CREATING ORGANISATIONAL CAPABILITIES: LEARNING BY DOING

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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 firms that were more successful in developing new static capabilities were distinguished by strong 'dynamic' capabilities: the capacity to change and adapt through integration of new information internally and from external sources.

1 INTRODUCTION

A huge literature has studied 'learning by doing' in manufacturing (Argote and Epple, 1990). The basic setting in that literature is the accumulation of useful experience in producing with a new technology, as evidenced in decreasing unit labour costs. Another, only tangentially intersecting literature examines the creation of 'organisational capabilities,' the capacity to mobilise and deploy resources in competitively useful ways (Winter, 2000). The settings in which organisational capabilities have been studied are many and diverse. Although certainly experiential learning could play a role in the creation of organisational capabilities (see for example Gavetti and Levinthal, 2000), we are not aware of work that has modelled these processes explicitly along the lines of the basic findings of the learning by doing literature. In the present research, we adopt this approach to studying Irish manufacturers' adaptation to the demands of suddenly-tightened environmental regulation in the mid-1990s.

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Despite a substantial body of theoretical, and to a lesser extent empirical, research in the area of organisational capabilities, questions about exactly how and to what extent activity and experience accumulate into a capability have been little explored. This paper aims to present an original approach to the measurement of practices, experience and performance in a way that contributes to the methodological debate in this area. We hypothesise that, over time, observable practices—analogous to but broader in type than manufacturing production—can leave organisational traces in the form of capabilities whose presence and impact on performance can be tested. We model and test those capabilities as arising from the process of learning by doing.

The paper is based on research funded by the Environmental Protection Agency of Ireland, on the environmental and economic performance of Irish companies. Ireland was an early adopter, in 1994, of a now-standard 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 affects their ability to meet IPC licensing requirements in economically competitive ways. For facilities in four industry sectors, we have constructed a database on environmental and economic performance; environmental technology and management practices; and various kinds of organisational capabilities that may complement the efficacy of practices in generating performance.

We will test the hypothesis that firms learned new, managerial and technological capabilities through ongoing practice in these areas—capabilities that are 'static' in that they allow companies to do particular kinds of things well in a given setting—and that the learning process was facilitated for some companies by superior 'dynamic' search and integration capabilities. Because we are going beyond the standard production-and-unit labour cost framework of the traditional learning by doing literature, we need to describe carefully what we think is being learned, how we hypothesise the learning is occurring, and how we have created data from which we attempt to infer the presence of organisational learning. In the sections that follow, we discuss the IPC licensing program and the information base it generates; the notion of organisational capabilities and the kinds of capabilities the IPC program has pressed licensed firms to acquire; how we have used the licensing information to create variables to operationalise the relevant capability constructs; and a statistical modelling framework in which to test the processes and concomitants of learning by doing.

2 IPC LICENSING IN IRELAND

In 1992 the Environmental Protection Agency Act[‡] 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.[§] 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 environmental impact and a shift of emphasis to pollution prevention rather than pollution treatment.

[‡] Environmental Protection Agency (Establishment) Order, 1994 (S.I. No. 213 of 1993).
[§] Environmental Protection Agency (Licensing) Regulations, 1994 (S.I. No. 85 of 1994)

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:

<u>Environmental technology</u>: 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).

<u>Environmental management systems</u>: 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[**] 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 the initial IPC licence application, monitoring results, reports of audit visits by the Agency, 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.

We present this overview of IPC licensing in order to demonstrate the availability of detailed information about the specific technological and managerial practices engaged in by sample firms, and also about the big issues they face: the kinds of things at which they need to become adept in order to meet the demands of environmental regulation. Before going on to discuss our measures of organisational practice, as well as of the capabilities that may have been learned from and then enhanced those practices, we need to review the relevant concepts and questions from the organisational capabilities literature.

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

3 ORGANISATIONAL CAPABILITY AND LEARNING

We referred to organisational capability earlier 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). This latter definition moves us closer to our goal, in that it focuses attention on 'tasks' and 'resources,' for both of which we can attempt to create empirical representations from our data.

