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ORGANIZATIONAL RESPONSE TO ENVIRONMENTAL REGULATION: PUNCTUATED CHANGE OR AUTOGENESIS?

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Theory predicts that when faced with threatening new conditions, managers often attempt to preserve the *status quo* by creating a buffer between the organization and the outside world. This paper presents evidence that in response to new water pollution regulation, managers indeed created buffers of technology and personnel, but in some organizations this very equipment and personnel initiated a process of incremental change that led to better environmental protection, more efficient production, and in a few cases, entirely new product and production strategies.

For public policy, this research suggests that environmental regulators should allow companies time and flexibility to learn and experiment. For organizational theory, this research suggests a link between punctuated-equilibrium models of organizational dynamics (Tushman and Romanelli, 1985) and theories of self-organizing systems (Drazin and Sandelands, 1992). That is, management may respond to external changes by attempting to preserve the *status quo*, but in so doing influence internal deep structures that then cause organizations to gradually evolve to different behaviours and shapes. Copyright © 2000 John Wiley & Sons, Ltd. and ERP Environment.

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INTRODUCTION

Central to many debates regarding environmental policy are questions of how and to what extent organizations respond to pressure to protect the natural environment. Many policy analysts and organizational theorists predict that when faced with threatening new conditions, managers and organizations attempt to preserve the *status quo* (Staw *et al.*, 1981; Ashford, 1993; OTA, 1994). Managers seek to confine responsibility for new conditions to the organization's boundary, and workers seek to maintain existing routines, structures and relations (Galbraith, 1977). Thus, companies change their interface to society, and insulate their internal processes, strategies or structures (Thompson, 1967). This pessimism regarding the potential for organizational adaptation suggests that government should design policies that directly mandate internal change.

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Debates about environmental policy match scholarly debates on organizational adaptation and change. One synthesis of the literature suggests that organizations (and perhaps other social systems) change through a process of punctuated equilibrium (Tushman and Romanelli, 1985). In this view, organizations change only occasionally and only in brief bursts, during which fundamental elements of the organization are disassembled (Gersick, 1991), reoriented, or recreated (Tushman and Romanelli, 1985), and after which the organization converges to behaviours consistent with the new arrangement of these fundamental elements.

That fundamental change might occur infrequently fits with many accepted notions of organizational behaviour, and Tushman and Romanelli (1985) support their model in part by enumerating at length organizational resistance to change. This resistance to change increases as organizations age and grow (Hannan and Freeman, 1977), routines develop (Langer and Weinman, 1981; Gersick and Hackman, 1990) and technological and organizational structures ossify (Abernathy and Utterback, 1978). As a result, organizations can change only in brief moments when resistant interlocking elements are broken and before new structures crystallize.

Punctuated change occurs in organizations because forces sporadically break these interlocking elements. Some general theories suggest that temporal modes can cause punctuated change (Gersick, 1991), but most organizational models suggest that punctuated change results from external events such as environmental regulation or by executive action. Sometimes, research suggests, executives cause punctuated change by attempting to reorient the organization in a burst (Tushman and Romanelli, 1985; Keck and Tushman, 1993). More often, executives choose to buffer the organization from changing conditions. For example, in response to regulation, executives may choose to acquire end-of-pipe filtration equipment to transform process waste into a form acceptable to regulators. This insulation reduces incentives to engage in pollution prevention and other system-wide changes.

Central to notions of punctuated equilibrium is the assumption that basic rules or structures in the organization cannot change incrementally. Gersick (1991) vividly illustrates the point by drawing an analogy to a game of basketball. Play continues until a sudden event precludes it (e.g. removal of the backstop and basket), after which the players develop new rules and begin to play a different sport (e.g. soccer). Thus, 'systems do not shift from one kind of game to another through incremental steps: such transformations require wholesale upheaval' (Gersick, 1991, p 19).

In its rejection of gradualism, punctuated equilibrium models most strongly differ from autogenetic models of organizations. In both, deep structures govern the action of people in the organization, but in autogenetics, through repeated iterations people create new deep structures and even change the observable organization. Autogenetics claims that the manifest organization (the organization one can see in organization charts) results from the interaction of deep structure (tacit rules that govern actions), elemental structure (states of actors and interactions among actors) and observed structure (organizational facts) (Drazin and Sandelands, 1992). A biological analogy best explains the model: deep structure is the genotype – the genes of the organization; elemental structure is the machinery that determines the iteration of these genes and observed structure is the phenotype – the shape and characteristics of the organism. Of course, as in biological systems, environmental conditions may shape development, but they do so through their effect on these internal codes. By providing for the opportunity for more fluid and undirected change, autogenesis allows the possibility that structural changes (even if they appear suddenly) result from incremental low level changes. For example, returning to the biological analogy, gene mutations can go unnoticed for generations until several incremental changes combine to cause the emergence of a new phenotype. Although deep structure change is occurring, on the surface the species appears unchanged. After a while, however, these changes in deep structure bring about a new form.

