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PROSPECTS FOR DEVELOPING ABSORPTIVE CAPACITY THROUGH INTERNAL INFORMATION PROVISION

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Theories of absorptive capacity propose that knowledge gained from prior experience facilitates the identification, selection, and implementation of related profitable practices. Researchers have investigated how managers may develop absorptive capacity by building internal knowledge stocks, but few have focused on the distribution of this knowledge within the firm and the role managers play in administering information to organizational subunits. In this paper, we explore the degree to which managers can develop absorptive capacity by directly providing information to agents in the organization that might potentially adopt a new practice. We find that the effectiveness of managerial information provision depends on the degree to which potential adopters have information from other sources. We find that information from previous adopters and past events reduces the effect of information provision, while experience with related practices amplifies it. Our research helps clarify when absorptive capacity may provide a sustained competitive advantage. Copyright © 2004 John Wiley & Sons, Ltd.

The ability to efficiently discover, assimilate, and exploit new practices is a critical element of sustained competitive advantage (Teece and Pisano, 1994). Imperfect factor markets can allow temporary profits from a novel practice, but usually increased competition and changing conditions eventually destroy the practice's competitive value (Lippman and Rumelt, 1982; Wernerfelt, 1984; Barney, 1986). To sustain economic rents, firms must have the capacity to adopt efficiently and repeatedly valuable new practices (Teece and Pisano, 1994).

Central to a firm's dynamic capability to absorb and implement new practices is absorptive capacity (Cohen and Levinthal, 1990). Absorptive capacity is defined as the 'ability to recognize the value of new information, assimilate it, and apply it to commercial ends' (Cohen and Levinthal, 1990: 128). Despite the strategic importance of absorptive capacity, its origins remain only partially understood. Previous research proposes that a firm's absorptive capacity derives from stocks of knowledge within the firm (Cohen and Levinthal, 1990; Zahra and George, 2002). Managers can help develop their firm's absorptive capacity by building knowledge stocks through investment in internal research and development and by creating linkages to external knowledge sources such as universities (Henderson and Cockburn, 1998).

However, researchers have focused less attention on the fact that knowledge stocks within the firm may differ across organizational subunits. In their seminal paper, Cohen and Levinthal (1990) emphasize that absorptive capacity 'depends on

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the transfer of knowledge across and within subunits that might be quite removed from the original point of entry (Cohen and Levinthal, 1990: 131).' Yet few empirical studies have directly explored the role managers may play in administering the flow of information within the organization to increase the likelihood that organizational subunits will adopt valuable new practices.

In this paper, we explore whether managers can develop a firm's absorptive capacity through internal information provision. By 'information provision' we mean the transfer of practice-specific data from a central knowledge repository (e.g., a corporate R&D lab) to agents within the firm that make technology adoption decisions.[1] Such information provision usually occurs through internal seminars, demonstrations, and promotional brochures. We find that information provision can be an important mechanism for developing absorptive capacity. We show that in some cases centrally provided information substitutes for alternative information sources, and in other cases it complements them. In particular, we find that centrally provided information can substitute for information arising from previous adopters and from prior events. However, we also find that experience with related practices complements and magnifies the effect of managerially provided information.

Our findings have important implications for the broader strategy literature. In particular, this paper contributes to the growing literature on the acquisition and creation of valuable resources and capabilities (e.g., Henderson and Cockburn, 1996). Understanding whether managers can develop absorptive capacity by directly providing information is critical to understanding the potential for absorptive capacity to provide a competitive edge. Like any other organizational ability, absorptive capacity should provide a competitive advantage only if barriers to competition prevent its efficient acquisition by competing firms (Zahra and George, 2002). To the extent that managers can acquire absorptive capacity through competitive factor markets, absorptive capacity should provide little comparative advantage. While we find that managers can develop absorptive capacity through information provision, we show that the impact of information provision is contingent on the extent to which potential adopters can access information from previous adopters and past experience at their local subunit.

THEORY AND HYPOTHESES

According to theories of absorptive capacity, a firm's stock of prior related knowledge determines the ability of a firm to absorb new knowledge and practices (Cohen and Levinthal, 1990). Existing knowledge begets related knowledge, because 'accumulating absorptive capacity in one period [permits] its more efficient accumulation in the next' (Cohen and Levinthal, 1990: 129). Prior related knowledge influences both the cost of discovering and acquiring new knowledge and the degree to which one is likely to engage in a search for new practices.

The relatedness of the knowledge stock influences which types of new knowledge and practices are likely to be absorbed. For example, knowledge of algebra aids in the learning and use of calculus more than it aids in the learning and use of American history. Arrow (1969) argues that acquiring knowledge often represents a fixed investment that then enables future related exploration and acquisition. Like an oil prospector searching for oil, an agent searching for new knowledge must make an investment just to see what might be there. As a result, where (and whether) one decides to prospect for new practices may depend on where one has found valuable practices in the past.

