990). Even if side payments are expressly allowed, different perspectives and cognitive frames may cause employers to challenge agreements among employees (Arrow 1974, Dunbar et al. 1996). It is precisely because managers and scholars have expected direct negotiations to fail that they have given so much thought to the problem of how to *design* and *mandate* solutions to the problem of interdependency.

Information Trading as a Means of Facilitating Unmanaged Negotiation

One way that the downstream could negotiate with the upstream is by providing useful information as payment for beneficial changes in behavior. Previous analysis has neglected this possibility because it assumes that operators can best gather information about their own task. Thus, downstream operators have no practical way of gathering information about ways to improve upstream performance relative to existing criteria (e.g. improved quality or efficiency). For example, a sales force may be able to efficiently learn about changing patterns of customer demand and become more adept at selling any product that manufacturing produces, but has no advantage in learning about ways to reduce the cost of manufacturing.

Previous research suggests that the cost of information extraction can depend on local context, and that the best context is not always collocated with the site where the task is performed (von Hippel 1994). Information that is expensive to extract in one location can be almost free in another location (Rosenberg 1982, Tyre and von Hippel 1997, von Hippel and Tyre 1995). In sequential tasks, material produced by the upstream often carries information in embodied form to the downstream task. Machined parts, for example, may contain information about tool wear on milling machines. Depending on the nature of the downstream task, it may be easier to extract this information at the downstream. Other examples where downstream activities allow the efficient extraction of information about upstream tasks include packing a product into form fitted molds, polishing a surface may make it easier to see surface texture anomalies, assembly may reveal missing parts or damaged attachments, and waste-treatment may reveal unusual waste elements.

A strictly rational model of information extraction demonstrates why some information useful to upstream processes may be extracted elsewhere. Suppose that, holding the quality of the output (S) fixed, efficiently operating the upstream process (A) requires some set of information, and that the cost to acquire this information varies, as does its benefit. For example, data about input factors (water, oil, etc.) might be easy to acquire, but other operational parameters (vibration, etc.) might be more difficult to measure. Even if we assume that agents accurately estimate the cost and benefit of acquiring data, some useful information would *not* be acquired because the marginal cost of extracting it would be greater than its marginal usefulness. This missed information is too "sticky" to be acquired at A. At a downstream process (B), new technology and further processing may change the *marginal* cost of retrieving embodied information or alter the marginal benefit of such data. Moreover, if agents optimize independently, and agents at process B have different costs and benefits for acquiring and using data, agents at B will retrieve some embodied data.

I propose that downstream agents sometimes acquire information about upstream tasks, and that the retrieval of this embodied sticky information provides a means for downstream agents to negotiate mutually beneficial changes with upstream agents. Downstream agents may simply provide the information to the upstream in the knowledge that improved upstream processes will result in improved downstream performance. For example, they might inform upstream processes of leaking oil to avoid the cost of removing this oil prior to processing at B. Alternatively, they may provide useful information in the hope that the upstream will so value this information assistance that they will be willing to make unrelated changes in order to maintain the flow of information.

Research Questions and Hypotheses

This article proposes that agents in charge of downstream tasks that are interdependent with upstream ones may be able to retrieve useful information about upstream tasks and use this information to negotiate beneficial changes to organizational technology and tasks. In this research, I seek to discover if agents at downstream processes retrieve and transfer embodied sticky information; does the transfer of embodied data match predictions from theories of sticky information; and do changes to the organization result from the transfer of embodied information?

(1) *Do agents at downstream processes retrieve and transfer embodied information*?

Embodied information will be more useful in negotiating changes if agents at both the upstream and downstream recognize that such information retrieval occurs. Thus, I *first seek to find out if agents recognize that information useful to improving upstream processes is retrieved at downstream tasks*.

(2) *Does the transfer of embodied data match predictions from theories of sticky data*?

The concept of sticky information is inherently an issue of the cost and benefit of information acquisition and transfer. von Hippel (1994) has emphasized the cost of acquiring and transferring information, but has not centrally considered the motivation of the transferring or receiving party. Szulanski (1996), on the other hand, has added issues of incentives and benefits to the theory of sticky data. Szulanski also argues that theories of information transfer between two parties should include both bilateral and contextual issues. The discussion below first presents bilateral costs and benefits, and then concludes with a brief review of rival contextual hypotheses.

Marginal Cost of Retrieving Embodied Data. Theory suggests that technology and the design of the processes influence the cost of data acquisition. Zuboff (1984) for example, maintains that information technology can help (or impede) acquisition of information about a system. Adler and Borys (1996) argue that equipment and procedures influence the "transparency" of both local tasks and more global issues. Likewise, technology and process design can influence the cost of retrieving embodied information. Some downstream processes respond sensitively to upstream process change and therefore make information about the upstream more visible. For example, in the process of making steel, Wheeling-Pittsburgh Steel Company produced coal gas and vented it to the air. For regulatory reasons, the company switched to burning the material in a flare. The large flare made it obvious when the coal gas was produced, and workers quickly invented ways to reduce or use the gas. After six months of using the flare, coal gas emissions were reduced by 90%.

Technology and the task design also influences the "causal ambiguity" of embodied data. Szulanski (1996, 30) argues, for example, that the stickiness of information is related to "ambiguity about what the factors of production are and how they interact during production." This is particularly relevant to downstream retrieval of embodied data. For example, mixing or storing material before processing obscures change (Sterman 1989).