Along these lines, we take our definition of organizational capability from Winter (2000: 983): 'An organizational capability is a high-level routine (or collection of routines) that, together with its implementing inflows, confers upon an organization's management a set of decision options for producing significant outputs of a particular type.' This definition, by basing itself on the 'broader concept of organizational routine' (Winter, 2003: 991) avoids the common charge of tautology in both the definition and measurement of capability by providing an independent basis, routines, for measuring capability separately from the performance enabled by that capability. 'It is the routines themselves and the ability of the management to call upon the organization to perform them that represents an organization's essential capability' (Teece et al., 1994, p. 15).

But where does this ability come from? We now turn back to Loasby's first concern, with capability as 'a by-product of past activities' (1998: 144). While it is the carrying out of the routine, the 'performative' aspect (Feldman and Pentland (2003), that enables the outcome under study to be achieved, Becker also suggests that such 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. Going back to the idea of routines as building blocks of capabilities, the logic of the situation suggests that new or modified routines (or combinations of routines) would underlie any new capabilities created by learning by doing.

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. Although it does not focus on the underlying mechanisms in terms of routines, this research has intersected somewhat with the organisational capabilities literature. (See for example Costello, 1996, and Figueiredo, 2003.) The learning curve approach offers a quantitative framework for thinking about organisational learning, to which we will return in the section below on empirical operationalisation.

The empirical literature on capabilities has struggled with the problem of tautology: it is hard to measure capabilities independently of the outcomes they are said to produce (ref). Capability as set of routines might in principle help, if one has observational data on routines. In the present study, we do not. The environmental technology and management practices that have been observed and reported in our use of the IPC files are not routines. They can be seen, rather, as the observable footsteps that create (here, unobserved) routine pathways that give companies new capabilities. In this research, we build measures of capability from company reports of what they do (routine as reflected in behaviour). We infer the capabilities from a hypothesized process of learning by doing an accumulation of related technology or management projects over time.

In the next section, we propose a methodology for inferring and testing the existence and role of these learning by doing capabilities. For now, we emphasise that what we see evolving in these companies 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). What is becoming known is how to meet the newly imposed survival tests of IPC licensing. Companies must respond to that change in the competitive regime, by becoming (more or less) adept at doing the kinds of things it requires. In that sense, these learned capabilities, although to some extent new, 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.

Is it possible that there is a special kind of capability that makes some firms better learners than others? It is a key stylised fact of the learning by doing literature that firms differ widely in their capacity for organisational learning. 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 sub-optimal lock-in. What allows firms to loosen this constraint?

We can go back again to the notion of routines. Becker et al. distinguish a number of sources of change within organizational routines, arguing that 'a central proposition of routines theory is that organizations change what they are doing and how they are doing it by changing their routines' (2005: 776). Routines can evolve as the tacit knowledge stored in them evolves (Becker, 2005). The role of deliberate managerial action is of key interest here. Nelson and Winter defined routines for 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).[††]

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 (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?

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 this and its related questions.

4 SAMPLE SELECTION AND VARIABLE DEFINITIONS

Following the large research literature on measuring the environmental performance of industry, we decided to study 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 wanted sectors with a useful range of characteristics. We chose a sample starting from all IPC-licensed firms in four 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 and casting.

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);

[††] 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).

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.

Slaughtering of livestock, NACE codes 1511 and (occasionally) 1513. Products include beef, lamb, and poultry, and processes involve killing and (at least first-stage) butchering of animals for food consumption. Key environmental concerns are organic discharges to water and smell. We have excluded facilities doing mostly or exclusively rendering, because EPA publications suggest considerable differences.

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.

Most of our information is from the EPA's license application and annual files for each company, supplemented with a mailed-out survey questionnaire to sample firms and financial data from the Companies Registration Office. There are approximately 100 firms in total, with an 'unbalanced panel' of data (not all years for all firms) covering 1997 (when IPC licensing began for these companies) to 2004 (after which the licensing regime was modified again).

