ORGANISATIONAL CAPABILITIES FOR SUSTAINABLE PRODUCTION

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Abstract

This study brings together insights from the research literatures on organisational capabilities and learning by doing to examine the response of Irish manufacturers to tightened environmental regulation in the 1990s. Using a fine-grained data set on firms' technology and management practices, we test whether those practices over time resulted in the creation of learned 'static' capabilities, the ability to do certain kinds of things well in a given context. We also examine whether better-performing companies displayed higher levels of ‘dynamic’ capabilities – the capacity to change and adapt through integration of new information internally and from external sources – which we model as fixed during the period studied. Finally, we bring the first two research questions together by exploring whether firms with stronger dynamic capabilities were more likely to develop significant static ones within the time frame of interest.

1 Introduction

Systematic investigation of the relationships between environmental and economic performance in business is high on current research and policy agendas, in order that the EU imperatives of growth and environmental quality might be bridged (Joint Research Centre 2004). A key question in this regard is the following: What determines inter-firm differences in environmental impact reduction when faced with heightened regulatory standards, as has occurred broadly world-wide and especially in the European Union in recent years? We approach this question through the idea of ‘organisational capabilities’: that over time, firms must develop the ability to perform core functions and activities well enough to meet the most pressing requirements of their competitive environments.

In the previous era of cheap energy and general unawareness of environmental damage arising from production, firms developed competitive capabilities without regard for what we now call sustainability. Recent decades’ rapid increase in market and regulatory demands for environmental performance has led to uneven responses among producers. Some have leveraged existing capabilities toward fundamental innovations in sustainable products and processes, others have remained mired in competitive strategies based on old ways, and most are somewhere in between. We seek to understand how firms evolve into these groups by using a fine-grained dataset we have created on Irish manufacturers to study the role and formation of innovation-boosting capabilities aimed at more environmentally sustainable production.

The paper is based on research funded by the Irish Environmental Protection Agency. Ireland was an early adopter, in 1994, of the European regime of Integrated Pollution Control (IPC) licensing. The project examines the initial decade of this Irish experience, asking whether differential organisational capabilities across firms affected their ability to meet IPC licensing requirements. For facilities in three industry sectors, we have constructed a database on environmental and economic performance; environmental technology and management practices; and organisational capabilities that may complement the efficacy of practices in generating performance. We explore the following research questions:

First, are (some) firms able, within the time frame studied, to accumulate new organisational capabilities that are ‘static’ – in the sense of doing particular kinds of things well in a given competitive situation – that help explain differences in their environmental performance? Lacking observable information on static management and technology capabilities, we borrow from the ‘learning by doing’ literature (Argote and

Epple, 1990) to define static capability variables whose values are inferred from measurable experience with the given kinds of activities. Second, are differences in the efficacy of environmental management and technology practices during the IPC period affected by cross-firm variation in a specialised set of capabilities geared toward organisational change, or 'dynamic capabilities' (Winter 2003)? Related, do differential underlying levels of dynamic capability help explain the extent to which companies are successful in learning and adapting, as measured by the strength of static capability accumulation?

In the next section, we discuss the relevant issues emerging from the literature on organisational capabilities, including the application of these concepts in understanding environmental sustainability. Section three presents our empirical building blocks: the information generated through the Irish IPC program; how we use it to construct variables for environmental performance, environmental practices, and corresponding organisational capabilities; and the sample. In section four, we present empirical tests and some very preliminary results on our research questions, and in a concluding section discuss the implications of the research.

2 Organisational capability and learning

2.1 Static capabilities

We can think of organisational capability as the capacity to mobilise and deploy resources in competitively useful ways. This rough definition suggests that capability is itself a resource—but one the literature has struggled to define. According to Loasby (1998: 144), '(c)apabilities .... are in large measure a by-product of past activities but what matters at any point in time is the range of future activities which they make possible.' We look first at the second issue, what that 'range of future activities' might entail. Capabilities have most frequently been defined in relation to the outcomes or performance that they enable (Dosi et al., 2000). 'Competences/capabilities are capacities for structuring and orienting clusters of resources – and especially their services – for productive purposes ... ' (Christensen 1996: 114). Helfat and Peteraf (2003) use the definition 'an organizational capability refers to the ability of an organization to perform a coordinated set of tasks, utilizing organizational resources, for the purpose of achieving a particular end result.' (p. 999). We return at the end of this section to consideration of environmental sustainability as outcome or end result.

But where does this ability come from? We now take up Loasby's first concern, with capability as 'a by-product of past activities' (1998: 144). Becker suggests that capabilities arise when routinised patterns of behaviour 'generate learning-by-doing effects' (2005: 828). Thus the effectivity can be two-directional, with the repetition of patterned behaviour building capability as it is honed and tested in achieving the particular outcome. A large literature on learning curves in manufacturing (see Argote and Epple, 1990) also addresses the notion that companies learn by doing: As experience increases with a technology or product, production grows more efficient. This research has intersected somewhat with the organisational capabilities literature (see for example Costello, 1996, and Figueiredo, 2003.) Because it focuses on unit costs in manufacturing, the traditional learning curve approach must be adapted for thinking about organisational learning, to which we return in section 3.

For now, we emphasise that learning by doing involves the accumulation of experience with a particular set of competitively important tasks. What evolves through this experience is "...the knowledge base of the firm as leading to a set of capabilities that enhance the chances for growth and survival" (Kogut and Zander, 1992, p. 384). Companies must become competent at meeting the demands of a given competitive regime. In that sense, these learned capabilities are what we call 'static,' or what Winter (2003, p. 992) calls "zero-level capabilities," which facilitate organisational performance along some dimension of a given set of product-process-market conditions. They represent the capacity to do particular kinds of important things well within a given context.

2.2 Dynamic capabilities

We entered this research with the working hypothesis that some companies were better equipped than others to translate IPC-related activity into new capabilities and then back again into more effective IPC practice. Organisational change is difficult. The evolutionary, capabilities, and resource based literatures have from the very start emphasised the sticky, path-dependent nature of change (Penrose, 1959; Nelson and Winter, 1982). Organisational knowledge is cumulative in nature, built up by experience and time, both a source of firm uniqueness and a barrier to imitation. But it can act as a constraint on change, as path-dependency can become lock-in.