Organizational response to environmental regulation

As presented above, the two theories represent alternative models of organizational response (see Table 1). In this strong form, they match two perspectives in current debate regarding environmental policy. Nicholas Ashford, for example, has repeatedly argued that firms resist change and thus draconian environmental regulation should be enacted to shock firms into fundamental change (Ashford, 1993). This message has been echoed by other business scholars (Porter and van der Linde, 1995).

Others argue that firms may seem to remain unchanged but actually gradually develop fundamentally new mindsets, strategies and information systems as a result of iterative incremental change (Mylonadis, 1993). A similar process of gradual change in mindsets also can occur at the industry level, scholars argue, and this may cause entire industries to progress through stages of response (Hoffman, 1997). This slow development may be caused in part by human resistance to new ideas (Roome, 1998).

In support of both theories, scholars have observed that companies respond to environmental pressure in stages. Hart (1995), for example, argues that firms must start with PC and end with sustainable development. As noted above, Hoffman (1997) suggests that the entire chemical industry progress through several stages. Consultants such as Arthur D. Little, and government analysts such as the Office of Technology Assessment also have suggested that firms progress through stages of response to environmental regulation (OTA, 1986).

How firms progress through these stages remains an area of active debate. Most scholars suggest that 'top management' direction and support is needed, but a few other scholars suggest that ideas may bubble up from below and provide an internal impetus for change. Lenox *et al.* (in press) argue that in design for environment, low level change agents often act as advocates and entrepreneurs for new environmental management strategies. In a study of two Finnish paper companies, Halme (1996) found that in one facility change was directed from above, while in another it was championed by a mid-level manager.

In summary, the organizational and environmental management literatures both contain two broad perspectives on how firms respond to environmental regulation.

One perspective suggests that top managers determine the response to changing conditions and when possible attempt to preserve the *status quo* (Tushman and Romanelli, 1985, p 178). The formation of a buffer, such as a waste treatment system, is often chosen as a tactic of this preservation (Thompson, 1967; Starbuck *et al.*, 1977; Staw *et al.*, 1981; OTA, 1994). The technological buffer reduces the need for change, and the agents in charge of the buffer seek to remain valuable to the organization by reinforcing their insulating role (Cebon, 1992). As a result, executive direction is usually needed to change to the organization's strategy, structure, technology, controls or values (Tushman and Romanelli, 1985). 'Direct intervention is required precisely because internal forces operate to maintain the *status quo*, often in spite of clear dysfunctional consequences' (Tushman and Romanelli, 1985, p 1980).

Table 1. Comparison of models

	Punctuated equilibrium	Autogenesis
Impetus for change	External shock or prolonged poor performance	Inconsistency in rules, structure and actions exposed through interaction
Internal agent of change	Top management	Distributed. External shock may increase internal inconsistencies
Timing of change	Sudden following shock or at temporal modes	Ongoing
Speed of change	Rapid change and then slow solidification of new form	Iterative

Another perspective suggests that change occurs in a more undirected manner through the repeated iteration of elements within the organization. Change need not be directed from above, nor need it occur soon after an environmental disturbance, nor need it occur in a sudden manner. A disturbance in business conditions such as environmental regulation may alter deep structures in the organization or change elemental structures – the rules that govern the interactions of these deep structures. Over time, these new deep structures and interactions will alter the manifest organization. In more practical language, actors in the organization (and their skills, values etc) change and are changed by organizational rules, technology and routines. Through this reciprocal process a new organizational form can emerge.

This research uses these two perspectives to guide an investigation of the response to environmental regulation in one industry. It explores the extent to which either prediction matches observed behaviour and seeks to understand how and when the two theories can be reconciled. In the remainder of the paper, we first present our research method. Then we describe (i) how firms initially responded to regulation, (ii) the nature of change following regulation, (iii) the process of this change and (iv) some examples of relative constancy. We use our empirical data to suggest how the two theories might be merged and reconciled. Finally, we discuss the implications of such a merging for environmental policy.

RESEARCH METHOD

Comparing the two theories requires studying both high- and low-level change over time. As a result, we used the triangulation methods described by Miles and Huberman (1984): semistructured interviews, structured interviews, archival data and survey data (Miles and Huberman, 1984). To use these multiple research methods, we sought a sample of organizations from one industry that (i) had experienced a relatively recent clear disturbance in its environment, (ii) contained comparable firms and (iii) allowed research access.

Selection of the printed circuit industry

The printed circuit board fabrication industry has many characteristics that make it amenable to our study. First, in the 1980s, environmental regulation changed business conditions in the industry. According to several industry CEOs, this regulation represented the most important new demand on process performance in the 1980s. Second, the industry has numerous similar firms, and thus allows better comparison of response to environmental regulation. Finally, regulators keep records on important changes in facilities, and these are open to the public.

