

Managing Know-How

Deishin Lee, Eric Van den Steen

Harvard Business School, Harvard University, Boston, Massachusetts 02163
{dlee@hbs.edu, evandensteen@hbs.edu}

We study how firms can use a knowledge management system to optimally leverage employee-generated know-how. In particular, we consider the following practical strategic questions for the manager of a knowledge-intensive firm: Should her firm develop a formal knowledge system? And if so, how should it be managed, particularly in terms of what information to record? We find that firms benefit more from a knowledge system when they are larger, face the same issues more frequently, have higher turnover, and face problems about which there is less general knowledge. In terms of what information to record, a key insight is that recording moderately successful practices can be counterproductive, because doing so may inefficiently reduce employees' incentives to experiment. This "strong-form competency trap" forces firms into an exploration-exploitation trade-off. Firms that value a knowledge system most should also be most selective in recording information. We further find that recording successes is more valuable than recording failures, which supports firms' focus on best practice. Beyond these main principles, we also show that it may be optimal to disseminate know-how on a plant level but not on a firm level, and that recording backup solutions is most valuable at medium levels of environmental change.

Key words: knowledge management; know-how; competency trap; best practice

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1. Introduction

Nearly all firms depend to some extent on know-how to gain a competitive advantage. Learning and its benefits have therefore been an important focus of the management literature, from the learning curve (Alchian 1963, Ghemawat 1985, Adler and Clark 1991) and the learning organization (Senge 1990) to the effectiveness of specific learning practices (Cohen and Levinthal 1990, Argote 1999). Furthermore, the literature on exploration and rugged landscapes (March 1991, Levinthal 1997, Rivkin and Siggelkow 2003), the role of information in organization design (Marschak and Radner 1972, Garicano 2000, Alonso et al. 2008), and knowledge-based theories of the firm (Conner 1991, Kogut and Zander 1992, Foss 1996) have related knowledge and know-how to the most fundamental issues in organizations and their design.

For some firms, know-how is so important that they develop formal systems to capture and disseminate the knowledge generated by their employees. Many professional organizations, for example, rely almost exclusively on knowledge for their value creation, whereas their high turnover and fast promotion require efficient ways to transfer such knowledge from one generation to the next. In response, firms such as McKinsey & Company and Booz Allen Hamilton implemented knowledge management systems to guide analyses and recommendations for future clients (Bartlett 1996, Christiansen and Baird 1998).

But such formal knowledge systems are not exclusive to professional firms. Siemens implemented ShareNet to record technical and functional solutions to problems (MacCormack 2002). Ford Motor company's "Best Practices Replication Process," which requires improvements to be quantifiable before they can be codified in the system, has saved the company an estimated \$850 million over four years (Stewart 2000). Finally, many companies codify best practices in the form of standard operating procedures and ISO 9000 documentation.¹

This raises an important strategic, and very practical question for the manager of any knowledge-intensive firm: Should her firm develop a formal knowledge system? And if so, what principles should guide the management and design of such a system? To make things more concrete, consider the following situation in a global management consulting firm. A consulting team has just completed a project to improve the effectiveness of the field service organization of an electronics firm. Because of this consulting firm's high turnover, rapid promotions, quick shifts in specializations, and limitations on working for competing clients, it is highly unlikely that any of the team members will ever work on the same

¹ Although the focus of this paper is on knowledge systems within firms, the ideas may also be applicable to other knowledge repositories, such as biological resource centers (Stern 2004).

problem again. But some other team in this consulting firm, working for a different client in a different country, may be faced with exactly the same problem some time down the road. Because person-to-person transfer of knowledge is difficult and expensive, the firm considers whether it should set up a formal knowledge system to make such know-how accessible to future generations of consulting teams faced with the same problem. This raises a number of important questions. First, the manager needs to know what factors drive the value of such a system to determine whether it would be worthwhile for her particular firm. Next, when considering the implementation of such a system, some of the first-order questions the manager would face—apart from technical considerations—is what information the system should record (i.e., all information versus only extremes; all information versus failures versus successes) and who should have access to that information. These specific but important questions have, to our knowledge, received very little attention in the management literature, which typically takes the knowledge recording (implicitly) as given. For firms that rely on knowledge for their success, the answer to such questions may directly affect their competitive advantage. Furthermore, as we will argue, these issues can have implications far beyond the basic issue of recording and spreading knowledge. For example, an important theme of this paper is that a firm's strategy in recording know-how may have an unexpected influence on its future ability to generate new knowledge. Moreover, as a system of complements (Milgrom and Roberts 1990), a well-functioning formal knowledge management system allows the firm to focus its hiring, staffing, and turnover processes on objectives other than knowledge or knowledge transfer, and may affect the relative attractiveness of potential projects and thus its optimal market strategy.

This paper considers how search and information economics can usefully inform a manager about these management issues, in particular whether to implement a knowledge system and how to manage it in terms of what to record. We study a stylized model to explore the managerial decisions of a firm that seeks to maximize the knowledge-based performance of its employees. As employees try different solutions to a problem and thus develop relevant know-how, the manager must decide whether to codify, at a cost, such findings in a knowledge system to pass on to future generations of employees.

One of our most interesting, and counterintuitive, insights relates to the management and design of a knowledge system. In particular, we find that it may be strictly optimal *not* to codify moderately successful practices. The reason is a strong-form competency

trap: Once a practice is codified, employees have less incentives to experiment further with actions that could lead to even higher performance than the current best practice. Therefore, the firm must trade off exploiting a known best practice versus continuing experimentation to get even better performance in the future. As a consequence of this tension between experimentation and exploitation, we also show that it may be optimal to disseminate a moderately successful practice at the plant level but not disseminate it at the firm level. That is, the firm should follow a hybrid strategy where part of the organization exploits the current best practice, while the rest continues to experiment.