The distribution of knowledge within the organization and the organization's ability to transfer this knowledge internally are critical to absorptive capacity (Cohen and Levinthal, 1990). Recognition and implementation of new practices requires information about available practices, local context, and the value of adoption (Arrow, 1974; von Hippel, 1994). Such diverse information often resides in different people and in different locations. For example, workers in production often know intimate details about what problems arise in manufacturing, but they do not know about newly developed practices or technologies, nor do they know the financial pay-off that these technologies might provide. While production workers might choose to invest in such information, if these workers do not know the value of a new technology,

[1] We reserve the term 'knowledge' to represent cognitive structures that embed learning. For example, a math teacher may transfer to a student the ability to calculate the circumference of a circle (knowledge) by having the student read a text book (information).

they likely do not know the value of searching for new technology, and may prematurely terminate their search (Arrow, 1969; Cohen and Levinthal, 1994).

The location where information can best be developed and maintained is often different from where it can best be used (von Hippel, 1994; Szulanski, 1996). Economies of information processing and routines for gathering information may allow a centralized office to scan for and gather information on valuable new practices at less cost than individual adopters (Allen, 1977). For example, R&D laboratories may gather information about new practices more efficiently or benchmark the value of different practices more cost-effectively, in part because they maintain linkages with important external sources of information (e.g., universities and suppliers).

We argue that because the best location for acquiring information often differs from the best location for harnessing it, managers' internal policies and programs for information transfer can play a critical role in developing their firm's absorptive capacity. By creating programs that distribute information on the value of new practices, managers may reduce search costs and consequently increase the likelihood of adoption. By providing information on the implementation of new practices, managers may reduce the cost of adoption and increase the speed of implementation (Mansfield, 1968).

Managers may provide information in a number of ways. They may conduct 'dog and pony shows' at company-wide meetings or in individualized seminars. They may undertake demonstration projects to illustrate the practice's value. Managers may develop brochures and other print materials to distribute across the organization. In some cases, top managers establish liaisons between corporate groups and business units or facilities. We hypothesize that such information provision by managers will be associated with a greater propensity to adopt the practice.

> *Hypothesis 1: The more central managers provide information about a practice, the greater a firm's adoption of that practice.*

The effect of such information transfer is likely conditional on the attributes of the receiving subunits. Decision-makers within subunits are not without information sources of their own. Centrally provided information may substitute or complement alternative sources of information from inside and outside the firm. Information from other adopters, past events, related practices, and directed information search all might influence the effectiveness of central information provision. We consider each in turn.

Agents within subunits can access information directly from external sources. The experience of other firms may be an important source of external information (Cohen and Levinthal, 1990; von Hippel, 1994; Lane, Salk, and Lyles, 2001). Previous adopters increase the likelihood that a nonadopter is aware of the existence of a practice (Ryan and Gross, 1943). Previous adopters also provide information about the costs and benefits of engaging in the practice by credibly revealing the value expectations of other managers (Mansfield, 1968). Thus, as the number of previous adopters increases, information about the existence and value of the practice increases. To the extent that such information substitutes for central information provision, we expect:

> *Hypothesis 2: The greater the number of previous adopters of a practice, the lower the effectiveness of central information provision as a means to encourage adoption of that practice.*

In addition to observing previous adopters, organizational subunits may build knowledge stocks through local experience. One type of local experience—unexpected events such as accidents or product failures—provides little information about implementing a new practice but can provide extensive information on its value. For example, when choosing whether to adopt a quality control practice, agents must estimate the rate with which problems (bad parts or injuries) occur, and then estimate how adopting the practice will affect this rate. Each time a product failure occurs, it reveals information about the value of quality control practice. Each event allows agents to better estimate the likelihood of a future event and to better estimate the value of avoiding such an event (Kleindorfer and Kunreuther, 1999). To the extent that information from such events is redundant with centrally provided information, we hypothesize a negative interaction between past events experienced by a potential adopter and the effectiveness of information provision.

Hypothesis 3: The greater number of related past events experienced by potential adopters, the lower the effectiveness of central information provision as a means to encourage adoption of a practice.

Agents may also gain information about a practice through their experience with related practices. As hypothesized by Cohen and Levinthal (1990) and demonstrated by MacDuffie (1995), the adoption of one practice may provide information about the value of similar practices. Furthermore, related practices may directly reduce the cost of adopting a new practice by providing information that eases implementation. Information gained through experience with related practices could substitute for centrally provided information. Information provided by managers might be redundant with that gained from the experiences of local agents. Thus, we hypothesize a negative interaction between previously adopted related practices and the effectiveness of information provision.

Hypothesis 4: The greater the adoption of related practices by potential adopters, the lower the effectiveness of central information provision as a means to encourage adoption of a practice.

Finally, local agents may collect information regarding new practices through active search. Search, in turn, is driven by the individual incentives of the local agent. In particular, managers may compensate those who adopt a desired practice. On the one hand, this will increase the likelihood of adoption regardless of the local agent's information set. On the other hand, the greater the local agent's expectation of being compensated for adopting a new practice, the more he or she will be motivated to learn more about that practice. This search activity will likely lead to information that is redundant to that which may be provided centrally. Thus, we expect that compensatory programs will directly substitute for information provision.

Hypothesis 5: The greater adopters are compensated for adopting a practice, the lower the effectiveness of central information provision as a means to encourage adoption.

All of the above hypotheses assume that there are diminishing returns to information and that information from different sources can be substituted. We recognize that information could also act as a catalyst. If this is the case, previous adopters, past experience, and incentives to search all may act as complements. For example, other sources of information might increase the credibility of information provision. Alternatively, multiple sources of information might provide synergistic data that raise the value of information from a central authority. While these ideas have received considerable attention, they are intriguing in part because they represent an exception to more general expectations of diminishing returns and substitution (Arrow, 1969). Rather than construct rival hypotheses reflecting the potential for complementarity between information sources, we have chosen to frame our hypotheses in this dominant perspective. In our analysis, however, we remain mindful of these potential rival expectations.