Is it possible that there is a special kind of capability that allows firms to loosen this constraint, responding to changes in the competitive environment by learning new static capabilities? In proposing the language of evolutionary economics, Nelson and Winter approached this problem by defining deliberate learning as the activity of 'search': 'routine-guided, routine changing processes' (1982: 18) which are themselves routines that 'operate to modify over time various aspects of [firms'] operating characteristics' (1982: 17). This idea has evolved into the notion of 'dynamic' capability. Teece et al. (1997) develop this as a concept of higher-order capabilities. 'We define dynamic capabilities as the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments. Dynamic capabilities thus reflect an organization's ability to achieve new and innovative forms of competitive advantage given path dependencies and market positions' (Teece et al., 1997, p. 516).[1]

Winter (2003) has examined the concept of dynamic capabilities as well, proposing that we understand them as first-order change capabilities, consisting of the capacity for search and learning, and mobilised toward the end of creating new zero-order

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[1] The development of the concept may also be seen as a response to criticism that the automaticity implied in Nelson and Winter's concept of routines means that the evolutionary economics theory of the firm is as deterministic as the neoclassical theory of the firm (O'Sullivan, 2000).

(static) capabilities. He distinguishes dynamic capability as patterned routinized processes and specialized resources for change. While we agree that dynamic capabilities entail rational, routinised approaches to change, we will step back a bit from making this too dependent on the role of routines for 'articulation' and 'codification' of new knowledge (Zollo and Winter 2002). Especially for the kinds of small to medium sized firms that make up most of our sample, and especially (as Zollo and Winter recognise) in times of turbulence in the competitive environment, the 'experiential' or even ad-hoc dimension of dynamic capabilities needs to be examined. Despite the absence for the most part of formal processes, are some firms systematically better learners and adapters than others?

In summary, we focus on three questions arising from the theoretical literatures:

> Can we identify static organisational capabilities that enable firms to perform effectively (perhaps some more than others) in key dimensions defined by a given competitive environment?
>
> If so, over what kind of time frame are such capabilities subject to purposeful change through decision processes that assess and implement new ways of doing things?
>
> And finally, can we locate dynamic capabilities specialised in effecting such deliberative learning of new static capabilities?

These questions suggest that empirically, we might look for changes in static capability during the less-than-a-decade span covered by our data, while the higher order dynamic capability might be treated as fixed over such a period.

2.3 Organisational capability and environmental sustainability

Before moving to empirical representation, let us look briefly at what kinds of organisational capabilities should be of interest with respect to the problem of sustainable development. Much early discussion of the role of firm-level innovation in easing the tradeoff between economic and environmental performance centered around the "Porter hypothesis" (Porter 1991; Porter and van der Linde 1995). The argument is that well designed environmental regulatory tightening might not impose costs on industry due to offsetting, induced technology innovation and diffusion. Many economists criticised the Porter hypothesis for suggesting that firms' existing technology and organizational choices are systematically missing achievable improvements (Walley and Whitehead 1994; Palmer et al. 1995). These critics argued that even if profitable but cleaner technologies exist, evidently search and adoption costs outweigh the private benefits.

Even researchers sympathetic to the Porter hypothesis have cited its lack of a coherent theory of how firm-level innovation and diffusion occur (Hilliard 2004). But an explanation of why 'environmental regulation does not lead inevitably to innovation and competitiveness or to higher productivity for all companies' (Porter and van der Linde, 1995, p. 134, emphasis added) might be provided by the theory of organisational capabilities. Old managerial and technological capabilities might be seen as retarding the emergence of cleaner but profitable innovations, and dampening the recognition and diffusion of those that already exist. Thus a capabilities-oriented framework could be suited to explaining the systematic presence of such phenomena that is intrinsic to the Porter argument (Gabel and Sinclair-Desgagné 1997; Jaffe et al. 2000).

Empirical research on the circumstances of environmental management decision making has observed the existence of a considerable body of practice that can be explained through a capabilities theoretic lens. Behaviour changes and performance improves when tightened regulation or changed corporate priorities induce a shift in managerial focus, so that options that were previously not very far out of sight come into view. Firms develop expertise in closely related technical and mangerial skill sets, such as pushing source reduction deeper into the chemical process chain in pharmaceuticals (Hilliard, 2002), or finding non-solvent substitutes for metal cleaning and coating in metal fabrication (Goldstein, 2002).

This research suggests that variation in firms' environmental performance is driven by differential organizational capabilities in combining related skills, technologies, and work processes regarding environmental management and technologies. Both the demand for environmental performance and the set of tools for satisfying it are evolving rapidly, and therefore dynamic capabilities are a key concern. In Ireland from the mid-1990s on, what needed to be learned was how to meet the newly imposed survival tests of IPC licensing. Companies were asked to respond to a changed competitive regime by becoming (more or less) adept at doing the kinds of things it required.

We turn now to the problem of how to use the available data to build up the layers of empirical representation required to begin to test these interrelated propositions.

3 Data sources and constructions

3.1 IPC licensing in Ireland

In 1992 the Environmental Protection Agency Act[2] established a national authority to assume the environmental responsibilities previously held by local authorities and in 1994 introduced integrated pollution control licensing (IPC) of industry.[3] The new regulatory regime was a radical change, replacing two previous environmental emissions licences: water and air. Under the old regime firms complied with static emission limit values (ELVs) set at the time of licensing and not subject to subsequent review. The IPC regulations, in contrast, demand continuing reduction of

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[2] Environmental Protection Agency (Establishment) Order, 1994 (S.I. No. 213 of 1993).

[3] Environmental Protection Agency (Licensing) Regulations, 1994 (S.I. No. 85 of 1994)

environmental impact and a shift of emphasis to pollution prevention rather than pollution treatment.