Standardizing the sample to allow comparative analysis

Many facilities in the industry use similar processes and organizational structures and produce similar products. The core of every organization is the electroplating and chemical etching process, which creates a pattern of conductive metal on a laminate substrate. In all of the firms in our study a process engineering manager governed this operation and reported directly to the head of the facility.

We identified 14 facilities that (i) produced rigid multilayer printed circuit boards, (ii) used similar production technology, (iii) were regulated under the same statute and (iv) were within driving distance. Eight of these facilities agreed to participate and allowed extensive access to managers and workers[1]. Sewer authority archives proved invaluable in understanding case histories. Most sewer authorities keep correspondence with each of their customers, and keep records of modifications to process technology and waste-treatment systems.

Research approach

Qualitative researchers generally use two approaches to data analysis: an analysis of data to uncover key themes, and more detailed

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[1] We told managers we were investigating innovation and interaction between departments in manufacturing.

analysis to measure and validate these themes (Glaser and Strauss, 1967; Miles and Huberman, 1984). We used interviews to understand the history of each case and an archival analysis or a structured survey to measure important variables.

Initial response to regulation

To understand how managers and the organization responded to the regulation, we interviewed a member of process-engineering, pollution-control and executive staff. We asked (i) the history of the pollution control (PC) department, (ii) how technology had been acquired, (iii) who made the decisions and (iv) how changes were understood and implemented. After these interviews, we conducted an archival study of sewer-authority records to check these recollections.

Change following regulation

To study how the organization behaved in the years following new environmental regulation, we interviewed company executives and the managers of three departments – quality, PC and process engineering. We interviewed each manager about the history of the plant, the response to regulation and major technical, organizational and strategic changes.

To obtain another perspective on changes and to check the memory of respondents, we reviewed the archives of correspondence between the facilities and the sewer authority to gather longitudinal data on the facility's process technology, treatment systems and water and waste emissions. Each sewer authority must inspect the plant (up to eight times a year) and describe the process technology and products of each plant. If a significant process change is made, companies must send a letter with plans to these regulators. We copied relevant correspondence and created files for each case study. In the two facilities that reported dramatic process improvements and reductions in emissions, we verified the reports by tracking the weekly emissions as recorded by the sewer authority.

Current organizational behaviour

As we will show below, all of the organizations created pollution-control (PC) departments. Our interviews revealed that (i) innovation and (ii) information flow was a critical differentiating aspect of these departments. To understand how these departments influenced the organizational core in 1991–1992, we investigated the degree to which PC personnel communicated with, informed and directly changed the core of the organization.

We used a modification of Allen's method to measure information flows (Allen, 1977). We administered a survey to the managers of process-engineering (PE) and PC personnel. We asked both managers to report the time spent communicating with personnel from other departments (quality, PC, production, maintenance, laboratory etc.). We also asked the PE managers to report the frequency with which personnel from other departments provided helpful information.

To measure the extent to which PC personnel initiated changes to the production process, we used a modification of Allen's method for measuring innovation (Allen, 1977). We asked the PE managers to report the five most important process changes that occurred in the last year. They were also asked to rate the members of each of the three groups in terms of their role in (i) 'identifying the opportunity or need that became the impetus for the change' and (ii) 'designing the change'. The managers were then asked to indicate the effects of these process changes on product, production capabilities, production costs and PC. Because measures based on discrete changes can be noisy, we also asked PE managers to judge the degree to which personnel from various departments made process changes (five-point Likert scale).

FINDINGS

Response to regulation: managers protect core process

Regulatory requirements for water-borne emissions increased sharply and dramatically in the early 1980s and then stabilized for the remainder of the decade. As late as 1980, most printed circuit companies faced few environmental regulations. Most sent their waste-water to sewer authorities, and these regulated only the acidity of emissions into the sewer system *so as to protect municipal piping*! Between 1980 and 1983, in anticipation of new Clean Water Act regulations, most sewer authorities switched to tough new emissions regulations. The level of these regulations was standardized on 15 June 1983 when the federal government promulgated standards for the industry.

Executives and top managers direct response

In response to new environmental regulation, a senior member of the technical staff and a top executive in every facility selected certain waste-treatment technology and formed a new department so as to allow the rest of the organization to continue unchanged (see Table 2 for actors involved in each facility). All executives interviewed remember the decision as a necessary step to reduce risk of regulatory trouble. As the president of one company expressed it: 'Make my industry stable and I'll look to making my industry better.' Or as another said, 'It's easier to pay someone to operate a waste-treatment plant than put up with meddling in manufacturing'.