Figure 1 summarizes the relationships specified in our hypotheses. We propose that information provision has a positive impact on the extent of adoption (Hypothesis 1). Moreover, we predict that the impact of information provision will be influenced by adoption of the practice by other firms (Hypothesis 2), local experience with related events (Hypothesis 3) and practices (Hypothesis 4), and compensation to adopt the practice (Hypothesis 5). We believe each of these factors has a direct impact on adoption as well. Specific measures for our constructs are presented in the parentheses in Figure 1. These measures are described in the section below.

DATA AND METHODS

To explore the dynamics of absorptive capacity and information provision, we collected data on the adoption of pollution prevention (PP) practices among manufacturing facilities within the information and communications technology industry. We define pollution prevention as the design, redesign, or modification of products and/or manufacturing processes so as to reduce pollution. This setting was chosen because our field studies revealed vast differences in the knowledge of pollution prevention practices between corporate managers and facility-level decision-makers. When it first

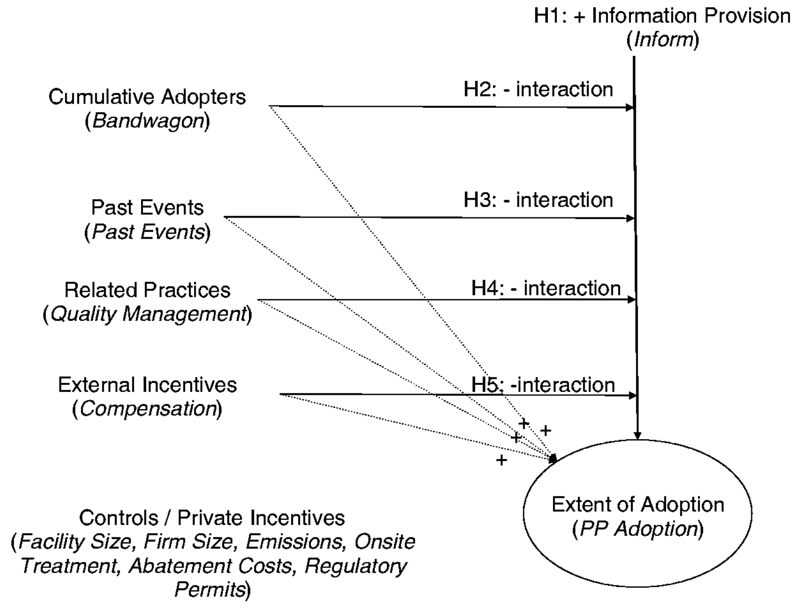

Figure 1. Predicted effect of information provision

appeared, pollution prevention was a new practice of uncertain value. Consequently, diverse expectations arose among potential adopters and managers.

Setting

Pollution prevention is a set of management practices and tools that aid in the consideration of environmental issues in the design of products and processes. The pollution prevention concept gained prominence in the late 1980s when companies began to eliminate chlorofluorocarbons (CFCs)—widely used as a cleaning agent in the production process of electronics firms—in response to the ban under the Montreal Protocol due to evidence that CFCs destroy the ozone layer. In the process, companies discovered that numerous applications using CFCs could be done with other less costly materials. Companies discovered that the liability, remediation, and process change costs associated with the use of CFCs could be avoided through pollution prevention.

Early research revealed a strong resistance by facility-level managers to adopting pollution prevention practices (King, 1995). Faced with the prospect of dedicating valuable time to the consideration of environmental issues, facility managers were reluctant to adopt pollution prevention practices without a clear indication of their value (Shelton, 1994). The impacts on the natural environment from individual design choices were often difficult to assess. Firms found it difficult to assess the return for a supposedly pro-environment decision. As a consequence, use of pollution prevention practice at the facility level was uneven and strongly influenced by local information sources (Lenox, King, and Ehrenfeld, 2000).

Corporate managers in a number of firms established company-wide programs to encourage the adoption of pollution prevention. In these firms, teams were charged with promoting pollution prevention in the firm. These groups developed pamphlets and held seminars touting the economic benefits of pollution prevention. In some instances, these groups helped ease implementation by providing training and various other types of technical assistance. Interestingly, adoption of pollution prevention practices remained voluntary in most cases. Corporate offices were reluctant to impose technological solutions on business centers. While incentives to adopt were provided in some cases, firms often found it difficult to monitor adoption.

Sample

To limit variance and increase comparability, we focused on the adoption of pollution prevention practices in only one industry: information and communications technology (ICT) manufacturers in the United States during the period 1991 through 1996. Firms within the ICT industry produce a variety of products essential to the information age: mainframes, workstations, desktop computers, servers, storage devices, telecommunications equipment, semiconductors, and printed circuit boards. The industry is marked by a high rate of technological progress and competitive turmoil. Firms must deal with ever shortening product cycles and ever increasing technological consolidation. Within the ICT industry are large, vertically integrated firms (e.g., IBM, Hewlett Packard, and Motorola) as well as focused firms (e.g., Dell and Cisco Systems). The industry includes a number of firms such as Xerox and Kodak that have traditionally specialized in other lines of business but increasingly find synergies with information technologies.