The impact on firms of the new regulations is a substantial competitive premium on managerial and technological capabilities for environmental impact reduction. Firms are required to meet standards for the emission of pollutants, but above that they are required to put in place environmental management and information systems, establish environmental management plans that set goals and report on progress, and demonstrate a continuous effort to upgrade their environmental performance through the adoption of cleaner technologies. The license includes the following key components:

Environmental technology: Standards for water and air emissions are set with regard to BATNEEC (best available techniques not entailing excessive cost). BATNEEC defines the level of environmental control to be employed by firms based on what is technically achievable. The EPA has made explicit its intention that all facilities should work towards attaining current BATNEEC, notwithstanding the provision of the legislation that it is mandatory only for new facilities. The explicit aim is the development in licensed firms of an environmental strategy focused on cleaner technology, rather than ‘end of pipe’ approaches: ‘It should be clearly understood that achieving the emission limit values does not, by itself, meet the overall requirements in relation to IPC. In addition to meeting such values the applicant will be required to demonstrate that waste minimisation is a priority objective...’ (EPA, 1996, p. 1).

Environmental management: Progress toward cleaner production is to be carefully planned, managed, and reported. Licensed firms are required to develop a five-year environmental management programme of projects and to submit an Annual Environmental Report (AER) to the EPA. Included in the AER are details of all environmental projects being carried out, with measurable goals, target dates and progress made. Firms must also develop procedures for environmental planning and management. The EPA is unusual among EU regulators[4] in its explicit focus on the activity content of structures for environmental management, including ‘document control, record-keeping, corrective actions etc.’ (EPA, 1997, p. 7).

The information available at the EPA includes monitoring results for facility-specific emissions, sites, and frequencies as designated by the Agency; reports of audit visits by the EPA inspectors; correspondence between the firms and the Agency; and the firm’s annual environmental reports (AER). Companies’ files at EPA offices thus contain detailed records of managerial activities, technology projects, and environmental outcomes for the years under license. In addition, a separate file contains the initial IPC license application for each firm, including information about technologies and systems in place and whether BATNEEC status has already been achieved. The application file thus provides a snapshot of pre-license period activity

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[4] A similar approach is taken in the Netherlands (Wätzold et al., 2001).

and expertise.

While most of our information is from the EPA's license application and annual files for each company, we have supplemented it with a mailed-out survey questionnaire to all sample firms. The response rate was 26% of firms that had not ceased production. Its basic focus is to provide us with information about organisational practices beyond that thought relevant by EPA given the purposes of its own data collection. We will note below where survey responses are utilised in variable constructions.[5]

3.2 Variable definitions

We have used this detailed information about the technological and managerial practices of sample firms, and their specific requirements under the demands of environmental regulation, to create measures of environmental performance, practice, and capability. Our methodology for the first two, along with preliminary statistical results on the determinants of environmental performance, are the focus of another paper (Goldstein and Hilliard, 2008). We include them briefly here because (as seen below) they are the basis for defining and measuring capability.

3.2.1 Environmental performance variables

The performance phenomena that matter, and how given indicators are to be assessed, are highly context specific. These contexts are in turn closely related to the facility's industry sector. Yet generalisability for research and policy purposes demands an effort to achieve comparability across sectors. EPA licensing files contain information that makes it possible to create comparable data along three important performance dimensions: key pollutant emissions, generation and disposition of wastes, and resource usage. For each, we have defined common variables that are constructed and scored according to sector- specific environmental considerations and have compared them across sectors to analyse a wide range of possible relationships (Goldstein and Hilliard, 2008). As explained in section 4, below, in the present paper we focus on the emissions dimension of environmental performance in exploring the role of organisational capabilities in mediating the relationship between practice and performance.

Key emissions: We define a single 'key emissions' variable for each facility, with values for each year on which we have data for the facility. The first step is determining which emissions are 'key.' EPA indicates its judgment on this for each license holder when it specifies which emissions must be monitored and reported – for air, sewer (effluent), and surface water discharges. Other industry sources have been used as well in determining which emissions are of greatest concern in each sector. We then look at the available data, and choose a set of specific emissions that are reported

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[5] In addition, we have conducted detailed in-person case interviews with managers at an additional 14 facilities. When fully analysed, these case studies will help flesh out our understanding of the dynamics underlying statistical results as reported here and in Goldstein and Hilliard (2008).v

by a significant number of sample firms in the sector. (See Goldstein and Hilliard, 2008, for listings.)

The second step is normalising emissions data where needed. Measures of facility pollutant emissions must be relative to some standard unit of production scale in order to be meaningfully comparable over time and across firms. Mass emissions data (say, kg/year) should ideally be normalised per ‘functional unit’ of output (MEPI 2001, p. 29). Because output data is not available, we normalise mass emissions relative to number of employees to proxy for scale of output. On the other hand, flow emissions data (e.g., mg/m3) is already normalized in that it is not affected by output scale.

The third step is creating cross-sector comparability by calculating each annual facility emission value as a ratio with its sector average.[6] When expressed this way, above versus below sector-average facilities can be compared across sectors although the specific emissions in each sector are different.

Finally, the individual emission values created thus far are averaged for each facility-year. We have created separate mass and flow key emissions variables, for each averaging the corresponding values in each facility-year.

3.2.2 Environmental practice variables

Environmental performance is directly affected by company practices. We distinguish between practices involving technology and those characterised by organisational systems or activities. We refer to the latter as ‘management practices.’

Management: We define three kinds of management practice. First is planning. This relates not to ‘planning’ qua orderly execution of pre-determined activities, but rather to evaluation of possible courses of action. We score reported planning projects based on the degree to which concrete goals or targets are specified; relevant data or information is used to factor past experience systematically into decision making; and there is evidence of follow through.

The second management practice variable is training. By disseminating information about environmental impacts, technologies, and/or management systems, employee training programs may affect companies’ environmental performance. We score training programs according to their concreteness and the extent to which they appear to drive changes in employee behaviour.

Third is procedures. Sample companies must track, record, and report regulated activities and outcomes. Such procedural activities may affect environmental performance by providing information on which impact-reducing steps can be based and evaluated. The timeliness and completeness of each year’s AER can be quantified.

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[6] Data integrity is guarded at this point by removing extreme normalised values using interquartile range analysis, and then requiring that sector averages in each variable contain data from at least three companies. See Goldstein and Hilliard (2008) for details.