With respect to the fundamental question of which firms should actually implement a formal knowledge system, we find that firms derive more value from a knowledge system when they are larger, when they face the same issues more frequently, when they have high turnover, and when they face issues with more uncertainty about the performance of alternative solutions or issues about which there is little general knowledge. The effect of firm size is particularly interesting because it derives from two scale effects: on the knowledge *generation* side, large firms have more employees experimenting, leading to better solutions, whereas on the knowledge *application* side, large firms can apply the same knowledge more broadly. The effect of uncertainty derives essentially from the option value implicit in experimentation. Interestingly and importantly, we find that these same factors make it also optimal for a firm to be more selective in codifying information (to avoid the competency trap).

In terms of knowledge system management, our findings also support the intuitive inclination of firms and the approach of total quality management (TQM) and ISO 9000 to focus more on "best practice." We find, in particular, that (for future generations of employees faced with the same issue) the direct informational value of successful practices is higher than that of failures. The reason is that information about a success tells an employee exactly what to do, whereas information about a failure merely excludes one of many possible courses of action. We do, however, also examine what factors may make information about failures valuable in this context.

To derive these results, we use an analytical approach to examine the mechanisms that are at work in this knowledge-based organizational setting. This allows us to systematically uncover costs and benefits of alternative principles for knowledge management. To keep the analysis tractable and thus transparent, we make simplifying assumptions. Such assumptions, however, may raise issues with respect to robustness (i.e., whether the results are in fact driven by

some “simplifying” assumption and would disappear if the assumption were relaxed) and applicability (i.e., which settings the model approximates reasonably well versus where more research is needed). With respect to robustness, we will argue that none of the simplifying assumptions seems to inadvertently drive the key results we derive, by considering the effects of relaxing the assumptions. With respect to applicability, the most important assumptions relate to our focus on the transfer of know-how from one set of employees to another via a knowledge system. In particular, our model applies particularly well to business settings where different employees face similar challenges over time or at different locations. This would be the case either when employees are geographically dispersed or when turnover or job rotation is commonplace, as in many large firms. Moreover, because the know-how is transferred via a knowledge system, the problems must be explicit and codifiable.² Our model would thus not apply to business settings where problems are difficult to describe (such as radical innovation) and performance is hard to measure, or to firms where there is very low turnover and frequent communication among all employees (such as small stable firms). Typical settings where our results would apply quite well would be the global consulting firm mentioned above or firms with multiplant networks that benefit from interplant knowledge transfer of operational practices.

1.1. Literature

This paper is related to several strands in the management and economics literature. One important area is the management literature on knowledge management. This research has focused primarily on empirical studies of how firms can effectively create, retain, and transfer knowledge (see surveys in Argote 1999, Argote et al. 2003, Holsapple 2003, and Levitt and March 1988). For example, Cohen and Levinthal (1990) suggest that an organization’s ability to leverage new information depends on its “absorptive capacity,” which is a function of its prior knowledge in a related area. Brockman and Morgan (2003) study how existing knowledge affects new product performance and innovation, whereas Sorenson (2003) studies how environmental volatility affects knowledge transfer in vertically integrated and vertically non-integrated firms. On the issue of learning from success versus failure, the popular business press has emphasized best practice (Bartlett et al. 2003, O’Dell and Grayson 1998), although some also side with a

body of academics who advocate learning from failure (Sitkin 1992, Leonard-Barton 1995, Miner et al. 1999, Canon and Edmondson 2001). Our paper differs from this literature through its explicit focus on formal systems for recording know-how, an issue that, to our knowledge, has been absent from this literature.

A second related stream of literature is the economics of search and optimization (DeGroot 1968, Jovanovic 1979, Weitzman 1979, Aghion et al. 1991), and in particular the literature on multiarmed bandits (Thompson 1933, Rothschild 1974, Adam 2001). This literature studies optimal search algorithms and strategies for an individual or for a group of people. One important application—from the perspective of this paper—is the competency trap as suggested by Levitt and March (1988) and studied more analytically by Jovanovic and Nyarko (1996). Whereas our paper uses the multiarmed bandit formalism as a building block, both our setting and interest are very different from this literature. In terms of setting, we study the transfer of information in a multigeneration or multi-group setting, which, to our knowledge, has not been explored before. In terms of interest, our focus is on knowledge management systems in firms, rather than on general principles of experimentation. This difference in setting and interest is also what distinguishes this paper from the more general literature on the economic value of information, such as Blackwell (1951), Hilton (1981), and Athey and Levin (2001). This literature focuses again on an individual decision maker in a general static context. Athey and Levin (2001), for example, study the demand for information by decision makers faced with “monotone decision problems,” i.e., decision problems in which actions and signals can be ranked such that higher actions are chosen in response to higher signals.

Also closely related to our work is the literature on rugged landscapes (Levinthal 1997, Kauffman et al. 2000, Siggelkow and Levinthal 2003, Siggelkow and Rivkin 2005). This research studies how organizations search and adapt to their environment, and how that search and adaptation is affected by organization form and processes.³ Our paper has some themes in common with that literature. The exploration–exploitation trade-off in this paper, for example, has similarities to the search–stability trade-off in Rivkin and Siggelkow (2003). But the focus of the rugged landscape literature is on the search behavior and how it is influenced by the organizational form, which is quite different from this paper’s interest in formal systems for recording know-how and their implications.

² If the actions or solutions are difficult to codify, the knowledge system could still refer to “experts.” But if the problem itself is not codifiable, then the knowledge system cannot even be indexed.

³ Some seminal work on this methodology was done in biology (Kauffman and Levin 1987, Kauffman 1993).