We have created variables of the following types:

- *Performance*—Measures of the competitive success against which firms' activities are tested. Here this involves both the environmental performance demanded by the regulators, and of course the economic performance required for market survival.
- *Practice*—Proximate technological and managerial influences on economic and environmental performance, independently of any accumulation of learning by doing from these practices. By 'practices' we mean concrete, time-delimited actions chosen by management. In general, the basic unit from which we start is the 'project': an activity or closely integrated set of activities undertaken at a particular time to bring about a well defined end.
- *Static capability*—The capacity to employ particular kinds of important practices well, within the given context of IPC licensing. We would like to know whether, in addition to the direct effects of management and technology practices on company performance, there is an indirect effect through the accumulation of particular kinds of learned experience that in turn enhances the practices' efficacy.
- *Dynamic capability*—First-order change capabilities consisting of the capacity for search and learning, mobilized toward the end of creating new static capabilities. We want to measure how firms locate, process, and utilise the requisite information by means of organisational integration: both internally within the firm and externally between the firm and sources in its environment.

Economic performance: We are interested in operating efficiency, not affected by differences in capital structure or accounting choices. Thus, we have defined economic performance as earnings or net profits before interest, taxes, and depreciation, as a ratio with total assets.

Environmental performance: We have information on firms' resource usage, waste, and emissions to air and/or water. But different industry sectors face different environmental problems, and even within a given sector not all companies are asked to report the same emissions. To facilitate cross sectoral analysis, we identify the key emissions, wastes and resource uses for each sector; normalise each firm's values by proxies for output; and express the firm's normalised value as a ratio with its industry average (see Goldstein et al., 2006 for details).

Technology practices: Managers choose and execute a stream of technology projects over time, where 'technology' is to be understood not only as physical capital but as the related activities involved in transforming inputs into outputs. We begin by creating for each sector a categorical matrix within which technology projects can be located. One dimension of the matrix, common to all sectors, categorises projects by pollution-reduction approach (US EPA, 1995): raw materials change; equipment change; loop closing via capture and reuse of waste product, materials, or byproducts; and other process changes. The other dimension of each sector's technology matrix breaks down its production process into major stages.
Each sector's matrix, with specific stages across the top, looks like the following:

	Product Design	Preparation	Middle Stage	Finish Work	Housekeeping & Other
Raw Materials					
Equipment Change					
Loop Closing					
Other Process					

The cells in this matrix define 20 highly disaggregated technology practice variables. Location in the appropriate cell within the matrix determines to which practice variable a project's score is assigned. The next step is to score each project according to its scale within the facility and whether it is 'clean' (reduces environmental impact at the source) or 'end of pipe' (merely treats given pollution). These determinations, like the delineation of production stages, draw upon the best available technical information for each sector. The third step is to sum the project scores for each year in each of the matrix cells.

Finally, we recognise that technology projects affect performance *cumulatively* over time. Projects once implemented potentially affect performance in subsequent years as well. But these effects decrease over time, as equipment depreciates, and as the fit between projects and the surrounding production systems in which they are embedded becomes less precise due to changes elsewhere. A large literature suggests that technology investments do not affect performance fully in the year of their implementation, and that once fully operational the 'efficiency schedule' of their impacts entails a geometric rate of decrease of about ten percent annually (Doms 1992).

Each of a firm's 20 technology variables starts year 1 with a value based on the information (if any) about technology in place, from the EPA license application files. In subsequent years, each new project's score enters the variable at half its value in the first year, full value the second, then ninety percent of the prior year's value in each succeeding year. For each company in each of its t years in the panel ($t \leq 8$), each of the 20 matrix-defined technology practice variables $TPRAC_t$ is defined as follows:

$$TPRAC_t = TPROJS_t / 2 + \sum_{\tau=2}^{t-1} .9^{t-\tau-1} TPROJS_\tau + .9^{t-1} TPROJS_1 ,$$

where '$TPROJS_t$' is the sum of the given type (matrix cell) of technology project scores for year t. The first term is the current year's (t) projects, the second gives the decreasingly weighted projects from the prior year ($t-1$) back to the first active year of IPC licensing, and the final term represents technology in place at the time of licensing. $TPRAC_t$ reflects the cumulative influence of the active technology stock, with the most recent projects (excepting the current year's) weighted heaviest.