Another source is EPA noncompliance notifications of a procedural (rather than pollution-oriented) nature, for which EPA's fairly precise set of phrases indicating the degree of seriousness are used to create a severity-weighted sum of the year's procedural noncompliances. The facility- year value for the management procedural variable is the sum of these AER and procedural noncompliance scores.

Technology: We use the files to identify technology 'projects': changes in the specific inputs, processes, and/or equipment by which outputs are created. The two main challenges in transforming technology projects into appropriate practice variables are allowing for cross-sector analysis while capturing sector-specific characteristics, and representing the ongoing effects of prior years' projects.

Cross-sector comparability is achieved using a technology matrix within which projects are located. One dimension of the matrix categorises projects according to pollution- prevention approach: raw material substitution, closing the loop by re-using waste input or output, equipment change, and other process change. The other dimension categorises projects according to stage in the production process: product design, preparation, core production, finish work, and housekeeping/other. Projects are assigned to the appropriate cell and scored according to sector-specific technical sources, with scoring based on scope within the company and whether the project is 'end of pipe' or 'clean technology' (Christie et al. 1995). All scores in each cell are summed for each facility year. Because the matrix structure is the same for all sectors, facilities' cell scores become variables whose values can be compared across sectors in analysing the data. The resulting 20 disaggregated technology practice variables can be aggregated for analysis – for example, the effect of equipment investment (across all production stages) or of finish work (across all pollution prevention approaches) on environmental performance.

Ongoing effects from prior years' projects are captured by defining technology performance variables cumulatively over time. Technology investments do not reach full impact in the year of their implementation, but once up to full strength, affect performance by decreasing amounts in subsequent years as any equipment depreciates, and as the fit between projects and their surrounding production systems becomes less precise. We assume five year project lifetimes; each new project's score enters the variable at half its value in its first year, full value the second, then 75, 50, and 25 percent of the original value in project years three, four, and five. Each facility-year value for each matrix cell is the sum of current and past cell projects weighted as just described.

3.2.3 Organisational capability variables

Strategies used by past researchers in operationalising the concept of capability have included asking for managers' own perceptions of organisational capability relative to their competition (Christmann 2000); defining capability as a statistical residual, a portion of performance unaccounted for by measured explanatory variables (Dutta et al. 2005); and inferring capability from observable concomitant activities or characteristics (Sharma and Vredenburg 1998). Our approach is most closely related to this last one.

Static capabilities: We hypothesise that firms build static capabilities through accumulated experience, or learning by doing (LBD). We quantify this by adapting the learning curve literature and using our annual technology and management variables.

The literature on LBD in manufacturing suggests that learning occurs through experience, measured as cumulative production with a technology or output, and evidenced as decreasing unit labour time (Argote and Epple, 1990). Rather than cumulative production, we will use the passage of time and the amount of practice, following implementation of particular kinds of projects, to proxy for experience.[7] We will also extend standard LBD usage by considering not only technology, but also management practices, as experience might increase the efficacy of management practices that affect performance. The LBD literature suggests that learning occurs with respect to experience with particular kinds of technology (Klenow 1998). This idea seems consistent with the capabilities approach, and we adapt it by using our technology and management practices variables to isolate specific kinds of experience: with raw materials change, say, or planning for alternative courses of action. Finally, rather than unit labour time, the variable that is thought to be enhanced by LBD in the present context is environmental performance. We do not attempt to estimate the parameters of this experience- performance relationship empirically, but construct a static capability variable on the assumption that LBD is taking place. Empirical results are then used to test the validity of the assumption.

The construction posits two contributors to ‘experience’ with a particular kind of technology or management practice: time since the appearance of the first project of that type, and the number of projects implemented. Consider, for example, a company that has been in the dataset from 1998 onward. Suppose its first project in, say, raw materials substitution occurs in 1999, and by 2003 it has implemented two additional like projects. The 2003 value for the corresponding static LBD capability variable will equal 7: 4 years post-initial project (the firm enters 2003 with the benefit of relevant experience in 1999- 2002) plus 3 total projects (through 2002).

This simple proxy for experience addresses two problems in empirical operationalisation of organisational capabilities. One is the difficulty in defining capabilities non- tautologically with respect to the performance they are thought to enhance. Our method does not depend on observation of successful outcomes to (falsely) infer the presence of an unobserved characteristic theorised as leading to the outcome; LBD as we define it is measured independently of environmental performance. Secondly, while static capability so defined is inevitably correlated with the related (technology or management) practice, we believe that it is not excessively so. Overall, the correlation of practice and corresponding LBD variables is approximately 30%, and we feel justified in entering both as ‘independent’ variables in

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[7] Solow (1957) suggests that the passage of time builds useful experience when increasing know-how in the broader environment is available to the firm.

section 4's empirical models explaining environmental performance. The data can then play its appointed role in falsifying the hypothesised relationships or not.

Dynamic capabilities: A key finding of the LBD literature is that significant disparities exist among firms in the pace and strength of organisational learning. Our theoretical framework suggests that differential dynamic capabilities may be at work. We want to measure how firms locate, process, and utilise the information involved in creating knowledge and capability. These processes occur through organisational integration (Grant, 1996): flow and processing of information both internally within the firm, and externally between the firm and sources in its environment. We create dynamic capability variables for each. As in the case of static LBD capabilities, we have defined dynamic capability independently of the performance outcomes it is thought to enhance, thus avoiding the tautological trap of inferring capability from performance.

Before defining these variables, we note that while theoretical considerations led us to specify static LBD capabilities as evolving during our sample period, it is not clear whether dynamic capability should be expected to change over this time frame. As noted in section 2, Winter (2003) suggests we are dealing with a first-order change capability, whose special function is to facilitate modification of static ones. This function suggests a higher order capability whose makeup is more or less fixed over the time period during which it acts upon changing static capabilities. In addition, the following discussion will suggest that our information on dynamic capability in sample firms does not consistently correspond to particular years. Thus for reasons both practical and theoretical, we define dynamic capabilities as fixed characteristics that do not vary with time, and incorporate them in the empirical tests accordingly.