More distantly related is the organization economics literature on communication and the use of information or knowledge (Marschak and Radner 1972, Bolton and Dewatripont 1994, Van Zandt 1999, Garicano 2000, Alonso et al. 2008). The focus of this literature is on the role of organization, and in particular hierarchy, in the aggregation of information and in problem solving. Van Zandt (1999), for example, studies decentralized computation as a model for information processing by organizations. These models are thus very different both in focus and in setup.

Finally, a paper that nicely complements ours is Manso (2007), who studies how to give agents incentives to innovate. Among other things, he shows that a tolerance, or even reward, for failure and timely feedback are key ingredients of incentive schemes that are conducive to innovation.

1.2. Contribution

The contribution of this paper is to study (analytically) two questions regarding the management and implementation of a formal knowledge system: (1) Which firms derive most value from such a formal knowledge system? (2) Which principles should guide the management and design of such a system in terms of what information to record and transfer?

The rest of this paper is structured as follows. Section 2 presents our model. Section 3 examines best practices and the strong-form competency trap, with §3.2 paying particular attention to the assumptions. Sections 4 and 5 consider, respectively, the issues of local versus global dissemination and how the results may be affected by potential changes in the payoffs over time. We discuss limitations and extensions of our model in §6 and conclude in §7. The online appendix (provided in the e-companion)⁴ contains all proofs and a more in-depth treatment of the issues discussed in §§3.2 and 6.

2. Basic Model

This section describes our basic model—which is a stylized representation of a firm that repeatedly faces the same set of issues, though each time through different employees—whereas §3.2 discusses some key simplifying assumptions and how they may (or may not) affect the results.⁵

As a motivating example for the model, think of the global consulting firm, discussed in §1, with its repeated projects in field service effectiveness. The firm learns about the performance of alternative approaches through its employees' trials and errors.

The firm has to decide whether to set up a knowledge system to capture such know-how and, if so, how to manage it.

To capture this in a model that delivers a transparent and tractable analysis, we will limit attention to one particular problem, e.g., improving field service effectiveness, and we will study a firm that faces this same problem in three periods. The reason to consider a three-period model is that this is the minimum number of periods to formulate all our results. To keep model changes to a minimum, we therefore formulate all results in such a three-period model.⁶

In each of these three periods, a new group or “generation” of the firm's employees will face that particular problem. Each such group or generation consists of I employees and there are no overlaps among the groups. The change in employees from period to period may reflect turnover, or it may reflect the fact that problems get allocated randomly and that the firm has a very large number of employees so that it is unlikely that the same person gets selected twice, or it may reflect a deliberate policy of the firm to put new people on the project from time to time, as we discuss later. The assumption that there is no overlap among the generations is made to impose a transfer of know-how and simplifies the analysis considerably.

Consider now one particular employee. To solve the problem she is facing, the employee can choose from a large number of potential solutions or approaches. This set of solutions will be denoted $A = \{a_1, a_2, \dots\}$ and is common to all employees. For simplicity, we will assume that this set of potential solutions is (countably) infinite.

Each potential solution a_j has a payoff $v_{a_j} \in \mathbb{R}$ that captures how well this solution solves the problem and, thus, how much benefit the firm derives from this solution. These payoffs are exogenously given but are originally unknown to the firm and its employees.⁷ To keep the analysis general, we will not pick any particular values for the v_{a_j} , but specify a distribution from which these payoffs will be drawn. We will assume, in particular, that the payoffs are independent and identically distributed draws from some nondegenerate and commonly known distribution G . Although this assumption is quite standard and captures a setting where there is little general prior knowledge about the solutions, we will show

⁶ Some of our results can be formulated and hold in a two period model. Other results, such as the strong competency trap, however, do require three periods to be nontrivial.

⁷ Our setup essentially embeds a multiarmed bandit problem in a context with multiple selections or generations of employees (and potential transfers of knowledge from one selection or generation to another). For general treatments of multiarmed bandit problems, see Berry and Fristedt (1985) or Gittins (1989).

⁴ An electronic companion to this paper is available as part of the online version that can be found at <http://mansci.journal.informs.org/>.

⁵ We delay this to the end of §3 to immediately discuss the effects on the results.

Figure 1 Time Line of Model

0	1	2	3
Setup	Period 1	Period 2	Period 3
(a) Firm chooses $n \geq 0$.	(a) New group of employees faces the problem.	(a) New group of employees faces the problem.	(a) New group of employees faces the problem.
(b) Performance $v_{a_j} \stackrel{iid}{\sim} G$ are drawn.	(b) Employees simultaneously choose actions a_j . Firm learns v_{a_j} .	(b) Employees simultaneously choose actions a_j . Firm learns v_{a_j} .	(b) Employees simultaneously choose actions a_j . Firm learns v_{a_j} .
	(c) Firm decides which (a_j, v_{a_j}) to record.	(c) Firm decides which (a_j, v_{a_j}) to record.	

later how these assumptions can be relaxed by allowing correlation structures or more differential information about the alternatives.

Whereas the payoffs of specific actions are originally unknown (beyond the fact that they are drawn from the known distribution G), a solution’s effectiveness—and thus its payoff—gets revealed to both the employee and the firm when an employee implements that specific solution. It then becomes temporarily part of the firm’s know-how. The firm can make this knowledge available to other groups, or to future generations, of employees by recording the action and its payoff in its knowledge system.