While firms' matrix cell variables are scored using sector specific criteria, the same set of variables is shared sample-wide for cross-sectoral analysis. These twenty disaggregated variables can then be combined as desired at later modelling stages—e.g., to test the effectiveness of loop closing projects at all production stages, or of projects at the preparation stage across all pollution prevention approaches. This ability to isolate technology practices of a particular, broader type will be important in considering organisational capabilities related to learning by doing.

Management practices—Planning: This variable relates not to 'planning' *qua* orderly execution of pre-determined activities, but rather to processing of and/or search for information in the course of evaluating possible courses of action. We score reported planning projects based on the degree to which concrete goals or targets are specified, relevant information is used to factor past experience systematically into decision making, and there is evidence of follow through.

Management practices—Training: By disseminating information about environmental impacts, technologies, and/or management systems employees, 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.

Each firm's management practice planning and training variables are then defined similarly, with $MPRAC\_PL_t$ and $MPRAC\_TR_t$ representing the sum of year t's project scores in planning and training project, respectively. We note here that both managerial planning and training activities, in facilitating information flows from internal or external sources, may contribute to organisational search and learning. Planning and training may thus not only function as practices in affecting performance directly, as considered here, but also contribute to dynamic organisational capability. We discuss the latter possibility in a later section.

Management practices—Procedural: 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 with which EPA monitoring, record keeping, and reporting requirements are met in the company's Annual Environmental Report (AER) can be quantified and combined into a measure of procedural management practices. Another source of data is EPA noncompliance notifications of a procedural (rather than pollution-oriented) nature. These notifications use a fairly precise set of phrases to indicate the degree of severity assigned to each noncompliance by the regulatory agency. For each year t, each company's management procedural practices variable $MPRAC\_PR_t$ is an AER score plus a severity-weighted sum of the year's procedural noncompliances.

Static capabilities: Strategies used by past researchers in seeking to define such capabilities empirically have included asking managers for their 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. We hypothesise that firms build static capabilities through accumulated experience, or learning by doing (LBD). We propose here a way to quantify this by adapting the results of 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. Rather than using 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.[‡‡] We will also extend standard LBD usage by considering learning from experience not only with technology, but also with management practices: Just as firms can get better at using particular technologies with experience, so might they 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 aggregating 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 as in the traditional literature, the variable that is thought to be enhanced by LBD in the present context is environmental performance. We will not attempt to estimate the parameters of this experience-performance relationship empirically, a project for future research. Instead, we will construct a static capability variable on the *assumption* that LBD is taking place, using an algorithm based on that literature. Results from empirical LBD research (Argote and Epple, 1990) suggest that

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

learning increases through increments in experience, but at a decreasing rate: It takes each *doubling* in cumulative production to decrease unit labour time (increase efficacy) by about 20%, or an 80% 'progress ratio.'

Consider a particular kind of technology or management practice. We would like both the amount of the practice and the passage of time since its inception to accumulate into the value of the corresponding LBD capability variable. Once it begins, each additional project adds to the stock of experience and hence to learning (doing more means learning more); but the marginal contribution from successive years' levels of the stock grows at a decreasing rate, as the available learning about a given practice is used up. Using '●' as a place holder for the specific kind practice/experience/capability, we capture this effect for each year *t*'s LBD capability (LBDC) by multiplying cumulative projects to year *t* times weight w_t, where the weights grow 20% for each doubling in time (at the 2nd, 4th, and 8th years of experience):

$$\bullet\, LBDC_t = w_t \sum_{\tau=1}^{t} \left[\bullet\, PROJS_\tau \right] .$$

Here $PROJS_\tau$ is all projects in year τ, and the weights w_t are 1.00, 1.20, 1.34, 1.44, 1.53, 1.60, 1.67, 1.73, and 1.78.

Our data permits us to define LBDCs (the 'dots') along a number of technological and managerial dimensions. Depending on how the matrix cells are aggregated, we can define technology LBDCs in particular kinds of pollution prevention approaches (raw materials change, equipment changes, loop closing, or other process changes) or at different stages in the production process (pre-production design, preparation, core production, finishing, and housekeeping). Organisational capability accumulated this way is *static*: Getting better at doing a particular kind of thing over time by repetition.