Internal integration might occur through the management training and planning practices introduced above. There we were concerned with the direct effect each year's practice might have on performance. Here we consider the indirect role that training and planning might play in facilitating the firm's ability to search for and usefully integrate new information. This kind of internal integration might also occur through management work practices like cross functionality and team production, which appear (although infrequently) in facilities' EPA files. When reference to relevant training, planning, or work practice activity appears, we score it according to the concreteness of its goals and the extent to which it is driving change. The sum of scores for training, planning, and work practice activities in a given year becomes a facility-year value for internal dynamic capability, and these annual values are then averaged across years for the facility's EPA- based internal dynamic capability variable. All sample firms have data for this variable.

Because information on internal integration-related practices in the EPA files is infrequent, appearing as a byproduct of what EPA requires rather than its focus, we have supplemented it with results from our mailed-out survey questionnaire. We combine survey responses relevant to internal integration into a single variable, encompassing number of key company personnel involved in environmental management; percent of workforce receiving environmental training; frequency of team problem solving; and frequency of interdepartmental cooperation. All of these activities can contribute to the flow of information within the firm: the search for, and identification and processing of, information that would facilitate learning and the creation of new static capabilities.

In contrast to the EPA data, which is contained in annual reports and other dated documents, we have not been able to verify that the survey data reliably distinguishes the specific years within the panel period that reported practices have occurred. Because of this and the theoretical considerations discussed above, for the subset of firms that responded to the survey, we create another single, time-invariant measure of internal dynamic capability for each facility by adding its averaged EPA-based measure and its survey-based measure. Both the EPA-only measure (all firms) and the combined one (survey subset) are used in the empirical tests.

External integration is dynamic capability operating through knowledge-creating information flows linking the firm and its outside environment. The variable is constructed from survey data only, because the EPA files do not contain information that is relevant here. External dynamic capability is constructed from scored survey responses on the number of key outside parties (customers, vendors, and others) involved in environmental management; integration of vendors with the sample company's own staff in managing new environmental technology; number of information sources on environmental issues; participation in ongoing stakeholder initiatives with community, NGO, or governmental bodies; memberships in professional associations; and number and longevity of formal certifications (ISO 9000, ISO 14000, and EMAS). Again, we define external integration as a time-invariant characteristic of the firm.

Finally, for the subset of survey respondents, we calculate a combined dynamic capability variable equal to the sum of the internal (EPA plus survey) and external (survey only) integration measures.

3.3 Sample selection

Following the large research literature on measuring the environmental performance of industry, we focus our study on particular industry sectors (MEPI 2001). Variations in what companies do that might affect the environment or the bottom line, and how these practices translate into outcomes, are often highly industry sector-specific: technological options, environmental impacts, and supply chain and market demand considerations. On the other hand, conclusions from a study that is too narrowly defined around homogeneous sectors may lack generalisability. Thus, we also want sectors with a useful range of characteristics.

Two additional factors informed the choice of sectors. First, because we hope to link the environmental data with financial results in future analysis, we favored industries with a high percentage of single-facility firms, where EPA's facility level environmental data would match with company level financial data. Second, again to safeguard the integrity of financial statistics, we avoided industries subject to substantial transfer pricing bias due to facility 'sales' to same-company subsidiaries elsewhere.

The sample starts from all IPC-licensed firms in three industry sectors. The sectors are defined by NACE categories, beginning with companies sharing four digit NACE codes, but also chosen from the three and even two digit levels when other information suggests a company ought to be included:

Metal fabricating, NACE codes 2811, 2812, 2821, 2822, and 2840. Products include electronics enclosures and cabinets; containers and tanks; structural steel and builders hardware; and radiators and heating panels. Common processes are forging or pressing, cutting, welding, degreasing and cleaning, and coating. Environmental impact-reducing technologies include segregation and recycling of used oils and waste metal, low-VOC or non-solvent cleaning and degreasing, and water-borne, high-solids, or powder coatings. We exclude facilities engaged predominantly in electroplating or casting, because these are very different processes.

Paint and ink manufacturing, primary NACE code 2430. Products may be solvent or water based. Processes involve mixing of pigments and bases, either manufactured on site or purchased. The key environmental concern is VOC emission from use (not manufacturing); thus water vs solvent based product is a key variable. Manufacturing issues include (non-)enclosure of storage, transfer, and mixing equipment; disposal vs separation and recovery of wash water and/or solvents for equipment cleaning; and handling of waste product.

Wood sawmilling and preservation, NACE codes 2010 and 2030. Processes involve cutting rough wood to shape and size, and pressure treatment for water resistance.

Typical products are construction lumber, building frames and roof trusses, posts, and fencing. Traditional pressure treatment utilises toxic substances like creosote or arsenic, giving rise to impacts including entry of treated wood into the solid waste stream and chemicals into ground and surface waters. The use of non-toxic alternatives is an important element in environmental performance. We have excluded facilities making composite products such as plywood, fibre board, or veneer products.

The sample consists of 59 facilities with significant amounts of data reported for the variables described above: 21 in metal fabrication, 13 in paint and ink, and 25 in wood preservation and products. The panel of data extends from 1996 (when IPC licensing began for these companies) through 2004 (after which IPC licensing was superseded by Integrated Pollution Prevention and Control, IPPC). It is an unbalanced panel, as not all years are represented for all firms.

4 Organisational capabilities in sustainable production: Some preliminary tests

4.1 Empirical framework

We have chosen nonparametric statistical techniques, for the following reasons. First, scatter plots of the data show that it does not conform even approximately to the usual assumption of a normal distribution. Related, many of the variables exhibit numerous extreme values, which can seriously bias parametric estimates. (We have attempted to distinguish between measurement or recording errors, to be corrected or excluded, and potentially legitimate values, of which we retain all but the most extreme as indicated by interquartile ranges.) Finally, given the novel variable definitions and data construction methods we have adopted for many of the key concepts in this study, as described above, it may be premature to attribute meaningfully uniform intervals to all the resulting values. Hence we are more comfortable with analytical techniques based on rank-ordering.