Let us now turn to the dynamic structure of the game, as described in Figure 1. At the start of the game, the firm has to decide whether to set up a formal knowledge system. Such knowledge system is characterized by its capacity $n \geq 0$, which is the maximum number of actions about which it can record information (i.e., each action and its performance, (a_j, v_{a_j}) , takes one unit of capacity). We assume that the cost of the knowledge system is proportional to its capacity, i.e., the cost of a system of capacity n is cn , with $c > 0$. After the system and its capacity have been chosen, the payoffs $v_{a_j} \stackrel{iid}{\sim} G$ are drawn. As mentioned before, the realizations of the v_{a_j} are not publicly revealed at this point (so that it does not matter whether these payoffs are drawn before or after the firm’s decision on a knowledge system).

After this “setup” period, there are three regular periods that correspond to the three groups or generations of employees who face the focal problem. These three periods are very similar to each other. In each of these periods, a new group of I employees is faced with the focal problem. Each of these employees learns (at no cost) all information that is currently in the knowledge system, and thus immediately knows the payoffs of all actions about which the firm has recorded information. These I employees then each (simultaneously) choose an action from the set A to try to solve the problem. The firm observes these actions and how well they solve the problem, i.e., their resulting payoffs. The firm then decides what know-how (a_j, v_{a_j}) , if any, to record in its knowledge system for future generations of employees. The

only information that can be recorded at the end of period t is whatever know-how was transferred from period $t - 1$ plus whatever was revealed through new actions undertaken in period t . We will assume that the firm has a discount factor δ . We discuss later how this discount factor has a number of useful alternative interpretations.

We assume that the firm maximizes its overall performance, i.e., the net present value of the sum of all employees’ payoffs. Each employee maximizes her own performance, i.e., the expected payoff from her own action. When indifferent, employees are assumed to act in the firm’s interest. When both are indifferent, employees choose an action at random (with all actions equally likely). Finally, when indifferent, the firm prefers to not store any information (as if recording information carries a tiny cost). These assumptions on what employees or firms do when indifferent are made for convenience and do not drive the results. Section 6 discusses the robustness of these results with respect to introducing explicit incentives.

3. Best Practice and Strong Competency Trap

In this section, we first derive the main results of the paper and then discuss how robust these results are to relaxing some key assumptions.

Because of the backward induction nature of the analysis, the results are in reverse logical order: Proposition 3, which comes last, indicates which firms should implement a knowledge system, whereas Propositions 1 and 2 indicate, conditional on implementing a knowledge system, how such system should be managed in terms of information recording.

3.1. Analysis

We thus consider first the following question: *Given* a knowledge system, how much and what information should be collected? Our first result, captured in Proposition 1, shows that the firm records only the “best practice” in its knowledge system. To present this result formally, let $B_t \subset A$ denote the set of actions

about which information is available in the knowledge system at the start of period t , let $C_t \subset A$ denote the set of actions selected by employees in period t , and let $\tilde{a}_t = \arg \max_{a_j \in C_t \cup B_t} v_{a_j}$ be the highest-payoff action in either B_t or C_t . We use superscript $*$ to denote optimized values.

PROPOSITION 1. *An optimal knowledge system has at most one unit of capacity ($n^* \leq 1$). At the end of each period t , at most the action with the highest payoff, $\tilde{a}_t \in B_t \cup C_t$, is recorded.*

It is useful to unpack this best practice result into two parts: the firm records only successes and, conditional on recording only successes, it will record only one, the best practice. These two results are driven by two effects. The first and most important effect is that information about successes (i.e., above-average performance) is more useful than information about failures (i.e., below-average performance): If an employee learns about an extremely good action, she can choose that action and receive the high payoff, but if she learns about an extremely bad action, she can only avoid that action and then still has to choose among the remaining actions, so that her payoff remains close to the average payoff. It is important to note that we consider here only the direct informational value of remembering a past action and its payoff. In particular, failures can be very valuable, for example, to discover organizational malfunctions. However, such considerations are quite different from the reason why you would record information in a knowledge system for employees to consult when faced with a new problem, in which case knowing what worked is more useful than knowing what did not. This effect provides an explanation for why companies such as McKinsey, Ford, and Siemens tend to focus on best practice or on successful approaches in their know-how systems.⁸ This is also reflected in the focus on best practice and benchmarking in TQM and ISO 9000 standards.

The second effect that drives this result is that among the actions in the knowledge system, employees will undertake the *one* action with the highest performance (conditional on that performance being greater than average). Once employees stop experimenting, it is also in the firm's best interest that the employees undertake the one best known action. It follows that from the perspective of both the employees and the firm, only the best among all observed

successes matters and is worth remembering. Because failures never get recorded, it follows that only one action is worth remembering from the firm's perspective, and that is the best practice. To see this from a different perspective, because no one cares about the second-best practice, there is no point in recording it.

The exact form of the result—that at most one best practice is recorded—is quite extreme, although it is actually common practice in TQM and ISO 9000. To understand what drives this, it is useful to split this again into two components: failures *never* get recorded and at most one success gets recorded. In both cases, the result is a combination of a general and broadly applicable mechanism with some specific assumptions that make the principle come out in a very stark way.

The outcome that failures *never* get recorded comes out in such a stark way in part because of the assumptions that there are an infinite number of potential solutions and that payoffs are perfectly observed. In particular, if there are only a finite number of alternatives, then it will be optimal to record (sufficiently bad) failures as long as no (sufficiently good) success has been discovered, as we discuss in §3.2. An important insight is that knowing about a pitfall cannot degrade performance beyond the cost of recording the information.

The outcome that at most one success gets recorded comes out in such a stark way in part because of the assumption that past performance perfectly predicts future performance. When this connection is less than perfect, there can be gains from recording more than one success. Two conditions that weaken the connection are that performance may change over time, which we will analyze in §5, and that information about past performance has some noise. We will also discuss in §3.2 that, when recording failures is optimal, it is often optimal to record more than one failure.