Thus, the first hypothesis is:

HYPOTHESIS 1. *The more the downstream process is sensitive to or reveals upstream process variation, the more frequently agents at the downstream will retrieve and transfer useful information to the upstream process.*

The knowledge of the downstream observer will also affect the cost of retrieving embodied information. Just as an observer's knowledge affects the equivocality of messages (Daft and Lengel 1986), observers of a process can retrieve information only if they understand the source of a signal and the implication of this signal. They must have the "absorptive capacity" to understand and assimilate the signals that they see (Cohen and Levinthal 1990). For example, a trained auto mechanic can acquire information from the sound of an auto engine (e.g. the sound of a slipping generator belt) because he knows where the sound originates and what it means. Likewise, knowledge of the production process should help personnel better match signals with their source and help them distinguish important signals from unimportant ones.

HYPOTHESIS 2. *The more downstream observers have knowledge of upstream processes, the more frequently they will retrieve and transfer useful information to upstream processes.*

The Cost of Information Transfer. Clearly, the likelihood of transfer of all types of information (retrieved from embodied data or not) decreases with the cost of transfer. Theory suggests that "shared coding schemes" and a shared language that facilitates communication can increase information transfer (Kogut and Zander 1992). This provides an alternative logic and explanation for Hypothesis 2. Theory also suggests that information channels and costs influence the extent of transfer of technical information. Technical information is often complex and ambiguous and thus requires a high bandwidth communication channel (Allen 1977, Allen et al. 1980, Daft and Lengel 1986). Szulanski (1996, p. 32) argues that "a transfer of knowledge, especially when the knowledge transferred has tacit components, may require numerous individual exchanges," and that thus "the ease of communication depends on the 'intimacy' of the overall relationship." Thus, I expect communication between upstream and downstream to occur predominantly in face-to-face discussions, and the cost of information transfer between the two tasks to depend on their relative physical proximity (Allen 1977).

HYPOTHESIS 3. *The greater the physical distance between the upstream and downstream, the less frequently downstream agents retrieve and transfer useful information.*

Theory and empirical studies show that integrating structures can also influence the cost of information transfer (Galbraith 1973). To facilitate communication, organizations often create integrating structures such as teams and task forces (Galbraith 1973). Thus, if personnel from the upstream and downstream process have scheduled forums in which they meet, one should expect a lower cost of transferring information and negotiating process changes.

HYPOTHESIS 4. *If upstream and downstream managers are jointly members of integrating structures, downstream agents will more frequently retrieve and transfer useful information to upstream agents.*

Incentives. Theory suggests that motivation of both the upstream and the downstream can influence the extent of information transfer (Szulanski 1996). Many scholars have suggested that management-created rewards can encourage personnel to share information (Womack et al. 1990, Adler and Borys 1996). But what should these rewards be? Rewards to improve the collective performance of the plant might encourage greater exchange of information and innovation by encouraging agents to consider the welfare of others. On the other hand, rewards to improve local performance can also encourage transfer (Coase 1960).

As discussed earlier, agents at the downstream process often benefit from upstream process improvements; thus, even if they are only rewarded for the performance of the downstream process they might still pass useful information to upstream agents. Likewise, even if the agents at the upstream are only concerned with their local performance, they should readily accept useful information provided by the downstream. Indeed, rewarding agents based only on local performance represents a clear distribution of property rights and responsibilities, and thus might help prevent shirking and free riding. Thus, the literature suggests two conflicting hypotheses.

HYPOTHESIS 5a. *Rewards to improve* **collective** *performance will increase the rate of downstream information retrieval and transfer*.

HYPOTHESIS 5b. *Rewards to improve* **local** *performance will increase the rate of downstream information retrieval and transfer*.

Downstream agents will transfer more information to the upstream if that is the best way to benefit from that information. The more agents at the downstream can appropriate some of the benefit of information without exchanging that information, the less they will transfer. For example, if downstream agents have extensive capital resources they may choose to purchase technology (such as a filter) that solves the problem at the downstream. If a lack of resources constrains them from making such changes, they will seek to change the upstream by passing information.

HYPOTHESIS 6. *The fewer the capital resources available to the downstream, the more frequently agents at the downstream will retrieve and transfer useful information to the upstream*.

The organizational context could also influence information transfer from downstream to upstream (Adler and Borys 1996, Szulanski 1996). For example, the degree of technical sophistication in the organization might influence the extent to which downstream agents retrieve embodied information. Operations strategy decisions such as production lot sizes and product complexity might also influence information acquisition. Older production operations might have less need for information transfer. Total quality management programs, worker training courses, and a general culture of communication might also influence information flow. In my study, I included these contextual measures as controls.

(3) *Do tasks and processes change as a result of retrieved embodied information*?

As discussed earlier, my analysis predicts that downstream operators will initiate changes that improve upstream operations. Because they have unique information, they will help negotiate changes to the production process that benefit both parties and will be perceived not as regulators of upstream behavior but as sources of information. They will negotiate changes to upstream processes that will help improve the upstream and the downstream relative to their local objectives.

My analysis predicts that the two agents will negotiate changes in the organization of tasks. One potential repartitioning is to make the upstream more responsible for acquiring information. Another is to give downstream agents problem solving roles in upstream activities.

Research Design

This study creates a difficult challenge to research design because it theorizes about the source, transmission, and impact of information. In general, it is hard to track information of a particular pedigree through the organization to its end use (Allen 1977). Those individuals that are transferring or using the information generally know from whom they received it, but not how it was originally obtained. The source of the information may be able to explain how the information was obtained, but cannot usually tell whether such information has been transferred or how it has been used. Therefore, I chose to use multiple methods to provide windows onto the acquisition, transferal, and use of embodied data. I interviewed the hypothesized source of the information (downstream personnel) to see if they retrieve embodied data. I used a survey to track information patterns to see if these correspond with those hypothesized for embodied data. Finally, I tracked innovations and changes in task partitioning to understand the importance of the transfer of embodied information.

Industry

The printed circuit (or printed wiring board) industry is an excellent domain in which to explore embodied data in sequential tasks. The production process involves sequential operations, and the structure of the industry allows comparison of similar production facilities. Most firms operate a single facility and use similar organizational structures and process technology to produce commodity products.