In an earlier study (Goldstein and Hilliard, 2008), we examine in some detail the relationships between environmental performance measures and their proximate determinants in management and technology practices. While many practices are associated with better performance in terms of lower emissions, as expected, a strong and surprising finding in that paper is that environmental performance in waste and resource usage generally show positive correlations with practice, especially in technology. We explore there the possibility that high levels of waste or resource use stimulate companies to invest more heavily in technology changes intended to improve performance, and find some support for this ‘reverse causality scenario.’ Because here we want to test the potential for organisational capability to act as a complement with practice in improving environmental performance, we will avoid these complications by focusing on the key emissions dimension of performance in what follows.

Our goals are to shed light on the following questions:

First, does static capability accumulate through practice within the time period of our panel? We would like to know if the kinds of purposeful activities implemented by sample firms generate a learning by doing effect, as differential levels of experience across firms and over time make given practices more effective in improving environmental performance. The maximum time in the panel is nine years, so we will be testing whether static capability and this mediating effect on the practice-performance relationship can develop that quickly.[8]

Hypothesis 1: Static capability will be negatively associated with emissions,

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[8] We are also, unavoidably, testing jointly the appropriateness of our learning by doing-based model of static capability and its significance so defined in mediating the practice-performance relationship. If standard statistical tests show ‘significance,’ then assuming we have defined capability appropriately, we have learned it is important in this setting. If standard significance tests fail, then either our hypothesis about learning by doing is wrong, or we have proxied it wrong, or both.

controlling for the effect of the corresponding kind of practice; practice will be less negatively correlated with emissions when controlling for the effect of the corresponding static capability.

Second, does dynamic capability facilitate adaptation to the heightened environmental standards ushered in by IPC licensing? Dynamic capability should improve learning, and firms that are better learners should be more successful in implementing management and technology changes that improve environmental performance. Thus we want to test whether companies with stronger dynamic capabilities responded more effectively to the demands of IPC licensing by building new static capabilities for particular kinds of environmental impact reduction.

Hypothesis 2: The relationships suggested in Hypothesis 1 will be stronger among the higher dynamic capability firms.

4.2 Empirical results

Because we want to test the effect of organisational capability on the relationship between environmental practice and performance, we start by presenting results on the latter relationship from Goldstein and Hilliard (2008). These results can serve as a benchmark as we complicate the picture by successively adding the effects of static and dynamic capabilities. Our earlier findings show there to be substantial cross correlation among the management and technology variables. To account for this, we test here the partial correlations of emissions with technology practice, controlling for the effects of management practice; and of emissions with management practice, controlling for the effects of technology practice. Table 1 shows these partial nonparametric correlations (based on Spearman's rho) for management practices combined (the sum of the management planning, procedures, and training variables) and technology practices combined (the sum of corresponding technology approach or stage variables[9]).

Table 1. Partial Correlations: Emissions vs organisational practice

(Probability values in parentheses; N=102)

Technology (all categories, controlling for management)	-.106 (.285)
Management (all categories, controlling for technology)	-.179* (.069)

*Significant at 10% level (two-tailed).
Based on Spearman's rho.

While both practices show the expected negative correlation with emissions, this correlation is not statistically significant for technology practice when controlling for

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[9] The technology approaches and stages variables sum to the same totals, capturing all projects row-wise or column-wise in the technology matrix.

management as in Table 1. It is possible that the strongly positive management-technology associations being controlled here reflect underlying organisational capability of some kind. We now begin explicitly to model and test the role of different kinds of capabilities.

4.2.1 Learning by doing: static capability

Our basic strategy in testing Hypothesis 1 is to model static organisational capabilities as complements to the effect of direct practices upon performance. This approach has been applied to environmental impact-reduction by Christmann (2000) and to the efficacy of information technology investment by Brynjolfsson and Hitt (2000). We start by specifying the complementarity in terms of a multiplicative interaction variable. For a given firm and year, we multiply the value of the technology or management practice variable of interest by the value of the corresponding learning-by-doing (LBD) static capability variable. The expected correlation between emissions and these interaction variables is negative: Given some level of practice, we expect a higher level of LBD static capability to reduce emissions; and given some level of LBD static capability, we expect a higher level of practice to reduce emissions. The two kinds of practice and capability tested here are again management combined and technology combined.

Given the substantial cross correlation among the management and technology variables, we test here the partial correlations of emissions with the technology practice-capability interaction variable, controlling for the effects of management practice and management capability; and of emissions with the management practice-capability interaction variable, controlling for the effects of technology practice and technology capability. Both emissions-interaction partial correlations are negative as expected and significant at the 10% level. These results appear in the first column of Table 2.

This test attempts to address the first research question posed above – whether static capabilities emerge through experience (learning by doing) during the IPC period covered by the panel. That question is animated in part by concern within the research literature with the relative importance of capability inherited from the past vs that which is subject to purposeful direction in the present. As defined in the above tests, the LBD static capability variables incorporate only experience tied to projects undertaken during the IPC years. But we also have access to information about pre-IPC activities, contained in firms' license application files. To use that information to address the issue of prior expertise, we have re-computed the LBD static capability variables to allow pre-IPC projects to feed into the accumulation of experience as measured in those variables; recalculated the practice-capability interactions for management and technology; and repeated the partial correlations between emissions and these interaction variables. The results appear in the second column of Table 2.

Table 2. Partial Correlations:

Key emissions vs practice-static capability interactions

(Probability values in parentheses; N=105)

	Static capability based on IPC period projects only	Static capability based on pre-IPC and IPC period projects
Technology interaction[+] (Practice • Static capability)	-.178* (.073)	-.196** (.047)
Management interaction[++] (Practice • Static capability)	-.164* (.090)	-.182* (.064)

**Significant at 5% level; *10% (two-tailed).
[+] Controls for management practice, static capability.
[++] Controls for technology practice, static capability.
Partial correlations based on Spearman's rho.

In comparison with the correlations based only on experience accumulated during the IPC period, the interactions for which the static capability term incorporates previously implemented projects are a bit more strongly correlated with reduced emissions.

Above we have tested jointly for the explanatory significance of both the practice and the related static capability accumulated through experience with that kind of practice. It is also important to pull apart the interaction and examine the respective roles of each, practice and capability. We approach this by looking at the partial correlations between emissions and both management and technology practice and static capability. Due to the cross-correlations, we control each time for the effects of the other three variables. Again, we test separately using static capability values calculated to include only the projects detailed in the IPC files, and the corresponding values calculated to include also pre-IPC projects. The results are in Table 3. As in Table 2, the first column in Table 3 shows results for the set of partial correlations for which LBD static capability is computed using only projects from the IPC years making up the panel, while the second column displays the partials based on LBD static capabilitie incorporating pre-licensing projects as well.