Despite these caveats, this first result has an important positive and normative implication with direct managerial relevance: From the point of view of information for solving similar future problems, firms should focus more on recording best practice in a knowledge system than on documenting failures.

In terms of managing a knowledge system, this first result gives managers guidance as to what information to focus on when setting up a knowledge system. But our second result is about a reverse effect: Some information has negative value and a manager designing a knowledge system should explicitly prevent such information from being recorded. In particular, it may be strictly optimal for a firm to explicitly not record information about moderately successful practices (i.e., actions with slightly above-average performance) even if doing so were free.

⁸Note that sample selection bias (or the bias from sampling on the dependent variable) is not an issue here because the companies observe the full population of experiments. Sample selection issues only arise when performance measures are noisy and observations are selected for further study based on their performance. For some perspectives on managerial implications of sample selection, see Carroll (1983), Denrell (2005), and Van den Steen (2005).

To show this formally, we will now derive the firm's optimal strategy for recording information. The following proposition says that in period 1 the firm will not codify actions with payoffs less than a threshold $\tilde{v}_1 > \mu_G$, even when their payoff is greater than the mean, μ_G ; only actions with payoffs greater than \tilde{v}_1 should be codified. Once an action is codified, employees will henceforth take that action as they know it will lead to higher than average performance.

PROPOSITION 2. *There exists thresholds $\tilde{v}_1 > \tilde{v}_2 = \mu_G$, such that for $t = 1, 2$,*

- *actions in period t with payoff $v \leq \tilde{v}_t$ never get recorded;*
- *the first time any payoff in period t strictly exceeds \tilde{v}_t , the action corresponding to the highest payoff in that period gets recorded; and*
- *from that time on, all employees undertake that one recorded action.*

This result is probably more surprising than the aforementioned results on best practice. It is caused by an agency problem that is central to firms' attempts at exploration and innovation: Because part of the benefits from experimentation are realized in the future or elsewhere in the firm, employees do not benefit as much from their own experimentation as the firm does. An employee will thus experiment less than what the firm would want her to do. In particular, in the context of our model, it takes the stark form that employees will stop experimenting once any above-average action is known. The reason is that the employee maximizes her one-period payoff and thus simply chooses the action with the highest (immediate) expected performance. To counteract this, the firm can force employees to continue to experiment by not recording information about actions with mediocre above-average performance. In fact, the firm would even be willing to pay to ensure that information on actions with mediocre payoffs disappears. This insight is complementary to the best practice policy described in Proposition 1: By telling employees what the best practice is, they adopt it; by not telling employees what the best (known) practice is, they experiment. What the firm decides to codify then depends on the value of exploiting the current best practice versus the future expected value from experimentation.

The effect that knowledge about moderately successful actions can actually hurt long-term performance is essentially a strong-form "competency trap." The notion of a competency trap, introduced by Levitt and March (1988) and further analyzed by Jovanovic and Nyarko (1996) and others, captures the idea that an (at first sight) valuable competency may have unexpected consequences that end up hurting the

firm. An essential component of the notion of a competency trap as suggested by Levitt and March (1988) is that the firm must become proficient using the inferior procedure. In particular, they describe it as a situation "when favorable performance with an inferior procedure leads an organization to accumulate more experience with it, thus keeping experience with a superior procedure inadequate to make it rewarding to use" (Levitt and March 1988, p. 322). The competency trap we identify here is stronger: the simple fact of knowing about the moderately successful practice inefficiently reduces the incentives for employees to experiment.

In a somewhat related argument, Sitkin (1992) suggests a complementary reason why success can be a liability to an organization: it can breed complacency and homogeneity, and organizations tend to punish failure disproportionately relative to inaction (or status quo). In this paper, we find that the liabilities of success can be even more extreme: risk neutral, performance-maximizing employees who are rewarded symmetrically for failures and successes will stop experimenting once information about a moderately successful practice is revealed to them.

Although the exact form of the result, as stated in Proposition 2, depends on the specific assumptions of the model, the general qualitative result—that it may be optimal not to record information even when free—seems to be robust. The reason is that, from the perspective of the firm, there is no upside to recording information about mediocre practices because the firm prefers employees to continue experimenting. An important managerial implication is that, *even without the use of incentives*, the firm can induce optimal experimentation by its employees by this strategic use of the knowledge system (as long as it is able to control on an individual basis who gets access to what information as in §4).

Although we know of no systematic research that shows that indiscriminate recording of know-how can hamper the further development of know-how, there is some informal evidence on these issues. For example, a large telecom company that implemented a knowledge management system for its 1,200 support center engineers was initially encouraged by the adoption and improved performance of its employees: "After the first year, the average time-to-solution for high priority problems was reduced to four hours from two days." However, in the long run, the firm discovered that "most engineers chose the easy way out by simply relying on the system to solve problems" (Chua 2007, p. R8). Similar worries that reliance on the knowledge system blunted experimentation and creativity have been raised, among others, at McKinsey (Bartlett 1996, personal conversations). The

results of this paper suggest that both a more critical approach to what information to codify and forcing teams from time to time to work without any access to the knowledge system (to force experimentation) may result in better long-term outcomes. In particular, the theory implies that firms should actively ensure that only know-how of sufficiently high quality gets recorded. Firms may implement this in different ways, from a formal approval system before information can be recorded (e.g., Ford Motor Company’s “Best Practices Replication Process”) to purposely raising the hurdles to record information.

Now that we derived what information should be recorded conditional on implementing a knowledge system, we can turn to the question of which firms get the most value from a knowledge system and are thus most likely to implement it. In particular, in our third main result we show that a firm derives more value from a knowledge system when it has more employees facing the same issue, when it faces the issue more frequently, and when it faces issues with more underlying uncertainty. Moreover, we show that these same drivers also make it optimal for the firm to be more selective about codifying information in its knowledge system, so that the value of a knowledge system and its optimal management are related.