In the printed wiring board (PWB) industry, I chose to investigate information transfer between two sequential tasks: the wet production process (upstream) and pollution control (downstream). Wet production is the central operation in making printed circuits. During this process, patterns of metal are etched and plated onto laminate material. Managers of this operation are usually called wet process engineers or wet process engineering (WPE) managers. The wet production process emits heavy metals, acids, and carcinogenic cleaners. As a result, in the last decade all facilities in the U.S. and Canada have added a downstream production process to treat the waste water and spent material. Because the production process for making printed circuits is relatively mature, the technology and processes used in wet production are quite standardized. In contrast, the process for treating waste is quite new, and so great variance exists in waste-treatment processes.

Data Collection

To better understand how embodied data influences problem solving, innovation, and task-partitioning, I performed case studies of eight manufacturers of rigid multilayer printed circuits. To gather a sample of process changes, I conducted a written survey of wet process engineering managers in these eight firms. Each manager was asked to (1) identify the "five most important process changes," (2) rate the importance of each department in initiating these changes (e.g., process engineering, production, quality, pollution control, etc.), and (3) indicate the effect of each process (relative to production cost, product quality, pollution-control, and production capabilities). For each process change initiated by pollution control staff, I interviewed the person who had reported the change, and those persons who were reported to have initiated it. Respondents to the surveys reported an additional five process changes during the interviews. To further understand the origin and history of these innovations, I interviewed top executives and process-engineering, quality, and pollution control managers in all eight facilities. In all eight facilities, I interviewed at least two managers engaged in process engineering and two of the pollution control staff.

To test the model of information acquisition and transfer, I conducted a written survey of printed circuit fabrication facilities. To make sure that all of the facilities in the sample make similar products and byproducts, I restricted the population to U.S. and Canadian manufacturers of exclusively rigid, multilayer printed-circuit boards who were members of the Institute for Electronic Packaging and Interconnecting (a total of 88 facilities). I sent surveys to managers of wet process-engineering (WPE) and pollution-control (PC) and received surveys from both managers from 38 facilities. Two facilities proved to produce numerous non-PWB products, and were removed from the sample. Two others had fewer than 50 employees and had no personnel assigned permanently to pollution control or process engineering. The remaining 34 firms match the general characteristics of the population in sales, employees, mean production lot size, and product sophistication (measured as minimum line thickness). I asked wet process engineering managers to estimate the frequency with which they received information that helped them to improve the production process. I measured numerous variables to test the model and to control for plausible rival hypotheses. (See Table 1 for the Measurement or Construction of Variables.) Drafts of the questionnaire were reviewed by two local PWB experts, six PWB executives, and with two members of the staff at the Institute for Electronic Packaging and Interconnecting (IPC). Piloting with local PWB personnel demonstrated that the measures were well and consistently understood.

Measurement of Constructs and Variables

Measurement of the variables and constructs involved several different methods. For example, the complexity of the waste treatment systems required the use of technical experts in creating a measure of downstream sensitivity. The degree to which rewards were local or

Table 1 Measurement of Variables

Construct	Variable	Measurement or Construction
	Dependent Variables	
Rate of retrieval and transfer of information useful to the upstream process.	Frequency PC personnel provide information useful to improving production process	Wet process engineering managers' reports of how often personnel from pollution-control gave information that, "will help you to improve the wet production process" (7-point frequency scale)
	Independent Variables	
Cost of Information Retrieval		
Degree to which the downstream process is sensitive to or reveals variance at the upstream	Waste treatment technology sensitivity	Rating of waste-treatment system sensitivity based on survey descriptions of technology received from pollution-control manager (scoring system compiled by two industry experts)
Downstream agent's knowledge of upstream process	PC Background and PC Education	Dummy variables (1 for previous work experience in wet-process) and (1 for college education in engineering or chemistry)
Incentives		
Rewards (Local over Global)	Degree to which management rewards local or global performance improvement	5 point Likert scales of the importance of six areas in job performance evaluations.
Access to capital to solve problem independently at D.S.	Access to capital at WPE as opposed to PC	Subjective analysis of PC & WPE managers to hypothetical scenario in which they compete for project funding ($25 K) for projects with equivalent cost and return (6 point scale)*
Transfer Costs		
Distance between U.S. and D.S. agents	Distance between WPE and PC managers' offices	Log of average of PC and WPE manager's report of distance between their offices
Integrating structures	PC and WPE jointly on a team	Either the PC or WPE Manager report being a member of team or task force with the complementary manager.
	Control Variables	
Just in time production	Production lot size	Log of average lot size used in production system
Extent of product and process instrumentation	Use of sophisticated automatic inspection equipment (AOI)	Sum of percentage of boards inspected by automated equipment at 5 stages of production process. (CAD, Artwork, Inner Layer, Outer Layer, Verify Station).
Product sophistication	Products with dense patterns of circuits	Finest line thickness the facility produces in products
Facility Age	Date of plant construction	Log year since facility constructed
Facility Size	Number of Employees	Log of number of employees in the plant including management staff and workers
Quality program intensity	Scope of quality program	Extent of training provided with Quality program in six possible training areas. SPC Training for 1) Production Staff, 2) Technical Staff, 3) Managers. TQM Training for 4) Production Staff, 5) Technical Staff, 6) Managers.
Age of quality program	Quality program age	Log of Time any quality program has existed at company
Training	Training time	Total hours spent "receiving training or educational support"

Note: D.S. = down stream, U.S. = upstream.