Previous research indicated that many of the leading practitioners of pollution prevention are within the ICT industry (Lenox, Jordan, and Ehrenfeld, 1996). While the ICT industry is generally thought of as clean industry, it faces a number of challenges in manufacturing, including high levels of water and energy use and the widespread use of toxic chemicals (Frankel, 1998). The information and communications technology industry has faced many environmental issues spanning the entire product life cycle: the phase-out of CFCs in manufacturing cleaning processes, the use and reuse of lead solder in manufacturing, the concern for energy efficiency during product use, and the recycling of metals and plastics at the end of product life.

We identified an initial population of 311 firms and 1026 manufacturing facilities that had facilities in the ICT industry (See Table 1) and were included in the U.S. Environmental Protection Agency's Toxic Release Inventory (TRI). The TRI was used as a condition for inclusion since it is the source of the dependent variable for the analysis—PP adoption. The TRI is a database of emissions and management practices in over 20,000 U.S. manufacturing establishments. Submission of TRI data is mandatory for all facilities with greater than 10 employees and that use greater than 10,000 pounds of designated toxic chemicals. Submission of data on source reduction activities such as pollution prevention has been required since 1991. The exclusion of very small facilities is not considered significant since internal diffusion dynamics are likely confounded by their size.

We collected data in two phases. We collected facility-level data from a number of archival sources. We collected company-level management data using a survey of corporate environmental managers within each firm. We used this survey to measure the degree to which information on pollution prevention was provided to facilities. We mailed the company-level survey to all 311 firms. We administered two follow-up mailings. We received 82 responses from corporate environmental managers for a response rate of 26 percent. The eighty-two respondent firms operated 494 facilities (48% of the initial sample). A number of facilities entered or exited (due to closure or sale) during the period 1991–96 and were excluded for those years from the sample, leaving 2172 facility–year observations.

Using the archival data collected for all 311 firms, we found that the final sample was not significantly different from the overall population with respect to any of our archival measures, with one exception. Firms in the final sample were significantly larger than those in the population

Table 1. Summary of the ICT industry

Segment	SIC Codes	Facilities	Examples[a]
Semiconductors	3674	182	Intel, Micron, Texas Inst.
Printed circuit boards	3672	289	Selectron, Hadco
Components and peripherals	3577, 3679	261	Cisco, Bay Networks
Storage	3572, 3695	51	Seagate, Quantum
Computers	3571, 3575	67	IBM, Compaq, Dell, Apple
Imaging technology	3579	73	Xerox, Kodak
Telecommunications equipment	3661, 3663, 3669	103	Motorola, Lucent

[a] Inclusion in this list does not necessarily mean the firm is in the sample.

as a whole (measured as the number of facility employees). It is often the case that larger firms respond more readily to surveys. We consider the potential implications of this respondent bias in the discussion section.

Measures

Dependent variable

PP Adoption. The dependent variable for our analysis is the adoption of pollution prevention practice at the facility level. We coded this variable (*PP Adoption*) as a count variable to reflect the varying degree to which a facility may engage in pollution prevention. As Rogers (1995) points out, most diffusion studies suffer from a binary treatment of adoption when in fact there are varying degrees of adoption. Our ability to differentiate levels of adoption allows us to address Rogers' concern. We measure adoption as the total count of pollution-reducing product or process modifications in a given year as indicated in the Source Reduction Activity (SRA) fields of the Toxic Release Inventory. The SRA fields list a number of practices that facilities may engage in to reduce pollution. 'Process Modifications' (elements W51, W52, W53, W54, W55, W58) and 'Product Modifications' (elements W81, W82, W83, W89) are a subset of those practices.

Independent variables

Inform. The primary independent variable in our analysis is the centralized provision of information on pollution prevention practice. We measure *Inform* as the number of fulltime-equivalents (employees) at the corporate level providing information and support for PP. Qualitative interviews revealed that this activity may take a number of forms, including producing and distributing brochures attesting to the value of PP, communicating past successes, and providing information on future regulation and labeling initiatives. We measured *Inform* using the surveyed responses of corporate managers of environmental affairs.[2] The survey proceeded in two stages. We first defined pollution prevention activities as 'the prevention of pollution through the design or redesign of products and/or manufacturing processes.' We asked whether 'anyone at the corporate level (headquarters) ever promoted pollution prevention practices within the company' and, if so, in what year this activity began. We then followed up this question with a series of questions to help clarify what we meant by 'promote.' Finally, we asked the respondents to specify the number of full-time equivalents (people) at the corporate level who worked to promote pollution prevention in each year since promotional activities began. The Cronbach alpha among the responses to the list of common mechanisms and the number of FTEs is 0.87, indicating strong inter-item correlation and increasing our confidence that FTE is an accurate reflection of information provision.

Cumulative Adoption. As discussed earlier, information about the costs and benefits of adoption becomes more available as the number of adopters increases. This is particularly true when adoption occurs within one's own industry segment. Learning from segment adopters has the benefit of allowing more easy comparison. As a result, computer disk drive makers are more likely to be influenced by other disk driver manufacturers than computer terminal producers. We measure *Cumulative Adoption* as the percent of all facilities within a given four-digit SIC code that have adopted pollution prevention practices in a given time period.