Technological choice suggests attempt to buffer core process

In general, managers chose to acquire waste treatment technology that maximized the degree to which PC could be independent from production. In the early 1980s, two main treatment technologies existed for treating waste from printed circuit facilities: clarification or ion exchange. Firms that chose to purchase a clarifier could then choose from several chemical systems – ferrous sulphate, DTC, TMT-55 and borohydrate. Ion exchange is less costly to operate, but requires the separation of some waste types and is relatively sensitive to changes in the production process. Employing this technology thus requires coordination between PC and production. At the other extreme, ferrous sulphate is costly to operate and produces large amounts of sludge, but is very insensitive to production changes. Indeed, ferrous sulphate clarification is sometimes sarcastically called the 'American system', because waste-treatment operators can independently (but inefficiently) solve most problems simply by adding more ferrous sulphate. Between the two extremes, DTC and borohydrate are reputed to be more sensitive to process change. As shown in Table 2, executives in all but two facilities chose to acquire ferrous sulphate clarifiers to remove metal contaminants from waste water. One facility initially installed an ion-exchange system and then installed a ferrous sulphate clarifier[2]. One facility that began later chose to use DTC.

The extent to which managers sought to insulate the organization from any potential regulation also can be gauged by the technology sizing decisions. In all cases, managers sized waste-treatment equipment for expected growth *plus* an enormous reserve (see Table 2).

The records show no evidence that managers expected that facility changes would reduce the need for waste treatment. Consider, for example, the decision of the president of facility D (in a letter from the consulting engineer on the project explaining the decision to the sewer authority):

> Presently [facility D] discharges approximately 20 000 gallons/day ... or 40 gallons/minute. Average production has been determined to be 643 sq. ft/day. Allowing for at least 50% increase in production and, consequently, water usage over the next 3–4 years, the treatment system would have to be sized to handle a maximum flow rate of 60 gallons/minute. However the [president] has required that the system be designed to handle a maximum flow of 100 gallons/minute.

More than ten years after this decision, facility D produced three times as many printed circuit boards and (due to an increase in multilayer production) more than five times a much surface area. Using their original calculation they should have used between 60 000

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[2] More details on this story are presented later.

Table 2. Top managers chose to create robust technical and organizational buffers to environmental regulators

Plant	Actors in decision	Treatment technology	Year	Sizing	Origin of PC department manager	Initial role of PC department
A	Plant manager; process engineer; facilities manager	Clarifier and ferrous sulphate	1980	30% over peak (for 1984 upgrade)	Facilities manager and new hire	'Everything was end-of-pipe'
B	Owners	Clarifier and ferrous sulphate	1984	1.5–2 times average expected	New hire	'Design [treatment equipment] and leave'
C	N/A	Clarifier and DTC	New plant in 1986	3 times expected	New facility	'. . . treat waste that's sent'
D	President; methods engineer	Clarifier and ferrous sulphate	1981	1.5–2 times expected	New hire for PC manager	Environmental engineers 'resisted [process] change and liked to work only with [treatment] equipment'
E	Vice president; process engineer; facilities manager	Clarifier and ferrous sulphate	1981	2–3 times expected	Technical manager to PC manager	'Try not to do anything that would cause production problems'
F	Corporate office; manager of plant enginner; process engineer	Ion exchange clarifier and then ferrous sulphate	1982; 1984	1.5–2 times expected (for 1984 system)	New hire for PC manager	'Compliance' with regulation and 'internal compliance'
G	Corporate office; process engineer	Clarifier and ferrous sulphate	1980	1.5 times expected	Engineer staff and new hire	'. . . just sludge puppies'
H	Owner; process engineer manager; special projects manager	Clarifier and ferrous sulphate	1984	1.5–2 times expected	Facilities manager to PC manager	'Fill out forms'

Table 3. By 1991, some PC departments were active innovators, process changers and important sources of information

Facility	Innovation rate[a]	PC procedure change activity	PC gives helpful information to PE	Communication hours per week (PC–PE)[b]
A	67	Active	Every day	2
B	50	Very active	Several a month	3
C	30	Active	Every day	5
D	46	Inactive	Several a month	4
E	?	Active	Once a month	4
F	18	Very inactive	Several a month	2
G	11	Very inactive	Once a week	1.25
H	8	Somewhat inactive	Less than monthly	0.5

[a] Percentage of innovations reported by PE manager attributed to PC personnel.
[b] Average of PC and PE reports.

and 100 000 gallons/day. Instead, they used 25 000 gallons/day or *about half the capacity* of their ten year old waste treatment system. Although over the next ten years most of the eight facilities grew by more than 300% in sales and production (square feet of boards), not one of the treatment systems reached capacity.

Pollution-control department formed to be organizational buffer

Purchasing and installing the treatment systems represented a substantial cost (total capital cost could be 5% of one year of sales), and often took more than a year. During this time, executives changed the organization to include a new department to manage the new technology and communicate with regulatory authorities. In five of the eight companies, managers hired a new employee to head this department. In three companies, the PC departments and the role of the 'PC manager' developed more slowly from existing structures and personnel (usually the Facilities Department).