<u>Dynamic capabilities</u>: 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 a dynamic capability variable for each.

Internal integration might occur through the management training and planning practices introduced above (*MPRAC_ TR* and *MPRAC_ PL*). 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 search for and organisational integration of new information. Internal integration might also occur through management work practices like cross functionality and team production. When reference to each practice 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 cross functional and team production activities in each year gives the value for that year's management work practices variable *MPRAC_ WP*. Because information on these kinds of practices in the EPA files is patchy, we have supplemented it with relevant results from our mailed-out survey questionnaire, *SURVEY_INT*. We combine these elements to form the dynamic capability variable for internal integration, *DC_INT*:

$$DC\_INT = MPRAC\_WP + MPRAC\_PL + MPRAC\_TR + SURVEY\_INT$$

Note that the time subscript '*t*' has been removed. Although the EPA data is reported by specific years, we have not yet been able to verify whether the survey data reliably distinguishes when reported practices have occurred. In addition, while theoretical considerations led us to specify and test static LBD capabilities as evolving during our sample period, it is not clear whether the higher-level DCs should be expected to change over this time frame. Thus at this stage of the research we will average annual EPA-based values and combine all DC data for each firm into a single, time-invariant measure. The modelling strategies presented in the next section will be consistent with this choice.

The second DC variable, *DC_EXT*, measures external integration, or knowledge-creating information flows linking the firm and its outside environment. The variable is constructed from survey data only, based on queries regarding memberships in professional associations; participation in ongoing stakeholder initiatives with community, NGO, or governmental bodies; and use of vendors or consultants for locating and implementing new technologies, when these processes also involve internal staff and thus information flows into the firm. Again, we define external integration as a time-invariant characteristic of the firm, *DC_EXT*:

$$DC\_EXT = SURVEY\_EXT$$

As in the case of static LBD capabilities, we have defined DCs independently of the performance outcomes they are thought to enhance, thus avoiding the tautological trap of inferring capability from performance. We turn now to using the empirical representations developed in this section to model and test the theoretical questions posed at the start of the paper.

5 TESTING THE ROLE OF CAPABILITIES AS ORGANISATIONAL LEARNING

The major questions that motivated our data collection, variable creation, and now statistical modelling, include: What is the role of organisational capabilities in strengthening IPC licensees' response to tightened environmental regulation? Were some firms able to develop significant new static capabilities within the (at most) eight year time frame studied? Did dynamic capabilities facilitate successful adaptation and change? The modelling strategies described below are still in formation, but are included here to show where we believe we can go with this empirical approach, and to stimulate feedback from the research community at this stage of our work.

Are learned static capabilities important?

Our basic strategy here 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). The idea is that not just each year's practices are crucial to understanding performance, but also underlying 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.

We start with the static learning by doing capabilities (LBDCs) described earlier, specifying the complementarity by means of a multiplicative interaction term. Using '*i*' to signify the firm and '*t*' the year, and '●' the particular kind of technology or management practice and corresponding LBD capability, we model economic or environmental performance as a function of practices, capabilities, and the interaction between the two:

$$Performance_{it} = b_0 + b_1{\bullet}PRAC_{it} + b_2{\bullet}LBDC_{it} + b_3INTER_{it} + e_{it}$$

where

$$INTER_{it} = {\bullet}PRAC_{it} \;\; x \; {\bullet}LBDC_{it}$$

being tested. Here we test directly for the explanatory significance of both the practice and the related static capability accumulated through experience with that kind of practice. But in addition, a statistically significant interaction term tells us that a higher level of learned capability increases the efficacy of any given level of practice. In addition, an F test can be constructed to test the joint significance of adding the capabilities related variables as a group, *LBDC* and *INTER*, to the model.