Past Events. As hypothesized, past events may also be an important component of prior related experience. The environmental performance history of a facility likely affects the assessment of the returns to engaging in pollution prevention. Prior events may provide a signal of the costs of pollution. Spills, lawsuits, fines, and regulatory violations are all significant events that shape a firm's information set. We measure *Past Events* as the cumulative number of these events experienced by a firm. Events include hazardous material spills as

[2] Four corporate environmental managers and ten product managers reviewed survey items. Pilot testing demonstrated that the measures were consistently well understood. We constructed the survey instrument using insights from a field study of four firms' attempts to diffuse DfE (Lenox, King, and Ehrenfeld, 2000). Data for these cases were gathered primarily through open-ended interviews conducted in each firm over a three-month period. Approximately a dozen interviews were conducted in each firm. Interviewees included corporate-level environmental managers as well as designers and product managers on the establishment level. These interviews were supported with additional information from company publications, journal articles, and news releases.

tracked through the U.S. EPA's Accidental Release Information Program (ARIP), completed environmental lawsuits filed against a firm as reported on the Docket Database of the U.S. EPA, fines and violations accessed under both the Clean Water Act and RCRA (available through the U.S. EPA's Permit Compliance System and the RCRA Information System), and the number of a firm's facilities investigated for inclusion on the National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), better known as Superfund. Since all the events listed occurred as a result of past actions, costs associated with these events may be assumed to be sunk and consequently have no direct effect on the costs and benefits of adopting pollution prevention practices.

Related Practices. Theories of absorptive capacity propose that prior related practices may inform the decision to adopt a new practice. In the case of PP, adoption of quality management practices is one of the most closely associated practices (King and Lenox, 2001). Adoption of quality management practices may encourage PP practice adoption by either lowering the cost of implementation (through learning) or increasing an agent's valuation of pollution prevention (by providing value-revealing information) (King, 1995). We use ISO 9001 certification as a proxy for the existence of quality management practices. ISO 9001 is a quality management standard created by the International Organization for Standardization. To be certified by third-party auditors, facilities must demonstrate that they have a number of quality management processes in place. We code *Quality Management* as a dummy variable, where '1' indicates that the facility is ISO 9001 certified for that year. We gathered certification data from the ISO 9000 Registered Company Directory of North America (McGraw-Hill, 2000).

Compensation. Finally, we expect that compensation systems will likely have a direct impact on the extent of PP practices adopted. We measure *Compensate* as the degree to which corporate environmental managers report that headquarters provides explicit rewards (or punishment) for adoption of (or failure to adopt) pollution prevention practices. We measure *Compensate* using a seven-item scale where zero indicates that PP practice adoption is rewarded 'not at all' and six indicates PP practice adoption is rewarded 'very much.' As with *Inform*, to increase the validity of this measure, we asked survey respondents a series of questions concerning various compensatory activities before being asked to indicate the overall level that management required (rewarded) PP practice adoption for each year from 1990 to 1998. Cronbach's alpha for these questions is 0.92.

Controls

A number of facility attributes likely influence the cost associated with the output of pollutants and consequently the benefit of reducing those pollutants through the adoption of pollution prevention practices. We include measures of several important variables as controls to further account for facility level differences.

Facility Size. A long tradition of diffusion studies has found that size is a predictor of adoption. In particular, larger facilities may enjoy economies of scale in the implementation of pollution prevention practices. To account for this possibility, we measure *Facility Size* as the natural log of the number of employees at the facility. We gathered baseline data from the Dun & Bradstreet Million-Dollar Data Set, and calculated trend data using production ratios specified in the Toxic Release Inventory. We tested and supplemented this trend information with industry data from the National Bureau of Economic Research.

Emissions. The amount of pollutants that a facility emits is likely influenced by the inherent characteristics of its product and process technology. Consequently, 'dirtier' facilities will be more likely to adopt pollution-avoiding practices such as PP. Facility-level pollution is measured as the total emissions of toxic chemicals. Toxic releases are calculated as the toxicity-weighted sum of all chemical releases as reported in the U.S. EPA's Toxic Release Inventory. We measured toxicity using requirements for emergency reporting (reportable quantities or RQs) for each chemical as reported under the CERCLA statute. Since TRI reporting requirements have changed for some chemicals, we used only those that have been consistently reported over the time period of interest.

Onsite Treatment. The traditional way of reducing pollutants is to treat emissions once they have been generated. Since the early 1970s, 'end-of-pipe' strategies have been the prevalent method of controlling emissions in U.S. industries. Facilities may adopt treatment technologies such as scrubbers to reduce the pollutants leaving the plant. We measure *Onsite Treatment* as the percent of total toxic emissions that are treated by the facility. Total toxic emissions are calculated by summing the total pounds of emissions released, transferred, and treated by a facility in a given year as reported in the Toxic Release Inventory.

Abatement Costs. The costs associated with treating plant emissions, i.e., abatement costs, vary greatly across industries. A given facility's PP adoption behavior is influenced by the costs associated with abatement in that industry. The total industry cost of abatement in U.S. dollars is calculated at the four-digit SIC code over the period of interest. *Abatement Costs* is calculated as the log of total industry cost of abatement.