Managers at all of the plants agreed that in the early 1980s the job of PC was to 'treat what production sent them' (facility C)[3] and that PC should 'try not to do anything to cause production people problems' (facility E). PC personnel reported that they had little communication with process engineers, because as one said, 'we were just sludge puppies' (facility G). In facility D, a consultant reported that the 'environmental engineer [resisted] change every step of the way... [liked] to work only with the environmental equipment and [didn't] like to think about the process'. In facility H, a PC manager said his job had been to 'fill out forms'. As a manager in facility A said, 'Ten years ago everything was end-of-pipe, and only five years ago we realized that source reduction was important'.

Change following regulation: some buffers become change agents

By 1991, some PC departments no longer operated as organizational buffers (see Table 3). Some were active in changing the production process, and indeed had become important agents in improving process performance and quality. In facilities A, B and C, the process engineering reported that PC personnel were active in changing the production process. They also reported receiving information that helped to improve the production process from PC personnel more than 'several times a week'. Finally, PC and PE managers reported talking with each other between 2 and 5 hours a week – more often in each case then they communicated with quality staff.

Tracking the source of major process changes also revealed the importance of some PC departments. Of 33 process innovations listed on the survey, 13 were attributed to PC

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[3] This manager was referring more to his previous experience at another company than to his experience at facility D. Facility D started in 1986 and seems to have incorporated learning from previous companies.

personnel. In two facilities (A and B), the Process Engineering Manager rated PC personnel as more important on average than *his own staff* in initiating change to the production process. In two other facilities (C and D), PC personnel were the second most important source of process changes. Moreover, PC driven process changes appear to be real innovations, not simply attempts to reduce effluent. Of all the process changes attributed to PC personnel (13), all but one resulted in a reduction of process costs, 61% resulted in quality improvement and 38% in extension of production capabilities. (In contrast, of all the innovations attributed to quality personnel 40% resulted only in quality improvement.)

Our data suggest, however, that in facilities F, G and H PC personnel continued to act as organizational buffers. They interacted infrequently with core personnel and infrequently influenced the core process. Facilities D and E represent intermediate or perhaps transitional cases. In facility D, the PE manager attributed several process changes to PC personnel, but then rated the PC department as 'inactive' in process change. In facility E, the PE manager reported that PC personnel were active in changing the production process, but not in providing useful information. We discuss these two facilities in more detail later in this paper.

The process of change: iterative evolution of roles and technology

We interviewed personnel and conducted archival analysis in eight plants to understand how and why the behaviour of some PC departments changed in the years following regulation. We found that PC technology and personnel brought a new agent into these organizations and a new source of information. PC personnel have an incentive to reduce process waste and anomalies. Reducing such anomalies allows PC to use more efficient (but also more sensitive) control technology, and reducing anomalies improves the performance of the production process. As one PC manager said, 'almost anything that I can do to help the production process helps me [to treat waste]'.

In our interviews, PC personnel explained that they could be effective in changing the production process because their role in treating the waste allowed them to acquire unique and useful information. To illustrate this, several told us that if the water in the treatment process turned blue it generally meant that chelated copper was leaking under particular squeegee rollers. Since PC personnel treat production waste from numerous stages and locations, they have access to information about the entire system. Thus, like a doctor diagnosing a disease, they can infer information about the production process from the nature of the process waste. PC engineers also said that they had unusual access to information from outside the company, because regulations cause them to gather and store detailed technical information. As a result, members of the organizational core sought out PC personnel to acquire information. Often, during an interview of the PC manager, someone from production or PE would interrupt to ask for some information. Sometimes, the questions related to issues of PC, but just as often, PC managers received requests for information not directly relevant to PC.

Why were PC personnel still able to acquire new and valuable information ten years after the regulatory shock? We found evidence that this information was part of an iterative, self-sustaining process of change. Usually the process began when changes in treatment technology increased the sensitivity of PC to changes in production. This sensitivity provided information to PC personnel and motivated them to understand and improve the production process itself. As PC personnel improved the production process, their relations with the rest of the organization and their roles changed to allow greater interaction between PC personnel and personnel in PE (see Figure 1). Improvements in the production process and changes in roles then allowed them to change their treatment technology, and the process began the next iteration (see Figure 2 for an example from facility A). In three facilities (A, B and C), this process led to iterative changes in treatment technology, organizational relations and eventually organizational structure. In both of the

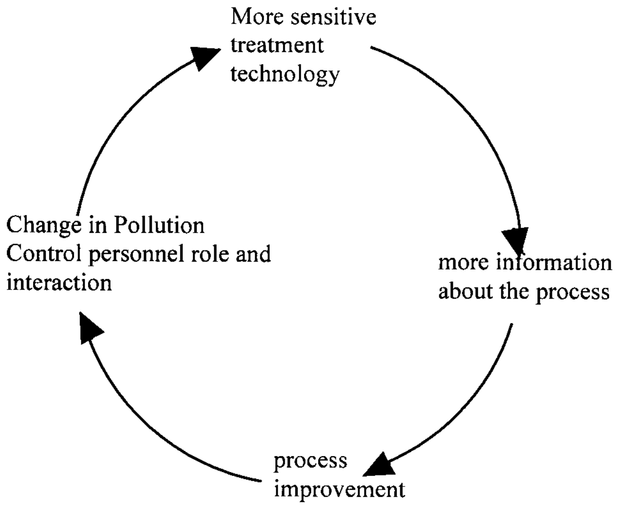

Figure 1. Iterative change of technology, process and roles.

companies, the process led to an official change of the title and responsibilities of the PC manager[4].