The fact that it is the same factors that drive the value of having a knowledge system and the optimal selectivity is important: The firms that are most likely to have a knowledge system should also be most selective. Had this relationship been the reverse, i.e., if such firms should have been least selective, then it would have weakened the importance of Proposition 2. Now, the result strengthens the importance of Proposition 2.

These comparative statics are derived in the following two-part proposition. To capture the notion that one probability distribution differs from another in the ex ante uncertainty about the payoffs, we will use a *mean-preserving stretch* to represent that one distribution is a stretched-out version of another. In particular, F is a mean-preserving stretch of G if $\mu_F = \mu_G$, and there exists a continuous function $\phi(x)$ such that $F(\mu_F + \phi(x)) = G(\mu_G + x)$ with $\phi(0) = 0$ and $1 < \phi'(x) < A$ for some $A < \infty$ and $x \in \mathbb{R}$.⁹ A special case is that F is a *linear mean-preserving stretch* of G if $\mu_F = \mu_G$ and $F(\mu_G + \beta x) = G(\mu_G + x)$ for some $\beta > 1$ and $x \in \mathbb{R}$. Let $v_{(l)}$ denote the l th order statistic and $G_{(l)}$ its distribution when the underlying distribution is G .

⁹Note that mean-preserving stretch is a stricter notion than mean-preserving spread. We want to capture the fact that the two distributions differ in their variance and in their variance only. Mean-preserving spread allows the distributions to differ completely, as long as they can be ordered by their riskiness.

PROPOSITION 3A. *The value of a knowledge system (with $n^* = 1$) is $\delta I(\delta P[v_{(l)} \leq \tilde{v}_1]) \int_{\mu_G}^{\infty} (v - \mu_G) dG_{(l)}(v) + (1 + \delta) \int_{\tilde{v}_1}^{\infty} (u - \mu_G) dG_{(l)}(u) - c$. The value of a knowledge system increases in firm size I , in the discount factor δ , and in a mean-preserving stretch of G , and decreases in the cost of capacity c .*

PROPOSITION 3B. *The optimal threshold for codifying knowledge, \tilde{v}_1 , increases in I , δ , and a mean-preserving stretch of G (strictly for $t = 1$ and weakly for $t = 2$).*

To see the intuition for the comparative statics on the value of a knowledge system, note that the value depends on two factors:

1. Effectiveness of experimentation: Relative to a naive (i.e., a random) solution, how much does experimentation improve the firm’s expected know-how?
2. Effectiveness of exploitation: For a given level of know-how (i.e., for a given improvement over the naive solution), how much value gets generated by deploying that added know-how to other groups (or future generations) of employees?

Consider then first the effect of firm size on the value of a knowledge system. Firm size acts on both factors. With respect to experimentation, larger organizations have more employees experimenting, so that the quality of the know-how increases, making it more valuable to remember and deploy. With respect to exploitation, larger organizations benefit from returns to scale because they have more employees who can apply the best practice (at no extra cost). In other words, knowledge systems have scale effects in both the experimentation (knowledge generation) and exploitation (knowledge application) stages. Casual observation indeed suggests that it is the large Fortune 500 companies, such as Ford and Siemens, and the large consulting companies, such as McKinsey and Booz Allen Hamilton, that have implemented knowledge management systems.

The effect of uncertainty about the actions’ performance works through the “effectiveness of experimentation” factor. Clearly, if there is little uncertainty and all actions perform similarly, there is little to learn from experimentation. If, on the other hand, there is a lot of uncertainty about how alternative practices will perform, then there is also a high option value from being able to remember the best alternative. It follows that we should see knowledge systems more in industries where there is high variability in the performance of alternative approaches and little general knowledge as to exactly which one is the best approach. This would predict that know-how systems are more common in settings with complex problems and in professions that are considered more an art than a science. General management consulting or cutting-edge surgery would be typical cases. This

can be operationalized, for empirical purposes, by the level of disagreement about the optimal approach.

A higher discount factor, finally, affects the effectiveness of exploitation factor: It makes the future, and thus the value of exploiting any improvements in know-how, more valuable. That will obviously increase the value of a knowledge system. This comparative static has another useful interpretation when we interpret the periods as time intervals of length T in a continuous-time model with discount rate r . In that case, the discount factor $\delta = e^{-rT}$ is also a measure for the time between intervals. A high discount factor thus corresponds to facing that problem more frequently (though every time by different employees). It follows that firms that are faced more often with the problem or that have high turnover would benefit more from encoding best practice and thus derive more value from a knowledge system. This suggests that large consulting firms with high turnover or rapid promotion and consulting firms that rotate their consulting staff over very diverse projects (rather than specializing them) will get more value from a knowledge system. Firms that make their consulting staff more specialized and that have low turnover get less benefit from a knowledge system.

The second part of the result is that the optimal selectivity in recording know-how is driven by these same factors. The intuition for these results on selectivity in encoding is actually quite similar to the intuition for the value of a knowledge system because it depends on the same two factors, though in slightly different ways. In particular, being more selective means forgoing exploiting a currently known mediocre practice in this period to experiment and exploit an even better practice in the future. The effect of being more selective then depends on the effectiveness of experimentation, as before, and on the *relative* effectiveness of exploitation. In particular, what matters in terms of exploitation is how deploying the mediocre practice in this period compares to deploying the improved practice in the future.