Regulatory Permits. The technological attributes of a facility's product and processes often influence the nature of government regulation applied. The production of certain types of wastes and pollutants require government-approved permits. In particular, the U.S. EPA requires permits for waterborne waste that does not go to waste treatment facilities (under the Clean Water Act) and for any hazardous waste that is produced or used (under the Resource Conservation and Recovery Act). We created a measure of the regulatory stringency associated with a particular technology by counting the number of federal wastewater and hazardous waste permits possessed by a facility. The greater the number of permits, the greater regulatory stringency the facility faces.

Firm Size. Finally, we wish to control for the possibility that large firms are more likely to adopt pollution prevention practices independent of the amount of information provision. Large firms attract greater attention from various stakeholders and often find their facilities under greater scrutiny (King and Lenox, 2000). To account for this possibility, we measure *Firm Size* as the natural log of the total number of employees at all the firm's facilities. The employee data used was based on the facility size measure described above.

Descriptive statistics and the correlation matrix for all variables described herein are presented in Table 2. No correlation between attributes was deemed large enough to raise serious concerns about multicollinearity.

Empirical approach

To make full use of these data, we examine the extent of adoption among facilities across the entire time period, 1991–96. Recall that our measure of PP adoption is the number of pollution prevention modifications made in a given year at the facility level. We address this issue by using a negative binomial model—a technique that is appropriate for overdispersed count data like ours and that is commonly used in the patent literature (Griliches, Pakes, and Hall, 1987). The negative binomial model allows us to take full advantage of the discrete measure of adoption employed in this study. It allows 'adoption' to be differentiated by degree and allows for the extent of adoption to vary from year to year.

We use a random-effects specification of the negative binomial mode to address possible problems with unobserved heterogeneity. Unobserved heterogeneity is caused by facility attributes that actually are not included as independent variables and can cause incorrect inferences concerning the magnitude and significance of individual effects. We did not choose a facility fixed-effect specification for two reasons: (1) facilities that never adopt pollution prevention practices would have been dropped from our sample, and (2) variables that are constant over the panel would have been collinear with the fixed facility effects. However, we did include *firm*-level fixed effects to control for stable cross-firm heterogeneity that may be driving our results. To check the robustness of our findings, we also ran a facility fixed-effect specification. The results of our facility fixed-effect specification were consistent in sign and significance with our random-effects models with firm fixed effects.

ANALYSIS AND RESULTS

In Table 3, we present a number of models using our random-effect negative binomial specification of the extent of PP adoption. Model 0 presents the results of a base model consisting only of

Table 2(a). Descriptive statistics (ICT industry: 1991–96)

Variable	Description	Mean	S.D.	Minimum	Maximum
PP Adoption	Total count of pollution prevention practice modifications	3.56	8.57	0	115
Inform	The amount of information disseminated by headquarters (measured in full-time equivalents)	0.31	0.82	0	7.50
Cumulative Adoption	Percent of all facilities in segment adopting pollution prevention practices	0.53	0.15	0	1
Quality Management	Whether or not the facility is ISO 9000 certified	0.09	0.28	0	1
Past Events	Number of past negative environmental events at facility (e.g., spills, fines, lawsuits)	0.23	0.88	0	9
Compensate	The degree to which PP adoption is rewarded (or failure to adopt is punished) by headquarters	0.54	1.30	0	6
Facility Size	Natural log of facility employees	6.20	1.70	2.30	9.89
Firm Size	Natural log of firm employees	9.89	2.39	2.30	12.43
Emissions	Natural log of total emissions of toxic chemicals	4.58	2.98	0	12.89
Onsite Treatment	Percent of total waste produced that is treated	0.19	0.31	0	1
Abatement Costs	Natural log of total segment abatement costs ($)	4.38	1.09	0.69	6.52
Regulatory Permits	Number of EPA issued NPDES and RCRA permits	0.53	0.64	0	3

Note: $n = 2172$.

Table 2(b). Correlations (ICT Industry: 1991–96)

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. PP Adoption	1.00											
2. Inform	0.08*	1.00										
3. Cumulative Adoption	0.18*	0.08*	1.00									
4. Quality Management	0.15*	0.12*	0.09*	1.00								
5. Past Events	0.15*	−0.00	0.01	0.05	1.00							
6. Compensate	0.07*	0.21*	0.17*	0.26*	0.04	1.00						
7. Facility Size	0.07*	0.06*	−0.05	−0.01	0.11*	−0.03	1.00					
8. Firm Size	0.09*	−0.08*	−0.04	−0.19*	0.08*	−0.14*	0.31*	1.00				
9. Emissions	0.31*	−0.01	0.00	0.01	0.14*	−0.05	0.21*	0.30*	1.00			
10. Onsite Treatment	0.07*	0.05	0.13*	0.11*	0.04	0.18*	0.02	−0.15*	0.11*	1.00		
11. Abatement Costs	0.12*	0.02	0.24*	0.00	0.11*	−0.05	0.03	0.16*	0.04	0.07*	1.00	
12. Regulatory permits	0.16*	0.00	0.16*	0.05	0.27*	0.06*	0.09*	0.19*	0.17*	0.05	0.15*	1.00

Note: $n = 2172$, * $p < 0.01$.