* The exact wording of the question was: "You propose to buy a piece of equipment. At the same time, the ⟨other⟩ manager proposes to buy a different piece of equipment. Both proposals have the same cost and payback. Your company can not afford to buy both. Who is more likely to receive the funds?" 6 point Likert scale.

global was measured using multiple questions about rewards. Other constructs were measured by physical attributes (distance, age, lot size, and so on). Table 1 lists each construct discussed in the hypotheses, and lists how each was operationalized into a variable and how the variable was constructed or measured. Table 2 provides information on the mean, standard deviation of each variable, and correlations among them.

The measurement of technology, operations, and rewards required more complex construction than can

Table 2 Mean, Standard Deviation, and Correlation of Variables Used in Regression Analysis

	$\bar{X}$ (s)	Sens.	PC Ed.	PC Bkgd	Dist.	Team	Incnt WPE	Incnt PC	Cap. WPE	Cap. PC	AOI Use	Lot Size	Min. Line	Age	Emp. Num.	Scop Qual.	Qual. Age	Train	Com. Qual
Treatment Sensitivity	3.9 (2.8)	1.00																	
PC Process Relevant Education (0 or 1)	0.57 (0.46)	0.25	1.00																
PC Process Relevant Background (0 or 1)	0.46 (0.45)	−0.03	0.07	1.00															
Distance (log yards)	3.79 (1.2)	−0.10	−0.10	0.01	1.00														
Jointly on Teams	0.65 (0.49)	0.19	0.02	0.08	0.07	1.00													
Promotion Incentives WPE	−0.79 (1.3)	−0.49**	0.00	0.23	0.00	−0.22	1.00												
Promotion Incentives PC	0.25 (1.4)	0.00	−0.17	−0.12	0.06	0.08	−0.02	1.00											
Access to Capital (reported by WPE)	3.2 (1.4)	0.02	0.00	−0.20	−0.09	−0.07	−0.26	−0.06	1.00										
Access to Capital (reported by PC)	2.4 (1.1)	−0.05	−0.05	−0.10	−0.26	−0.22	0.09	0.20	0.07	1.00									
AOI Usage	3.3 (1.5)	−0.09	−0.42*	−0.12	0.33	−0.10	−0.12	0.45**	−0.07	0.15	1.00								
Production Lot Size (log)	3.5 (0.72)	−0.45**	−0.02	0.07	0.01	−0.26	0.44**	−0.09	0.05	0.24	0.09	1.00							
Minimum Line Thickness	4.3 (1.4)	−0.10	0.41*	−0.29	−0.27	−0.08	0.12	−0.26	−0.03	0.22	−0.40*	0.24	1.00						
Log Age of Plant	2.8 (0.47)	−0.02	−0.20	0.19	0.33	0.14	−0.06	0.10	−0.15	0.04	0.08	0.14	0.19	1.00					
Number of Employees	223 (183)	−0.04	−0.39*	−0.02	0.36	−0.05	−0.24	−0.12	−0.06	0.19	0.25	0.06	−0.04	0.25	1.00				
Scope of Quality Program	4.3 (1.6)	−0.06	0.10	0.22	0.18	−0.13	0.02	−0.22	0.11	0.12	0.23	−0.04	−0.24	−0.02	0.14	1.00			
Quality Program Age	5.9 (4.8)	−0.29	−0.19	0.00	0.15	−0.27	0.02	0.04	−0.02	−0.13	0.11	0.02	−0.22	−0.03	0.13	0.00	1.00		
Time spent in training programs (PC and PE)	32.4 (20.8)	0.05	−0.01	0.03	0.38*	0.09	−0.20	0.01	0.19	0.05	0.29	−0.15	−0.11	0.30	0.24	0.14	0.21	1.00	
Hrs. Talking w/Quality	5.0 (4.6)	0.05	0.32	0.09	0.11	−0.15	0.00	−0.16	−0.10	0.05	−0.03	−0.03	0.05	−0.10	0.05	0.01	−0.01	−0.03	1.00

Pairwise significance: * $p < 0.05$, ** $p < 0.01$.

be fully presented in the table. Below, I provide additional information on these variables.

Downstream (Waste Treatment) Sensitivity. During the case studies, PC personnel reported that there were three types of equipment in the industry: (1) ion exchange and reverse osmosis, (2) advanced clarification systems, and (3) simpler clarification systems. The main difference between the last two categories was the use of sensitive or more robust treatment chemistries. For example, one chemical system, borohydrate, has a reputation for being "twitchy," while another, ferrous sulfate, is jokingly called the "American" system since all problems can be solved just by adding more.

Since some of the survey respondents used combined systems (ion exchange on one stream and a clarifier with ferrous sulfate on another), two experts in the industry were asked to read the descriptions and place the descriptions into ten bins (numbered 1 to 10) set up on a table. The two respondents agreed in their rank ordering but could not rank all of the systems because each was unfamiliar with some of the chemicals or systems used by some of the companies. Working together, however, they had experience with all of the systems and could completely rank the companies into the ten bins. This allowed the gradations between the three classes to be filled in.

Interestingly, trichotimizing the systems into the three types first suggested during my case studies does not reduce the explanatory power of the model. However, for parsimony and to aid in discussion, I have used the continuous variable in presenting the findings.

Extent of Product and Process Instrumentation (AOI). Any measure of waste treatment sensitivity could be a proxy for the level of information acquisition in the facility. To make sure that this is not the case, I measured the degree to which companies employ an important form of product and process measurement technology—Automatic Optical Inspection Equipment. The AOI measure asks for the percentage of production that uses automatic inspection at 5 likely stages of production. The measure goes from 0 to 5 ($\bar{x} = 3.3$, $s = 1.5$). As expected, this AOI measure is correlated with the line thickness ($\rho = -0.4$) and with the number of layers in the board ($\rho = 0.5$). Companies that make finer and more layered boards must do more inspection.