The comparative statics are then similar as those for the value of a knowledge system, but come through slightly different channels. First, the effect of firm size now comes completely through its impact on experimentation: Larger firms generate in expectation better know-how when they experiment (whereas both the costs and the benefits of exploiting the current practice now versus the improved practice in the future are proportional to firm size). Larger firms should thus be more selective in what to encode. Second, the effect of uncertainty comes, as before and for the same reason, from an increased effectiveness of experimentation. Third, the effect of the discount factor, which is more subtle and potentially weaker in

this case, comes from the relative benefit of deploying the current mediocre practice in this period compared to experimenting in this period and deploying an improved practice in future periods. This balance obviously tilts toward experimentation and thus toward higher selectivity when the discount factor is higher. To see this another way, the cost of experimenting one more time is independent of turnover, but the ensuing improvement in the best practice is more valuable in firms with higher turnover because it will be applied sooner and more often. It is thus optimal to be more selective.

These results on the optimal selectivity are a bit more subtle than those on the value of a knowledge system because the underlying argument and trade-offs require more steps in logic. Although we believe that these results are also robust, more research is needed to confirm this.

3.2. Robustness

In this section, we explore the effect of relaxing some key assumptions of the model. Apart from providing insights in the mechanisms, the analysis suggests that the main results seem quite robust. The discussion in this section is supported by more formal analysis and (some) more in-depth discussion in the online appendix.

3.2.1. No Overlap Among Generations. A first important assumption in our model was that there is no overlap among different groups or generations of employees. This assumption makes the analysis very clear and transparent, because it essentially imposes a transfer of know-how from one generation to the next, but it also excludes two quite common situations.

The first excluded situation is that an employee faces the problem more than once. Such employee longevity has two effects. First, and most obvious, the fact that employees may remember their payoffs from an earlier period reduces the benefits of recording payoffs in a knowledge system. Second, employee longevity gives the employees more incentives to experiment: because they may face the problem again, they capture more of the benefits from experimentation. Nevertheless, a formal analysis of a simple variation on the model of §2 (presented in the online appendix), in which there is some probability that the employee stays for the next period, suggests that the main effects of the paper, such as recording successes over failures and the competency trap, carry over to such a setting.

The second excluded situation is that employees from one group (or generation) can communicate directly with employees from a previous group (or generation). Intuitively, such communication would weaken some of the effects of the paper but would not eliminate them. In particular, such communication is

likely to be very random and ineffective unless there is some system to identify which employees solved the problem successfully, and thus which employees are the experts on the problem. But the model in this paper can be reformulated as being about a system that identifies which employee is an expert (i.e., which employee knows which actions deliver a high payoff): Instead of recording the action and payoff, the system records the name of the employee who knows these actions and payoffs. The same principles as derived in this paper would thus apply to such a system. It follows that what the assumptions really exclude is random, nontargeted communication. But such communication has very similar effects as letting random employees stay for another period, so that the main qualitative results would again hold.

One interesting conjecture is that the firm may actually *prefer* to have no overlap among generations. In particular, because of the competency trap, the firm may prefer that the problem gets solved by a new group of employees (if the old group had come up with only moderately successful solutions) to ensure that the organization “forgets” mediocre practices. This practice of “bringing in new blood” to get more experimentation seems quite common.

3.2.2. No Prior Information (or Identical Distribution). A second important assumption was that all payoffs are drawn from the same distribution and no player has any information about the payoffs prior to trying a particular action, i.e., employees have no relevant experience. In the online appendix, we formally relax this assumption in two ways. First, we analyze a simple setting where each employee has experience in the form of perfect knowledge about a finite number of randomly selected actions. Second, we examine a setting where players do get a private but imperfect signal about the payoff of each action, as if the players can make educated guesses about the actions’ payoffs. We show that under both scenarios only successes get recorded and the competency trap still exists.

3.2.3. Independent Draws. The model also assumed that the payoffs are independently distributed. The key implication of this assumption is that knowing the payoff of one action gives you no information about other actions. The online appendix shows that the competency trap and the value of successes over failures still hold in a simple model where each action is positively correlated with a finite set of other actions. Although this analysis shows that the key qualitative results do not depend on the independence assumption, that does not imply that the correlation structure of the payoffs does not play a (potentially important) role. In fact, the correlation structure may sometimes allow interesting know-how strategies for knowledge management. For example, the

fact that correlations give only partial information about the inferred payoff may allow a combination of exploration and exploitation.

3.2.4. Infinite Action Set. Another important assumption was that there is an infinite number of potential actions. Although business conditions call for creative managerial solutions that usually cannot be exhaustively listed, there are situations where it makes more sense to think in terms of a finite set of options. For example, production workers often have to choose from a finite number of tools to perform each production operation, translating to a finite set of actions in the framework of our model. Another important setting is when the potential actions, though infinite, can be grouped in a much smaller (finite) number of “solution types” with all actions of one type having similar performance. Such a setting can be usefully approximated by a finite action set with one action per type.

We conjectured earlier that the simplifying assumption of an infinite action set may partially drive the result that failures *never* get recorded, a result that is at odds with the informal observation that firms do sometimes document failures (to prevent them from reoccurring). The online appendix studies this conjecture more formally by looking at a numerical example¹⁰ with a finite number of actions and derives the following results. First, failures *do* get recorded. In fact, when some players have above-average performances and others have below-average performances, the firm may record only the below-average payoffs. Second, because the benefits from remembering failures are additive, there is essentially no limit on the number of failures that get recorded (though remembering failures and remembering success are mutually exclusive in this particular model). Third, remembering failures does not reduce the incentives to experiment, so that the reasons for not recording failures are less strong than for not recording mediocre successes. Nevertheless, once a sufficiently good action is discovered, only that best practice is recorded henceforth, as before.