our control variables. Consistent with diffusion theories, we find that the more other facilities within a facility's industry adopt PP (*Cumulative Adoption*), the greater the extent that the facility will adopt. Our findings are also consistent with theories of absorptive capacity. We find that the prior related experience of a potential adopter, in the form of *Quality Management*, influences the decision to adopt. We do not find that those firms who have experienced past negative environmental events (*Past Events*) were more likely to adopt PP. Finally, we find that the more top management

Table 3. Analysis of the extent of adoption: conditional random-effects negative binomial model (PP adoption)

	0 Without information provision	1 With information provision	2 Interaction with segment adoption	3 Interaction with past experience	4 Interaction with compensation
Inform		0.178***	0.544***	0.169***	0.217***
		(0.024)	(0.075)	(0.033)	(0.041)
Inform × Cum. Adoption			−0.556***		
			(0.108)		
Inform × Quality				0.071*	
				(0.034)	
Inform × Events				−0.062**	
				(0.023)	
Inform × Compensate					−0.012
					(0.010)
Cumulative Adoption	2.987***	2.739***	2.931***	2.746***	2.681***
	(0.154)	(0.147)	(0.153)	(0.152)	(0.156)
Quality Management	0.251***	0.180**	0.151*	0.161*	0.187**
	(0.070)	(0.064)	(0.064)	(0.069)	(0.064)
Past Events	0.041	0.038	0.037	0.093*	0.037
	(0.037)	(0.034)	(0.034)	(0.039)	(0.0333)
Compensate	0.085***	0.033†	0.037†	0.039†	0.042†
	(0.021)	(0.021)	(0.021)	(0.021)	(0.023)
Facility Size	0.110**	0.087†	0.072†	0.087*	0.084*
	(0.043)	(0.041)	(0.041)	(0.041)	(0.041)
Firm Size	−0.123†	−0.161†	−0.146†	−0.164**	−0.159*
	(0.067)	(0.064)	(0.064)	(0.064)	(0.064)
Emissions	0.034*	0.043***	0.045***	0.045***	0.044***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Onsite Treatment	0.040	0.120	0.106	0.160†	0.115
	(0.090)	(0.086)	(0.086)	(0.088)	(0.086)
Abatement Cost	−0.024	−0.031	−0.035†	−0.034†	−0.031
	(0.021)	(0.020)	(0.020)	(0.020)	(0.020)
Regulatory Permits	0.124†	0.140**	0.134**	0.145**	0.139**
	(0.049)	(0.047)	(0.047)	(0.047)	(0.047)
Firm Dummies	Included	Included	Included	Included	Included
Intercept	2.515**	10.318	11.854	11.371	9.253
	(0.856)	(18.972)	(36.565)	(26.434)	(11.565)
No. of facilities	494	494	494	494	494
No. of observations	2172	2172	2172	2172	2172
Wald χ^2-Stat	2587.88***	1045.40***	1061.36***	1051.24***	1047.20***

† $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ (standard errors in parentheses).

compensates managers for adopting PP, the greater the extent to which PP is adopted.

In Model 1, we test Hypothesis 1 by adding information provision to our model. We find that information provision has a significant, positive impact on the extent of PP adoption. This finding supports Hypothesis 1. The inclusion of information provision explains a moderate amount of additional model variance, and we have high confidence in our estimate ($p < 0.001$). Furthermore, we find that the magnitude of this impact is of economic significance. On average, every additional FTE spent providing information increases the likelihood of adopting an additional pollution prevention practice by 15–20 percent.

In Model 2, we examine the interaction between information provision and cumulative adoption. We support Hypothesis 2 by finding a significant, negative coefficient for the product of *Inform* and *Cumulative Adoption*. In other words, the greater the number of adopters in a facility's industry, the less impact information provision has on adoption. Our estimates suggest that information provision continues to have a positive effect on adoption over most of its range ($+3\sigma$), but that this positive effect decreases as cumulative adoption grows.

In Model 3, our findings support Hypothesis 3. We find a significant ($p < 0.05$), *negative* coefficient for the interaction between information provision (*Inform*) and the experience of negative environmental events (*Past Events*). As hypothesized, events may cause renewed search for information and thus substitute for central information provision. Furthermore, the events themselves may reveal information directly about a new practice. Our analysis suggests that information provision (*Inform*) continues to have a positive effect on adoption for most firms that have had a past event. For firms with three or more previous events, however, our analysis suggests that information provision could actually reduce the adoption of new practices. It is possible that several events cause the organization to retrench around existing practices and distrust external information sources (Staw, Sandelands, and Dutton, 1981).

Interestingly, Model 3 provides evidence that contradicts Hypothesis 4. We find that experience with a quality management program complements, not substitutes for, information provision. The interaction between *Inform* and *Quality Management* is found to be positive and significant at the 0.05 level. In other words, information provided by management influences those facilities that have previously adopted the ISO 9000 standard more than those that have not. In contrast to Hypothesis 4, we find that information provision is about 50 percent more effective in stimulating adoption of a PP practice in facilities with quality management programs.

In Model 4, we examine Hypothesis 5 by exploring the interaction of information provision with the level of compensation provided. We find no evidence that information and compensation interact. Thus, we do not find support for Hypothesis 5. It may be that two processes offset each other. As hypothesized, providing compensation for adoption may provide incentives for information search and thus act as a substitute for information provision. However, compensation may also signal that pollution prevention is a valuable practice and thus make facility managers more receptive to centrally provided information. These two forces may cancel each other out.