Quality Program Scope. Since waste equipment technology and processes might be the outcome of other waste reduction efforts in the company, I measured the scope of the quality program. At the suggestion of the Institute for Electronic Interconnecting and Packaging (IPC) I measured the extent to which the quality program includes TQM and SPC training for Managers, Technical Staff and Production Staff. Since each can vary from 0 to 100%, the cumulative measure runs from 0 to 6 ($\bar{x} = 4.3$, $s = 1.6$).

Rewards. To capture the extent to which the agents are given rewards for local or global performance by their superiors, respondents were asked to: "rate the following five areas in terms of their importance in how your superiors evaluate your performance." The five areas were: (a) "your performance on teams," (b) "your ability to work with the Quality Department," c) "your ability to work with the ⟨PC or WPE⟩ Department," (d) "performance of the ⟨PC or WPE⟩ process," and (e) "your role in making the plant perform better."

For both managers the questions seem to be measuring two constructs—one that measures incentives to improve local or global performance, and a second that seems to measure direct incentives to work with the reciprocal parties.* I have reported regression analysis for Factor 1, but to check the reliability of my findings, I ran regressions with the second less reliable factor, and with each

* For WPE managers, the Factor 1 loadings were: work with the Quality Department (0.78), local department performance (−0.80), and plant performance (0.68). For the PC managers, the Factor 1 loadings were: working with quality department (0.87), and plant performance (0.83). The Factor 2 loadings were in order for the two managers: performance on teams (0.54, 0.59), and work with ⟨PC or PE⟩ (−0.87, −0.92). Chronbach's alphas were as follows: WPE($factor_1$: 0.69, $factor_2$: 0.53), PC($factor_1$: 0.73, $factor_2$: 0.47).

variable. None provided significant explanatory power.

Findings

This section presents analysis of the research questions and hypotheses. It first establishes that embodied data is retrieved by pollution control personnel. It then tests the hypothesized patterns of information transfer. Finally, it tracks the source of innovations in the upstream process to investigate the impact of retrieved and transferred embodied information.

PC Reports Retrieving Embodied Information

All the pollution control (PC) managers recognized that process waste could be used to diagnose problems in the upstream process. Most commonly, PC personnel told me that if the water in the treatment process turned blue it meant that chelate copper was leaking from a particular production step. In some firms, I found evidence that production personnel perceived PC personnel to be a source of information. Several times, during an interview of a pollution-control manager, someone from production or process engineering would interrupt to ask for some information. For example, during one interview the process engineering manager asked the pollution control manager how many chemical additions occurred during the second shift. Because PC personnel were concerned that waste water flows increased after such additions, they had begun to gather these data. Quality and WPE personnel focused almost exclusively on the yield on "laminate layers," and as a result had overlooked information about yield on water, chemicals, copper anodes, and other inputs to the process.

PC personnel believed that they had an incentive to improve the production process. Managers of the PC departments claimed that they could improve their own performance by improving the production process. For instance, one PC manager argued that "almost anything that I can do to help the production process helps me [to treat waste]." Another told us that "the more I can get the process under control, the better I can reduce waste treatment."

The interviews uncovered numerous examples where the retrieval of embodied information led to an important process change. My research uncovered 18 important changes to the production process that had been initiated by pollution control personnel (see Table 3). By interviewing personnel involved in each innovation, I found evidence in 13 that embodied data had been retrieved and used in making the innovation.[1] For example, pollution control personnel noticed excessive ammonia in the waste stream and tracked it to a production problem. In another example, PC engineers noticed that they frequently received stacks of circuit-boards that had been etched and plated but not electrically tested (Table 3, Innovation 2). PC personnel thought it curious that boards were discarded after partial processing and before electrical testing. They investigated and found that the plating operation performed best when the hoist contained a full load of boards. To ensure the best performance, production workers padded the end of production jobs to guarantee a full load. Extra boards were then discarded. PC and process engineering personnel designed a system of reusable dummy boards. As a result, the firm avoided discarding 5,000 boards per year (an estimated value of $50,000 or 0.5% of sales).

In five cases, other information sources provided pollution control personnel with information that led to the innovation. For example, vendors suggested changes to the technology and operation of one stage in creating the circuit (Tin Masking).

Information Transfer

The analysis presented below suggest that bilateral issues influence the degree to which (in the opinion of the WPE manager) useful information is transferred to him by environmental personnel. The cost of information transfer (as captured by the distance between the communicating parties, and their joint participation on teams) and the degree to which the WPE manager perceived himself to have greater access to resources influenced the extent of information transfer. Importantly, the sensitivity of the treatment equipment added significant power to the model—suggesting that a substantial component of the transferred infor-

[1] In one case, the person most involved was severely ill and so I could not make a determination.