Two other facilities reported a similar process of incremental technical and organizational change. In facility C (started in 1985), the process seems to have started at a more advanced stage. In facility D, physical barriers to interaction between PE and PC seem to have decreased the rate of iterative change.

In facility E, we found conflicting and almost schizophrenic impressions of the role of PC personnel. Our survey showed that the PC manager was 'very active' in making process changes, and for this reason, we were told, he was given the responsibility of managing the facility's laboratory. When we first visited the site we were told by the owner that the PC manager was 'the only one who really knows what is going on around here'. Twice during one interview with the PC manager, process personnel interrupted to ask for help with production problems (squeegee roller buckling and gold plating line miscalibration). On the other hand, the PC manager felt that his main role was still to 'protect the plant from [the regulating authority]'. On this, the owner of the organization concurred, but the process manager vigorously disagreed. We believe this seeming inconsistency to be a reflection of the facility's history. During the 1980s, this company was cited for compliance problems and the owner saw these as a personal attack. Although the PC Manager's *de facto* role seems to have changed, the owner's personal opinions and feelings may have impeded the PC manager acquiring an *officially* larger role.

PC departments cause broad changes

One might expect that changes initiated by PC personnel would be limited and narrow, but in some organizations, the iterative changes in technology and behaviour brought on by PC workers were broadly influential. In fact, in facilities A and B changes initiated by PC led to substantive changes relative to all of the criteria that Tushman and Romanelli (1985) suggest are needed for a fundamental change in the organization (or, in their words a reorientation; see Table 4). PC activities helped change the firm's strategy, power relations, structures, controls and perhaps even the firm's core values[5].

In these and other facilities PC initiated board changes through several means. First, as PC personnel became more involved with the production process they directly influenced organizational behaviour by acting as 'big QC guy(s)', or by teaching classes in TQM methods (facility C). One PC manager (C) called the research team after completing the survey to ask about how to reduce problems with worker 'mind [expletive]s' (i.e. mindless mistakes). He had tried teaching a TQM class and organizing improvement teams, but he still was not satisfied.

Second, PC began to act as intermediaries and facilitators of innovation. As one PC manager said: 'The guys [production workers] often talk to me first, and I tell them to go talk to [the PE manager]. Sometimes I go directly to [the PE manager] but usually I tell them, 'hey, he'll be interested' and then tell them what to say . . . how to talk to him' (facility E).

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[4] Appendices with more details on these companies were removed to save space. They are available from the author on request.

[5] In facilities C and D, we found evidence that controls and values changed, while in facility G, structure and controls changed. The other three facilities exhibit less change as a result of PC activity.