We are seeking in the above to test the role of organisational capabilities, specifically a LBD static kind of capability. It is important to recognise that in any effort of this sort, we are unavoidably jointly testing the appropriateness of our LBD model and the significance of LBD so defined in mediating the practice-performance relationship. If standard statistical tests show 'significance,' then assuming we have defined LBD appropriately, we have learned it is important in this setting. If standard significance tests fail, then either our hypothesis about LBD is wrong, or we have proxied LBD wrong, or both.

It is true that our LBD variables are constructed in relation to the practice variables appearing alongside them in this set of models. However, both conceptually and statistically *LBDC* conveys additional independent information. *LBDC* is accumulated in relation to an evolving stock of technology or managerial experience; at a very intuitive level, we can think of it as a kind of integral over time for that experience (conversely, the technology or managerial experience stock is a sort of time rate of change of *LBDC*). The two are related, but each conveys distinct information. Concretely, the calculus analogy is not exact: The algorithm used to accumulate technology projects into the stock technology $PRAC_{it}$ variable is based on the capital investment 'efficiency schedule' literature, and management $PRAC_{it}$ does not cumulate annual managerial activities at all. On the other hand, the algorithm used to accumulate both technology and management $PRAC_{it}$ variables into corresponding $LBDC_{it}$ variables is based on the learning curve literature. Given these different algorithms, we do not expect that the statistical correlations between the $PRAC_{it}$ and related $LBDC_{it}$ variables will be strong enough to create multicollinearity problems.

Researchers have been concerned that models like the above will be affected by fixed, underlying 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) Differential underlying organisational capabilities might be an important source of this 'heterogeneity' problem. It can be dealt with best by ensuring that all relevant explanators are explicitly represented; we do that with the LBDC variables above and the dynamic capability ones discussed below. We will also test for the possibility of unobserved heterogeneity by seeing if fixed effects versions of the models produce substantially different results.

A key question throughout has been whether we can distinguish among our sample firms in terms of their success in creating new static capabilities. We turn now to a methodology for testing whether dynamic capabilities for change in static ones played a role in determining which firms best adapted to the new regime.

Do dynamic capabilities affect organisational learning?

We would like to know whether higher levels of DCs are associated with a stronger complementary role for static learned capabilities in mediating the effect of practices on performance. In other words, is the data consistent with the idea that some firms have stronger change capabilities, represented by observable processes for search and learning?

Our modelling strategy here is different from that for static capabilities. We have described fixed, non-time varying measures of DCs, representing processes of knowledge-creating information flows both internal (work practices, planning and assessment, and training)[§§] and external (professional, stakeholder, and vendor relationships). There are two potential problems with entering these DC variables directly into statistical models as we do above with LBDCs. One is that the DC measures do not vary over time, and so will wash out of any fixed effects model. It is true that their interactions with other, time-varying variables would not drop out under fixed effects. But given that we already have a set of interactions between static LBD capabilities and practices in the basic models, a second reason for not entering DCs directly is to avoid the added complexity and loss of degrees of freedom they would bring.

Instead, we will divide the sample into halves: the higher and lower DC firms so defined. We can do this separately for DCs defined according to internal and external integration, and also for the two combined into a single index of DCs. Then we re-run the tests from the preceding section, separately now for the higher and lower DC segments. Does LBD play a stronger role among the higher DC firms? We think it will: these are the companies whom theory suggests will be most capable of learning and adaptation to change.

[§§] Management practices involving planning and assessment are wearing two hats here. On the one hand, we include them in the previous section's models of the determinants of performance, because arguably, evaluative activities may affect environmental outcomes. On the other hand, planning and assessment just as arguably may contribute to the search and learning involved in DCs. Sorting this duality out econometrically remains a challenge for continuing research.

6 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 experiential character of LBD fits well with the emphasis in capabilities research upon tacit, routinised, path-dependent organisational learning and capability. Nevertheless, the approach we have taken suggests an 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).

Our econometric tests will go some distance toward suggesting whether this is true, to the extent that our LBD measure of static capability operationalises the concept adequately. But we will not know from observing even a very substantial string of individual projects whether combined they represent strategic investment, versus merely a series of responses to particular needs, opportunities, or regulatory demands as these arise. Company case studies will be required to distinguish these scenarios.

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