Table 3. Partial Correlations:
Key emissions vs practice, static capability

(Probability values in parentheses; N=105)

	Static capability based on IPC period projects only	Static capability based on pre-IPC and IPC period projects
Technology practice	-.103 (.302)	-.070 (.483)
Technology static capability	-.094 (.346)	-.211** (.033)
Management practice	-.170* (.088)	-.189* (.057)
Management static capability	-.013 (898)	.057 (.567)

*Significant at 10% level.
Each partial controls for the effects of the other three variables on emissions.
Partial correlations based on Spearman's rho.

Hypothesis 1 suggests that the effect of practice on performance is mediated by static capability. In a partial correlation framework, this implies that some of the apparent effect of practice on performance in fact reflects the role of capability. Thus, in moving from Table 1 (with no representation of capabilities) to Table 3, we expect to see the partial of practice reduced.[10] Meanwhile, we expect to see a negative partial correlation of static capability with emissions performance. Looking at the first column of results in Table 3, we find (incomparison with Table 1) no additional explanation of emissions performance when adding LBD static capability excluding pre-license period projects. Both technology and management practices still appear weakly correlated with emissions, only management significantly so; and neither static capability is significantly correlated with emissions. This changes for technology in the second column; allowing its capability variable to capture prior experience permits the expected mediation effect to appear, with the role of practice (controlling for capability) reduced while capability displays a strongly negative association with emissions performance.

Tables 2 and 3 provide limited support, then, for Hypothesis 1: Static capability measured according to learning from experience acts, in many of our results, as a complement with related practices in reducing emissions. These two tables also suggest that this capability takes time to evolve. In what follows, we therefore focus on the LBD static capability measures that include pre-IPC licensing experience. We turn now to testing whether dynamic capabilities played a role in determining, via their success in creating new static capabilities, which firms best adapted to the new regulatory regime.

4.2.2 Dynamic capability and learning

Earlier (section 3) we defined an internal integration dynamic capability (DC) variable using EPA information on evaluative planning, workforce training, and cross functional and team work practices. This DC measure gives data coverage that is extensive across firms and years, comparable to that employed in the preceding tests of static capability. But it is not intensive, giving only fleeting glimpses of the relevant activities because that is not what EPA's reporting requirements set out to achieve. Thus we will look both at the role of internal integration measured from EPA data, EPA_INT (in the full sample), and then at the more intensively defined internal DC measure for the 16 companies that responded to our survey. In addition, we have a survey based measure of external integration DC. A preliminary step in exploring the role of DC in learning new static capabilities is to look at the correlations between these two kinds of capability. Table 4 shows the simple correlations for reference.

Table 4. Simple Correlations:
Static vs dynamic capability
(Probability values in parentheses)

	Management	Technology

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[10] See for example Siegel and Castellan (1988). An alternative might be to segment the sample and re-run the partial correlation tests for emissions and practices, separately for low and high static capability firms. The problem is that for static capability (unlike dynamic capability in the next sub-section), we look a priori for change over time, and in fact have time series data across firms with which to test for this.

	static capability	static capability
EPA-based internal integration dynamic capability (EPA_INT)	(Not meaningful)	.178** (.001)
Survey-based internal integration dynamic capability (SURV_INT)	.041 (.705)	-.283*** (.008)
Survey-based external integration dynamic capability (SURV_EXT)	.246** (.014)	-.028 (.778)
***Significant at 1% level; **5%; *10% (two-tailed). Correlations based on Spearman's rho.		

As described in section 3, all the DC variables have fixed values over time for each facility. EPA_INT and management static capability are highly correlated by construction, so that statistic is of little interest; both incorporate the same management planning and training projects over time. EPA_INT and technology static capability can be correlated, and display the expected strongly positive association. For the small subsample with survey data, the correlations are mixed: management static capability is positively related to external integration DC as expected, technology static capability is negatively related to internal integration DC, and the other two pairs are uncorrelated.

These simple correlations are naïve, in the sense that they do not directly address the determinants of the accumulation of static capability in mediating the relationship between practice and emissions performance. It is the importance of dynamic capability to the learning of new capabilities that we would like to test, and that experiential learning is defined in terms of the practice-performance relationship. We expect higher levels of dynamic capability to strengthen that complementary practice-performance relationship.

Our modelling strategy here is to divide the sample into halves: the higher and lower DC firms so defined. We do this separately for DCs defined according to internal and external integration. Then we re-run the complementarity tests from the preceding subsection, separately now for the higher and lower DC segments. We expect that learning by doing will play a stronger role among the higher DC firms: A decrease in the relative performance-determining role of practice when static capability is partialled out, and a significantly negative association with emissions performance for static capability itself. Table 5 gives the results for the first set of partial correlations, segmented into those facilities with above and below median values for the EPA-based internal integration DC measure.

Table 5. Partial Correlations:
Key emissions vs practice, static capability
For low, high *internal integration* segments (EPA data)

(Probability values in parentheses)

	Below-median EPA_INT N=19	Above-median EPA_INT N=86
Management practice	.444* (.085)	-.290*** (.008)

Management static capability	-.593** (.015)	.089 .423
Technology practice	-.740*** (.001)	.024 (.832)
Technology static capability	.281 (.293)	-.226** (.040)
*Significant at 10% level. Each partial controls for the effects of the other three variables on emissions. Partial correlations based on Spearman's rho.		

The results in Table 5 are partly unexpected. The predicted complementarity in management practice and static capability appears in the low DC segment (although a positive practice-performance association is not predicted) but not the high one, contrary to expectation. In the high DC segment, in fact, static management capability plays no independent role, but management practice is strongly, negatively correlated with emissions. We return to this finding in the discussion. For technology, on the other hand, the pattern is the reverse: in the low internal integration segment practice shows a strong association with reduced emissions, while in the high DC segment, as expected, the predicted complementarity relationships appear. Another unexpected result in Table 5 is the asymmetry in the number of observations for the two segments: The low DC facilities according to the EPA based measure report far less data. Again, we discuss this finding in the final section.