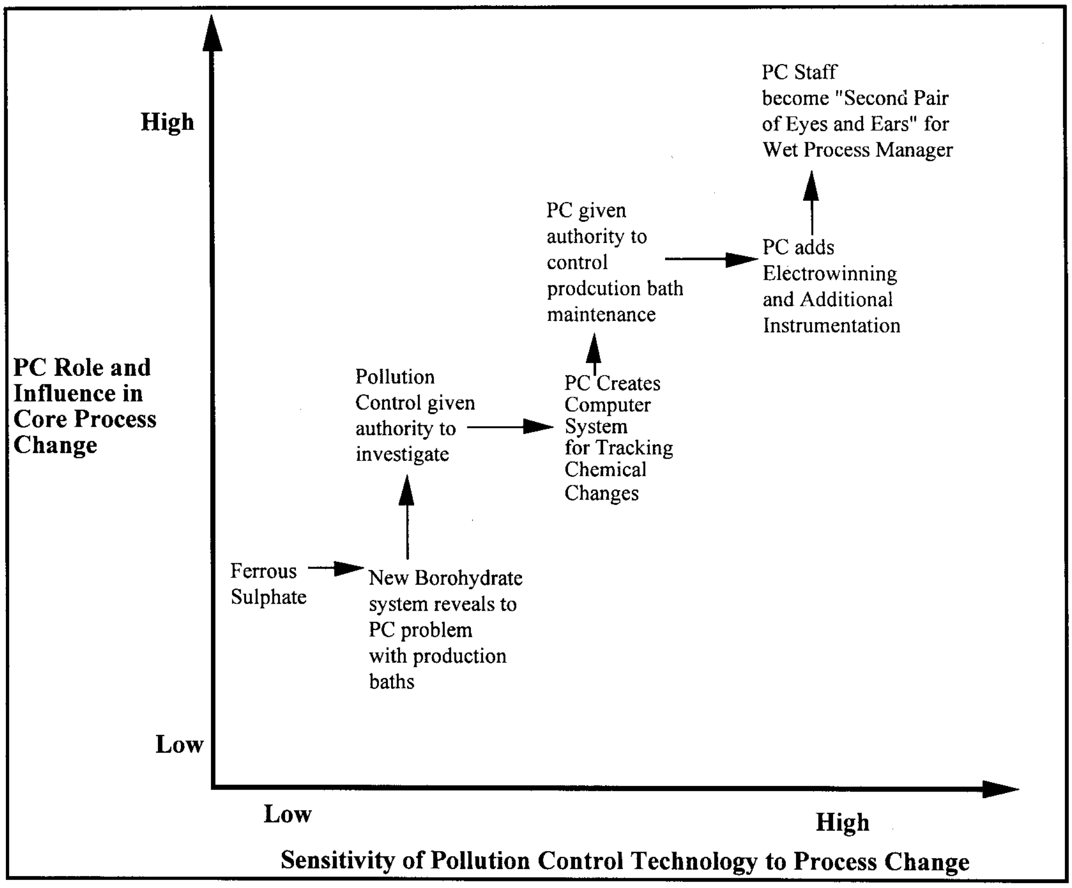

Figure 2. Iterative process leads to progressive change.

Third, PC technology caused more thoughtful responses to errors. Workers could no longer wash spilled or spoiled chemicals down the drain, and instead had to learn to take more considered action.

Finally, the skills and procedures that workers adopted in response to PC facilitated the acquisition of other skills. For example, PC caused improvements in production work that then allowed the firm to more easily shift to smaller production lots. One manager (E) told us that his company was gradually 'evolving' in response to PC as workers became more 'cognizant of spills . . . and all kinds of things'. These more thoughtful workers had helped make the process more 'transparent to workers' and thereby facilitated the movement to small lot production.

Relative constancy: some PC departments remain buffers

Three facilities (E–G) reported behaviour that more closely matched the initial buffering role. Why did the iterative process of change fail to begin or to progress as far in these organizations? One possibility is that conditions necessary for initiating the iterative process never existed. In each of these facilities, PC personnel were (and are) located a great distance from the engineer and process personnel. It may be that this distance prevented inference between waste and process performance or impeded the development of closer interactions between PC personnel and the rest of the organization. In these organizations, PC personnel remained an autonomous filter between the production process and regulating authorities.

Table 4. Incremental change led to change equivalent to an organizational reorientation

Criteria for reorientation	Example from facility A	Example from facility B
Strategy	The plant switched from competing on product reliability to competing on product *and* process reliability. To demonstrate their commitment to process reliability, the company placed a photo of the waste-treatment system on the cover of their marketing brochure and added 'environmental quality' as one of their four strategic thrusts.	Owner reports that environmental changes caused the company to shift from selling 'Chevys' to selling 'BMWs'. Thus the company began providing more sophisticated products on a quick-turn basis. In addition, the company added PC consulting to its products.
Power	In the early 1980s, the process engineers rejected even simple suggestions from PC workers. By 1992, PC personnel were reported to be 'secondary process engineers'. PC personnel were moved to head the laboratory and wet-process engineering.	Company originally hired a consultant to make a treatment system and expected him to be gone in 90 days. Over 9 years, he was hired into the company, promoted to PE manager and eventually became a part-owner.
Structure	In response to the success of plant level PC, corporate executives created a corporate-level PC office and staff. Facility staff were promoted to this job.	PC department became one of the three main divisions in the organization (with operations and marketing/scheduling) and then became Advanced Engineering.
Control	PC personnel instrumented a new computer system for tracking production, a new computer system for tracking chemical changes and a new procedure for monitoring and disposing of chemical baths. PC personnel gained control of process baths.	Company adopted a new technical and procedural system for controlling image development.
Values	Pollution control changes from garbage men to 'second pair of eyes and ears'.	Process engineering manager: 'Doing waste-treatment correctly, [you] expose a lot of problems . . . They [the regulators] gave us a couple aspirin and we felt a lot better'.

The history of facility F suggests the importance of iterative change in preparing the ground for new technology and processes. In facility F, management chose to respond to regulation by purchasing an extremely sensitive treatment technology (ion exchange). Sewer archives show that the Manager of Plant Engineering chose this technology because he wished to avoid sludge disposal costs and to reduce water consumption. Unfortunately, sewer records suggest that PC personnel did not have the skills to manage this technology, nor was the production process ready to receive it. In June 1984, the local sewer authority (responding to complaints from residents) found the plant to be out of compliance for copper emissions, and process engineers discovered that the treatment system had been severely damaged. As a result, the Manager of Plant Engineering took over responsibility for PC, added a robust treatment technology to their system (ferrous sulphate clarifier) and ceased to use the other system.