This finding is particularly interesting when taken with the weak evidence that directly providing incentives to adopt had an impact on the actual diffusion of PP practices. We may speculate that providing information may be more effective than providing incentives when adoption is hard to verify and agents have underlying incentives to improve practice. In certain contexts, top management may not be able to rely on power and influence to push through their agenda within the organization and, thus, may need to resort to information provision as an alternative strategy.

Endogenous choice processes may confound the analysis of interactions between *Inform* and *Compensate*. Some top managers are more likely than others to encourage the internal diffusion of pollution prevention practices. Those who decide to encourage diffusion choose between information provision and compensation. Those who decide not to encourage diffusion choose neither. In ongoing research, we explore the decision by managers to provide information vs. compensation. For the scope of this paper, we have focused on the adoption decision by facility-level managers and thus have treated top-level manager decisions as exogenous.

In summary, we find strong support for Hypothesis 1. Our results suggest that information provision has a significant, positive impact on the extent of adoption. In the case of pollution prevention, we estimate that each additional individual dedicated to information provision raises the extent of adoption. We find evidence for Hypothesis 2 that information provision has decreasing influence on adoption as the number of cumulative adopters of a practice increases, but we are cautious in our interpretation. We find evidence for Hypothesis 3, but not for Hypothesis 4. Consistent with Hypothesis 3, we find that, in the case of pollution prevention, information gained from past environmental experiences may substitute for centralized information provision. In contrast to Hypotheses 4, we find that a *lack* of prior related experience, in the form of a quality management program, strongly *decreased* the effectiveness of information provision. Finally, we do not find support for an interaction between information provision and compensation systems (Hypothesis 5).

Our paper helps to refine when firms adopt pollution prevention practices. It provides additional evidence of a link between experience with quality management and the adoption of pollution prevention practices (King and Lenox, 2001). It further demonstrates that coercive institutional pressures (e.g., permits and emissions) exert considerable influence on the diffusion of pollution prevention (Starik and Marcus, 2000; Majumdar and Marcus, 2001). Most importantly, our research lends additional support to previous studies that suggest that pollution prevention results from an interplay between external industry conditions and internal firm processes (Klassen, 2001; Marcus and Geffen, 1998; King, 1999; King and Lenox 2002). Increased pressure for environmental protection can interact with existing firm attributes to allow some firms to more readily adopt pollution prevention.

As with most empirical studies, we must recognize that our analysis and conclusions have limitations. Our sample of ICT firms is biased towards larger firms. It is possible that centralized information provision is less important in small firms because physical proximity aids spontaneous information transfer and thereby reduces the need for a centralized program. If so, our findings may apply only to larger firms. Differences in the expertise of those providing information may also affect our findings. A long line of research highlights the cognitive limits of upper management (March, 1962; Starbuck, Greve, and Hedberg, 1978). Managers themselves may lack the information necessary to recognize and disseminate valuable new practices. Thus, greater information provision may indicate a higher degree of managerial awareness. This awareness may prove to be a vital precondition for the effectiveness of centralized information provision. In future research, we hope to further explore the interplay between managerial expertise, information provision, and absorptive capacity.

CONCLUSION

In this paper, we argue that the existing literature on absorptive capacity underemphasizes the role of managers in administering information to organizational subunits with unique knowledge stocks. We find that managers can directly affect a firm's absorptive capacity by providing information to potential adopters in the organization. We show that the effectiveness of such action is contingent on the degree to which other sources of information are available to these agents. Some of these other sources dampen the effect of central information while others amplify it.

Why did some alternative sources of information act as complements to centrally provided information, while others acted as substitutes? One possibility is that the relatedness of information from different sources determines when such information is a substitute or a complement (Cohen and Levinthal, 1990; Arrow, 1974; Zahra and George, 2002). Previous adopters and past events provide information that bears directly on agents' assessments of the value of engaging in the practice, and thus may substitute directly for information on the value of adopting pollution prevention practices provided by managers. In contrast, experience with quality practices provides information about a related practice, not pollution prevention practice itself.

We infer that information provision is most useful when an organizational agent has little information that directly relates to a new practice, but a great deal of information that is moderately related to this practice. In other words, managerial 'tutoring' is most effective if the 'student' knows little about the topic at hand but a lot about a related subject. There is anecdotal evidence that managers recognize that previous related experience can increase the effectiveness of information provision. For example, managers at Xerox adopted the term, 'Design for Environment' for its pollution prevention efforts, to draw an analogy to previous experience with Design for Manufacturability and Design for Serviceability (Lenox *et al.*, 2000; Reinhardt, 1999).

These results suggest both limits and opportunities to sustained profits from absorptive capacity. On one hand, the ability of managers to improve the absorptive capacity of their firms through active information provision suggests that the advantages of absorptive capacity will be short-lived. Faced with a technical challenge (such as entry by innovative start-ups), established firms may be able to enhance absorptive capacity in domains in which they do not have much experience. On the other hand, our research suggests that information provision cannot fully replace prior experience. The ability of managers to provide information and the ability of individuals within the firm to assimilate that information is contingent on experience with related practices. In the case of pollution prevention, facility managers were more receptive to the information provided by corporate headquarters when they had a basis for understanding built from exposure to quality management programs. While managers may be able to develop absorptive capacity through internal information provision, this ability is contingent on the distribution of related experience within the firm.

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