Table 3 PC Innovations from Facilities in Case Studies

Description of Innovation	History of Innovation	Retrieved Embodied Data Used	Benefits				Tasks Changed
1*) Changed process bath maintenance system	PC notices waste from scheduled maintenance of production baths and traces it to out of date maintenance procedures.	Yes	Q	C		P	P
2) Use of electroplating blanks	PC notices pattern in disposal of circuit-boards and identifies problem in handling of production lots.	Yes	Q	C	R	P	
3*) Change in copper anode enclosure	PC notices copper anode waste and traces problem to container system.	Yes		C			
4) Chemical Dumper Process Change	PC notices that schedule dumping requires extra labor and more treatment, and suggests new method.	Yes		C		P	P
5*) Water Reduction	Combination of efforts. PC notices high water use and tries to reduce water use to a) reduce costs and b) expose problems.	Yes		C		P	
6) Computerized chemical change-ordering system	PC notices waste from poor coordination between laboratory and production technicians.	Yes	Q	C		P	S & P
7*) Water Quality Change	PC notice that incoming water often has impurities that need pretreatment and suggest a new source and system.	Yes	Q	C		P	S
8) Water Usage Change	PC notices high water usage and recommends changed cleaning procedures. Reduced flow then exposed more problems.	Yes		C		P	
9) Water Meters	PC notices problems from valves that were inadvertently left on, and places meters to warn of unexpected flow.	Yes		C	R	P	S
10) Flow Valves	Similar to above, accept valves used to prevent excessive flow.	Yes	Q	C		P	S
11) Hydro-etch change	PC notices variance in effluent and encourages a change in control system.	Yes	Q	C		P	
12*) New sensor for Ammonium Hydroxide on etching line.	PC notices large amounts of AH in waste and tracks it to miscalibrated sensor.	Yes	Q	C		P	S
13) Etchant Chemical Change	PC and WPE both notice problems (numerous chemical adds and changes in effluent.) caused by poor vendor material.	Yes	Q	C		P	
14) Waste Treatment Change	PE decides to change to a more sensitive treatment process (DTC)	No				P	
15) Tin Bath Change	Combination of instigators PC wishes to reduce Pb usage. Customer wants better mask.	No		C		P	
16) Solder Mask Equipment Change	Vendor suggest new technology to WPE and PC who both implement it.	No	Q	C	R		
17) Permanganate Desmear Change	PC initiates change to reduce use of sulfuric acid and hexavalent chlorine.	No	Q	C	R		
18) Electroless Deposition Change	Unknown	?	Q	C	R	P	
Total $N = 18$		13 yes	11	17	5	15	7

* Innovation communicated during interview, not by survey. S: new sensing responsibility for wet-process. P: new problem solving responsibilities for pollution control. C: cost improvement to wet-process. Q: quality improvement, R: range of capabilities increased, P: pollution control improved.

mation came from the retrieval of embodied information.

Of course, with only 34 data points one must be cautious in forming conclusions. These data do not provide enough degrees of freedom to test simultaneously all the model and control variables. Instead, I used a series of regressions to test the model and the significance of each control (See Table 4). Model 1 is the fully specified model and includes the one significant control variable. In Model 2, I removed all nonsignificant variables. Model 3 through Model 9 demonstrate that including other variables neither improves nor greatly weakens the significance of the variables used in Model 2. Model 10 shows that removing the one significant control variable weakens the explanatory power of the model, but does not diminish the importance of treatment sensitivity or access to resources. Although not shown, a model constructed exclusively of all the control variables has an adjusted R^2 of 0.00 and an F statistic of 0.81.

Acquisition Costs Influence the Rate of Retrieval and Transfer. As predicted by Hypothesis 1, PC personnel who used more sensitive equipment more frequently passed information to wet process engineers. In Model 2, this variable accounts for about 13% of the total variance, and alone this variable will explain 16% of the total variance. The variable remains statistically significant in all of the models. Thus, these data suggest that technology influences the cost of retrieving embodied data, and that this in turn influences the extent to which data is retrieved at the downstream. It also suggests that such embodied data represent a significant part of the useful information communicated to upstream tasks.

On the other hand, the data provide no evidence to support Hypothesis 2. Neither the formal education of the pollution-control manager nor his previous experience in a production job provided any additional explanatory power (see Models 1 and 3). Perhaps this is because, as some of the interviewed managers suggested, backgrounds that are too similar encourage competition between WPE and PC personnel and tend to discourage cooperative exchange of information.[2] Such competition could have mitigated the improved ability of downstream agents to retrieve and transfer information.

Lower Costs of Transfer Encourages More Transfer. The data support Hypothesis 3: Physical distance seems to decrease the frequency with which PC personnel pass helpful information to the wet process engineering manager. Indeed, since the regressions used the log of distance, these data suggest that a change of a few yards of distance would greatly influence the transfer of information when the parties are relatively close together. When farther apart, however, this same change would have less of an effect. Thus, the data seem to suggest that "intimacy" is indeed important to upstream information transfer. Likewise, the data weakly support Hypothesis 4: Joint participation on teams and task forces seem to support communication of useful information.

Incentives to Encourage Acquisition and Transfer of Information. The data do not support either Hypothesis 5a or Hypothesis 5b: Incentives to improve plant performance or cooperate with other departments did not add explanatory power to the model. Models 1 and 4 show that the principle constructs from the two scales (reward for local performance relative to reward for plant performance) did not add explanatory power to the regression. The less reliable second factors also did not add explanatory power, nor did any of the individual variables used in the scales. Thus, the data provide no evidence that management rewards (to encourage either local or global performance improvement) significantly influenced the acquisition and transfer of information.

Access to Resources Influences the Rate of Acquisition and Transfer. The data partially support Hypothesis 6. WPE managers reported that they more often received useful information from PC personnel when pollution-control had relatively less access to monetary resources from top management. However, PC managers' reports of their access to resources did not corroborate this finding. In fact, PC and WPE personnel differed extensively in their perception of their relative access to resources. On the basis of interviews in several companies, I believe this disagreement results from differing perceptions about power and roles in the organization. PC personnel believe that they have great access to resources when these resources are needed to maintain compliance with legal codes.

It is also possible that WPE managers more frequently perceive information from PC departments to be helpful when they believe that PC departments pose less of a threat to their own ability to access funds. Alternatively, if they think PC managers could have solved the problem independently, they may distrust the intentions of the PC personnel and thus perceive transferred information to be less useful. Thus, the relative access to capital may influence not

[2] It is also possible that the education and professional background of the PC manager didn't fully capture the skills of the PC department. We only measured the background of the PC manager, and his education would not influence information transferred by other PC workers.