This story suggests that the production personnel and process were not ready for the introduction of this sensitive system. According to industry experts, the problem with facility F's treatment system occurs when lead waste is discharged into a copper waste stream. It is likely, they suggest, that production personnel accidentally discharged lead waste into the copper stream and damaged the PC equipment. Revealingly, following the difficulty, the facility also 'renewed employee awareness sessions on the matter of PC . . . '.

The record also suggests that PC personnel had not yet learned to interpret signals from the waste-treatment system. PC personnel not only failed to diagnose the cause of the damage to the treatment system, they did not even recognize that the waste-treatment system was damaged, and only discovered the problem after *green foam began to escape from nearby manhole covers alarming local residents.*

Interestingly, after a hiatus of 8 years, the facility's organizational practices may have improved to allow the implementation of a highly sensitive treatment system. In 1987, PC moderately increased the sensitivity of the waste-treatment system. In 1992, their new PC manager told us he was working hard to let everyone in the plant know that 'the black box on the end of the pipe [waste-treatment] is not omnipotent'. He was trying to change the old attitude that 'as soon as I've done with it [production waste] I'm opening the valve [sending it to waste-treatment] and washing my hands of it'. This attitude, he said, was common among production workers and processing engineering 'was a party to it'. In 1993, they purchased a more sensitive treatment system. Thus, by the early 1990s the iterative process of change may have been advancing in facility F.

CONCLUSION

In this article, we show that managers directed the initial response to a change in environmental regulation. As predicted by punctuated equilibrium theories, managers attempted to preserve the *status quo* by acquiring technology and personnel to protect the organization from regulators. In other organizations, this technology and personnel independently acted as an effective buffer to new regulations and allowed the core organization to remain unchanged. In some organizations, however, these very elements set in motion a process of incremental but eventually fundamental change. They did so by iteratively changing their interaction with the rest of the organization and their own attributes. As they became more sensitive to the core organization, they also became more interconnected, useful and influential. In some cases, they helped reorient the organization.

Thus, this research suggests a link between punctuated equilibrium models of organizational dynamics (Tushman and Romanelli, 1985) and theories of autogenetic systems (Drazin and Sandelands, 1992). As suggested by punctuated equilibrium, executives direct the response to external changes – at least initially – and tend to attempt to preserve the *status quo*. However, in so doing managers influenced internal deep structures that then cause organizations to gradually evolve to different structures and behaviours.

This research also links divergent theories of environmental management. It supports theories that managers will tend to buffer themselves from regulation rather than initiate broader organizational and operational change. It shows, however, that this very attempt at buffering may then cause changes in mindsets, organizational structures and operational practices that allow the firm to engage in profitable pollution prevention. It shows how repeated interaction within an organization can expose the potential for mutual gains and thereby change mindsets and perceptions. As these mutual gains accumulate, participants begin to change their roles, their perceptions and their expectations of the value of future actions.

This research shows how and why companies evolve through a series of stages – each of which is useful in advancing to the next. Thus, it helps clarify the theories of Hart (1995) and Russo and Fouts (1997) who suggest that environmental management should be perceived as the progressive development of capabilities within the firm. Hart, Russo and Fouts also argue that environmental capabilities can be protectable because their nature and functioning is often hard to observe. This research provides an example of such inscrutable capabilities. As our data indicate, none of the managers recognized the potential value of PC personnel until regulation forced them to hire them. Thus it seems reasonable that such advantages might be very hard for other firms to discern and thus might provide a sustainable advantage.

For practitioners, this research suggests a new perspective on the role and value of PC personnel. Managers, it suggests, should see them not as a cost centre but as a potential source of valuable new information and innovative ideas. As a result, managers should locate PC personnel near to other line personnel (both organizationally and physically) and provide opportunities for interaction.

For policy makers, this research suggest that a defensive, end-of-pipe response does not preclude a more integrated and complete response. Thus, its appearance does not signal the need for tougher regulation. Change may indeed be occurring below the visible surface of the firm.

Future research should consider the extent to which PC departments are unique in their ability to initiate and sustain iterative change. As discussed above, PC departments must process mistakes and waste from other departments, and thus internalize costs that are external to other tasks in the organization. They use sensitive technology and perform a sophisticated process that allows them (and perhaps even requires them) to interpret and understand the core process. Thus, our research suggests that the following combination of deep and elemental structures may be important: (i) incentives to improve the core process and (ii) interconnections that allow access to universally valuable information. Other organizational entities also possess these attributes to greater or lesser degrees. Quality departments, for example, internalize quality costs and diagnose production problems by inspecting off-spec products. Future research may find other organizational entities that may belong to this class of meddlesome boundary-spanners.

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