Tables 6 and 7 show the results when the dataset is segmented according to facilities with below and above median values for the survey based DC variables in internal and external integration.

Table 6. Partial Correlations: **Key emissions vs practice, static capability** **For low, high *internal integration* segments (survey data)**		
(Probability values in parentheses)		
	Below-median SURV_INT N=10	Above-median SURV_INT N=15
Management practice	-.781** (.038)	.435 (.157)
Management static capability	-.285 (.536)	-.276 .385
Technology practice	.226 (.627)	-.120 (.709)
Technology static capability	.179 (.701)	.158 (.224)
*Significant at 10% level. Each partial controls for the effects of the other three variables on emissions. Partial correlations based on Spearman's rho.		

Table 7. Partial Correlations: **Key emissions vs practice, static capability** **For low, high *external integration* segments (survey data)**		
(Probability values in parentheses)		
	Below-median SURV_EXT N=3	Above-median SURV_EXT N=22
Management practice	Insufficient data	.161 (.509)

Management static capability	Insufficient data	-.171 .484
Technology practice	Insufficient data	-.017 (.946)
Technology static capability	Insufficient data	.114 (.643)
*Significant at 10% level. Each partial controls for the effects of the other three variables on emissions. Partial correlations based on Spearman's rho.		

For the survey based internal integration segmentation in Table 6, the low DC group shows a straightforward negative management practice-emissions association, but no other significant correlations. It is true that moving from low to high internal DC reduces the direct role of practice with static capability partialled out; but the static capability itself shows no significant independent association with reduced emissions. For the survey based external integration segmentation in Table 7, the above-mentioned asymmetry in reporting across the segments leaves insufficient data in the low DC group; in the high external DC segment, no statistically significant correlations appear.

5 Discussion

We set out to address a set of questions about the nature, evolution, and role of basic kinds of organisational capabilities. We have proposed that companies in the Irish EPA's IPC licensee base would need to learn new capabilities, the ability to mobilise needed skills and routines to effectively implement the kinds of technological and managerial practices required by IPC licensing. We have sought to contribute to the literature on empirical representation and testing of capabilities by bringing the findings of learning by doing research to bear, and by distinguishing change-directed dynamic capabilities involving search and informational integration, both internal and external.

The idea is that not just each year's practices are crucial to understanding performance, but also underlying static capabilities that enable ongoing practices to be implemented effectively. Thus organisational capability, the capacity to mobilise relevant resources toward some goal that is important to the organisation's success, complements or mediates the practice-performance relationship. The innovation here is that the complementary organisational capability is modelled as being learned through practical experience.

What do our results suggest? Table 2 supports this notion of complementarity, showing that multiplicative interaction variables between practice and the corresponding static capability are associated with lower emissions as expected, for both management and technology, and that these relationships are somewhat stronger when pre-IPC period experience is accounted for in the static capability measures. When we separate the practice and static capability variables out in Table 3 for the entire sample, we find (again when allowing pre-IPC experience to feed into static capability) the predicted complementarity results for technology: controlling for static capability weakens the measured practice effect on emissions, while static capability itself correlates significantly with lower emissions.

This mixed pattern continues when we attempt to bring dynamic capability into the picture, re-testing for practice-static capability complementarity in low and high dynamic capability segments. An unexpected finding is that firms below the median using any DC measure – EPA data-based internal integration, or survey based internal or external integration – report far less data and hence offer fewer observations for testing. We infer from this that companies with greater capability in searching for and processing of new information systematically do better in meeting the basic demands of the (then) new IPC regulatory regime: tracking environmental impacts and reporting them along with practices thought to be relevant in reducing those impacts. This offers some indirect corroboration of our initial working hypothesis in this research, that dynamic capability would be important to adaptation and change.

Based on the mixed DC segmentation results reported in Tables 5-7, we suggest the following interpretive categories:

1. If the relationships among emissions, practice, and static capability are unchanged in the high DC segment (in comparison to the unsegmented or low DC segment results), we reject Hypothesis 2.

2. If in the high DC segment, the independent effect of practice on emissions is reduced (controlling for static capability), while static capability exhibits a significantly negative association with practice, we find support for Hypothesis 2.

3. If in the high DC segment, the independent effect of static capability on emissions is reduced, while that of practice increases, we infer that DC facilitates adaptation – but directly and not through the medium of learned static capabilities.

Clearly, these results are only preliminary and require much more analysis and elaboration. Our study of the proximate determinants of environmental performance (Goldstein and Hilliard, 2008) disaggregates management and technology practices and examines the three industry sectors individually, and we need to do both in bringing organisational capabilities into the analysis. In additin, a critical issue completely unaddressed here is that models like the above may be affected by fixed, underlying but unobserved cross-firm differences that are correlated with the independent variables, hence accounting for any apparent causal significance of those variables. (See King and Lenox, 2001, 2002.) Nonparametric panel methods with fixed effects have been used to control for this 'heterogeneity' problem, and that is a necessary direction for the current research.

On the other hand, these preliminary results give some promise that the methodology employed for measuring and testing the role of organisational capabilities, along with the detailed information made available by IPC (now IPPC) licensing, is capable of answering important questions in the search for more sustainable production. For example, the experiential character of learning by doing as modeled here fits well with the emphasis in capabilities research upon tacit, routinised, path-dependent organisational learning and capability. Nevertheless, our findings suggest a potentially important role for agency. Managers chose the practices whose cumulative implementation we measure as static capabilities, and the implication is that the content and pace of capability formation is subject to some degree to purposeful action (Gavetti and Levinthal 2000).

We have asked whether static organisational capabilities are learned through experience, so that they play a complementary role with current practices in improving environmental performance. And we have explored whether higher levels of change-oriented dynamic capability are associated with a stronger complementary role for static learned capabilities in mediating the effect of practices on performance. These preliminary findings suggest a cautious affirmative response to the first question, that the jury is still out on the second one, and that further research is needed to provide the kinds of answers sought by policy makers and practitioners concerned with a sustainable path for economic development.

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