Table 4 Predicting the Rate of Acquisition and Transfer of Embodied Information

Dependent Variable: Frequency with Which Pollution-Control Personnel Provide Information to the Wet Process Engineering Manager That Improves the Production Process

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10
					Model Variables					
Constant	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**	0.00**
	(1.7)	(1.3)	(1.5)	(1.4)	(1.3)	(2.3)	(1.4)	(1.5)	(1.3)	(1.2)
Treatment Sensitivity	0.37*	0.37**	0.33*	0.39*	0.36**	0.37*	0.36**	0.36*	0.35*	0.35*
	(0.12)	(0.09)	(0.10)	(0.11)	(0.09)	(0.11)	(0.09)	(0.10)	(0.09)	(0.09)
PC Process Relevant Education (0 or 1)	−0.15		−0.11							
	(0.60)		(0.58)							
PC Process Relevant Background (0 or 1)	0.14		0.14							
	(0.67)		(0.66)							
Distance	−0.40*	−0.32*	−0.33*	−0.33†	−0.37*	−0.33*	−0.30†	−0.33†	−0.34*	−0.21
	(0.25)	(0.23)	(0.23)	(0.23)	(0.24)	(0.24)	(0.25)	(0.26)	(0.23)	(0.23)
Jointly on Teams or Task Forces	0.29	0.25†	0.27†	0.28†	0.23	0.26†	0.28†	0.26†	0.28*	0.28
	(0.60)	(0.53)	(0.56)	(0.55)	(0.53)	(0.59)	(0.55)	(0.60)	(0.53)	(0.56)
Rewards WPE (local over global)	0.10			0.05						
	(0.27)			(0.25)						
Rewards PC (local over global)	0.15			0.15						
	(0.21)			(0.20)						
Access to Capital (WPE over PC as reported by WPE)	0.43*	0.42**	0.41**	0.43*	0.43**	0.43**	0.40**	0.41*	0.44**	0.41**
	(0.21)	(0.17)	(0.19)	(0.19)	(0.17)	(0.19)	(0.18)	(0.20)	(0.17)	(0.18)
Access to Capital (WPE over PC as reported by PC)	0.15				0.15					
	(0.27)				(0.25)					
					Control Variables					
AOI Usage	0.49*	0.33*	0.36*	0.41*	0.36*	0.31†	0.30*	0.30†	0.34*	
	(0.21)	(0.15)	(0.18)	(0.18)	(0.16)	(0.18)	(0.16)	(0.17)	(0.15)	
Production Lot Size (log)						−0.11				
						(0.45)				
Minimum Line Thickness						−0.15				
						(0.32)				
Log Age of Plant							−0.17			
							(0.04)			
Log Number of Employees							0.12			
							(.002)			
Scope of Quality Program								0.08		
								(0.18)		
Quality Program Age (log years)								−0.05		
								(0.06)		
Time spent in training programs (PC & PE)								0.01		
								(0.02)		
Time spent talking with quality									0.16	
									(0.05)	
Adjusted R^2	38%	44%	40%	41%	44%	37%	42%	35%	44%	35%
F for Eq .	2.99*	6.07**	4.08**	4.33**	5.26**	3.68**	4.32**	3.19**	5.37**	5.4**
N	33	34	34	34	34	33	33	33	34	34

† $p < 0.1$, * = $p < 0.05$, ** = $p < 0.01$ (see Table 1 for description of variables).
Top value: standardized coefficient; Bottom value: standard error.

only incentives but the degree to which the downstream is "perceived as reliable" (Szulanski 1996).

Organization Context: The Effect of Technology and Operational Measures. Organizations might develop an organizational context that encourages downstream information acquisition and transfer (Szulanski 1996, Kogut and Zander 1996). For example, the technological sophistication of the facility might influence the rate of data acquisition and transfer, or the organization might develop a norm of communication. I found some support for the importance of the technological context. As shown by comparing Model 2 with Model 10, the addition of a variable measuring the use of automatic optical inspection (AOI) increases the explanatory power of the model without reducing the statistical significance of any of the model variables. I found no evidence that a norm of communication influenced upstream information transfer. For example, the total time the WPE manager spent communicating with quality staff was uncorrelated with the transfer of useful information from PC (Model 9). The time the WPE managers spent talking with other departments (production, chemical laboratory, etc.) separately or in total did not add explanatory power (not shown in Table 4). Not surprisingly, the time WPE managers reported talking with the PC staff greatly strengthened the model (Adjusted $R^2 = 58\%$) and increased the significance of all of the model variables except the distance variable.

The Effect of Total Quality Management. Proponents of Total Quality Management might suggest that excellent quality management allows the implementation of more sensitive waste-treatment technology and simultaneously causes better cross-departmental communication and assistance. Similarly, many authors suggest the use of Total Quality Management (TQM) programs or increased training to encourage assistance and process improvement (Schonberger 1982, Womack et al. 1990, MacDuffie 1991). Model 8 on Table 4 shows that my data provide no statistical evidence that the scope of the firm's quality program, its duration, or the amount of training provided to pollution-control and process-engineering managers helps explain the frequency with which pollution-control personnel provide helpful information to the process-engineering manager.

The Effect of Age and Size. Population ecologists argue that the date of founding for an organization influences its conduct, and many management experts argue that size affects organizational behavior (Hannan and Freeman 1977). The survey data provide no evidence, however, that age (date of plant construction) or size (log number of employees) add significant explanatory power to the model (Table 4, Model 7).

PC Initiate Process and Organizational Change

As predicted, agents from downstream operations initiated changes in upstream processes that improved the upstream performance relative to local objectives. Table 3 lists 18 innovations that wet process engineers attributed to pollution control personnel. In each case, these innovations improved the production process relative to nonenvironmental objectives. Process engineers reported numerous examples of joint benefits: Of the 18 innovations, 17 improved production efficiency, 11 improved quality, 5 extended production capabilities, and 15 improved pollution control.

As expected, downstream agents negotiated task partitioning changes. Of the 18 innovations, seven resulted in new task partitioning. In three, PC personnel adopted new problem solving responsibilities; in four, wet-production gained new sensing responsibilities. For example, in *Innovation One*, the PC personnel observed that production baths were disposed of on a fixed schedule, and suggested a system of disposal based upon process performance. As a result of this suggestion, PC became responsible for determining and scheduling production bath disposal and renewal. In contrast, in *Innovation Nine*, PC personnel added water meters so that *wet process* personnel could better track flow rates from cleaning baths.

In the case studies, I found extensive evidence of ongoing organizational change in response to the retrieval of embodied information. Process engineers in several companies reported that their perception of pollution-control workers changed. When the PC departments were first formed, they considered PC personnel to be "garbage men"; now process engineers perceived pollution-control workers to be a "second pair of eyes and ears." Pollution control personnel seem to have become important sources of information by iteratively increasing the sensitivity of their technology. This change in technology accompanied changes in the role of pollution control. Consider for example the following string of events (*Innovation Six*):

Pollution-control workers noticed patterns in unexpected disposal of baths. They discovered that mistakes in adding chemicals occasionally damaged or destroyed process baths (thus requiring waste-treatment). These workers traced the problem to misunderstandings or mistakes in communication between laboratory workers and technicians. They discovered that the laboratory orders chemical changes and the technicians carry out the change, but sometimes a mistake occurred in the hand-off. Both sides blamed the other. To solve the problem, pollution-control workers created a computer program that prevented grievous errors in ordering and required the technicians to report their actions. Mistakes decreased and pollution-control now had an additional information source.

In this example, one can discern an iterative process of mutual adaptation of technology and organizations (Leonard-Barton 1988). Waste-treatment allows pollution-control workers to extract, transfer, and use embodied information. This information improves process control and increases communication with process engineering, thereby allowing pollution control to obtain new technology, new roles in the organization, and new information sources. The iterative process change seemed to be remarkably self-sustaining—as problems were solved, new technology and structures were implemented, which allow new problems to be discovered and solved. In two of the eight companies, this iterative process led to changes in the role, status, and structure of the pollution control department. While the process must have some limit, years after the implementation of environmental regulation, the process was still continuing.

Conclusion

This article proposes that embodied sticky information can be transferred between interdependent tasks, recovered at a downstream process, and used to independently solve problems of interdependence. It develops and tests a model predicting when downstream agents transfer information to upstream agents. It shows that the downstream agents can use retrieved embodied information to negotiate mutually beneficial changes to upstream processes, and that some of these changes may include a restructuring and repartitioning of the production system.

My research suggests that firms can use technology, structure, and access to resources to create an internal market that then encourages information exchange among agents within the firm. Are such techniques equally tractable in a market? Certainly, one can imagine a contract between separate firms stipulating the technology to be used in pollution control or even the proximity between personnel. The potential for a firm to stipulate capital constraints on other firms seems less obvious. It is true that banks often prohibit borrowers from obtaining additional loans, but General Motors (for example) does not commonly prohibit its buyers from accessing capital. Such a contract would require costly surveillance of financial records and technical changes. Thus, the ability of the firm to restrict capital within its internal "value chain" might explain some of the information benefits of firm structure. As hinted at by Foss (1996b), firms may benefit from knowledge transfer by better constraining resources available to agents performing certain tasks, and as suggested by Alchian and Demsetz (1972), firms may benefit from better structuring contracts that encourage an internal market for information.

However, such a conclusion is fraught with problems of second-best analysis (Lipsey and Lancaster 1956). My data show that a distortion in incentives to transfer information can be offset by a second distortion constraining the downstream's access to capital (thereby changing the downstream's production function so that it benefits more from transferring information to the upstream). Whether such techniques are even needed in market transactions is hard to determine. It is possible that market transactions reduce or eliminate the incentive distortion, thereby eliminating any potential advantage the firm could gain by better constraining the assets of the downstream.

Rather than providing a definitive winner in the debate about the value of firm structure, this article suggests a merging of two theories of the firm. In their current form, these theories argue that firms (1) allow better information logistics (Conner and Prahalad 1996, Kogut and Zander 1996) or (2) allow better control of opportunism (c.f. Foss 1996a, 1996b). This article demonstrates the extent to which better information logistics and the control of opportunism are linked. Retrieved embodied data allowed agents to directly solve problems of opportunism. The need to solve problems of interdependence determined the extent to which the agents retrieved and transferred embodied data. Inversely, the degree to which the firm facilitated information exchange must have influenced how effectively agents negotiated solutions. In this context at least, control of opportunism and the exchange and use of information were inseparable. Thus this paper suggests that the distinctions between current theories of the firm may be overdrawn. Firms may exist to provide better information exchange and to better control opportunism.

For theories of organizational design, this research adds to evidence of the need for a modification of the existing calculus. It suggests that in some cases the negative effects of interdependence can be mitigated by increased retrieval and transfer of embodied information. Thus, interdependence simultaneously increases coordination problems and the potential for agents to directly solve these problems. As a result, it suggests that in some circumstances, organizational design should not seek to reduce interdependence but to increase it. In this, the article corroborates evidence that low levels of work-in-process inventory (and thus greater interdependence between machines) increase information sharing and joint problem solving more than such low levels increase the costs of coordination (Sakakibara et al. 1997).

I hope that future research will extend this initial attempt to define when embodied information is retrieved and used to ameliorate problems of interdependence. It seems likely, for example, that future research may find that some types of downstream operations are more likely to uncover such information. Colleagues have suggested that rework personnel often uncover embodied information. Others have suggested that company health personnel learn about process problems by diagnosing patterns in accidents or sickness. Both these and the environmental tasks discussed in this article involve the detailed undoing of upstream tasks. Does this suggest that production cleanup activities are not ancillary organizational activities, but actually sources of important improvements? I hope that future research will further investigate when and where embodied information is retrieved within organizations, and how it is used to negotiate improved organizational arrangements.[3]

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