In fact, the intuition suggests that it is true in general—in a model with a finite number of possible actions—that successes are more valuable to record

¹⁰ The reason for working with a numerical example is that even a simple general model turns out to be surprisingly involved. The reason for this complexity is that firms and employees will try to draw inferences (and try to anticipate each others’ inferences) about actions that were not recorded, taking into account what was recorded and the firm’s equilibrium recording strategy. All cutoff values then become a function of recorded values, and equilibria typically cannot be derived in closed form. Moreover, though less importantly, the fact that recording an action may suggest that an employee should either avoid or undertake that particular action raises the issue of multiple equilibria.

than failures. To see this, consider a two-period model with a finite set of N actions. Each action's payoff is still an independent draw from G . Suppose first that the firm records a low-payoff action a^- , with payoff $v^- < \mu_G$, so that employees can avoid it. Relative to the case when no information is recorded, each employee's expected payoff for the next period increases by $(1/N)(\mu_G - v^-)$. Essentially, employees will have an equal probability of picking any action except the one that they know gives a lower than average payoff. Note that the value of recording a failure is proportional to how bad the failure actually is. Suppose next that the firm remembers a high-payoff action a^+ , with payoff $v^+ > \mu_G$, so that employees can replicate that action. Relative to the case when no information is recorded, each employee's expected payoff for the next period increases by $((N-1)/N)(v^+ - \mu_G)$. Clearly, for the same deviation from the mean, it is still better to record successes than to record failures (unless the firm wants employees to experiment); and recording failures may make sense but only temporarily until a sufficiently good best practice is discovered. Note that our result that successes are more valuable than failures does not imply that organizations cannot learn from failure. On the contrary, knowing how to avoid a misstep can be a huge advantage. However, knowing a course of action that results in success will also serve this purpose and often more.

The online appendix discusses some other settings where remembering failures may be optimal. The most natural is when not all actions look the same ex ante, and some of the actions that look most promising actually lead to failures. One example would be a setting where all players get a common public but imperfect signal about some or all the actions's payoffs. This is an important avenue for future research.

4. Local vs. Global Dissemination

The previous section considered the basic setting in which the firm can control what information is recorded, but not who can access it. In other words, any recorded information is automatically available to all employees. This is the case for many formal knowledge systems, such as those of McKinsey or Booz Allen Hamilton (Christiansen and Baird 1998). In other settings, however, the firm may be able to control which employees get what information. One such case is when the firm can decide whether certain know-how should be disseminated on a plant level versus on a firm level. A related case is when a firm, like Philips, sometimes has both insiders and outsiders working independently and in parallel on product design (where the outsiders do not have

access to the firm's existing body of know-how but the insiders do) or when a firm isolates a new product design group from the rest of the firm. This section studies this situation by assuming that the firm can choose in each period which employees observe the recorded knowledge.

For that case, the following proposition says that, as long as the firm has discovered only mediocre best practices, it is optimal to communicate information about these practices to only a subset of employees, while forcing the other employees to continue to experiment. To state this result formally, let $v_{\hat{a}_1}$ denote the best known payoff at the end of period 1, corresponding to action \hat{a}_1 . Let $\underline{v} = \inf\{\text{supp } G\}$ and $\bar{v} = \sup\{\text{supp } G\}$, with $\underline{v} < \bar{v}$ because G is nondegenerate.

PROPOSITION 4. *There exist cutoff values $\hat{v}_1, \dots, \hat{v}_I$, where $\mu_G < \hat{v}_1 < \dots < \hat{v}_I < \bar{v}$, such that*

- *if $v_{\hat{a}_1} \leq \hat{v}_1$, then no information is communicated and all employees experiment in period 2;*
- *if $\hat{v}_{j+1} < v_{\hat{a}_1} \leq \hat{v}_j$, $j = 1, \dots, I-1$, then $v_{\hat{a}_1}$ is communicated to $I-j$ employees, who then undertake action \hat{a}_1 in period 2 while the other j employees experiment;*
- *if $v_{\hat{a}_1} > \hat{v}_I$, then $v_{\hat{a}_1}$ is communicated to all employees, who undertake \hat{a}_1 in periods 2 and 3.*

To see the advantage of being able to control access, note the following. As discussed earlier, the firm captures benefits from experimentation that employees do not, which forces a trade-off between experimentation and exploitation. All-or-nothing access presented the firm with an extreme choice between experimentation and exploitation because the only way to force an employee to experiment was to not record information at all, and thus to have all employees experiment. When the firm can control who can access the know-how, however, the firm can have the best of both worlds: while one part of the firm reaps the benefit of the best known practice to date, another part of the firm experiments to provide future performance improvements.

This two-pronged strategy can be optimal because the optimal number of employees who should experiment is finite. The reason is that the incremental benefit from an extra employee experimenting decreases with the number of employees already experimenting, whereas the incremental cost is constant because it always equals the opportunity cost of not applying the best known practice. The optimal number of experimenters is reached when the marginal cost of one extra employee experimenting exceeds the marginal benefit.

This ability to control who can access information in the knowledge system actually enables the firm to induce the *first-best* level of experimentation among its employees *without the use of incentives*. An informal personal account suggests that it is exactly such

experimentation motives that drove a firm such as Philips to rely on outside development teams either exclusively or in parallel to inside teams.

5. Effect of Change

In the basic setting, we also assumed a static environment where the actions' performance do not change over time. In many cases, however, market conditions and technological capabilities change over time, and a successful action at one point in time may not give the same result some time later. An interesting example of this is the design of high performance racing yachts for the America's Cup sailing regatta. In 1995, Team New Zealand won the America's cup with a boat design that was a generation ahead of its competitors. The lead designer then defected to the Italian team in 2000, bringing with him the winning design from 1995. However, sailing conditions at a different venue in 2000 were very different from 1995, and the Italian team lost to a newly designed Team New Zealand boat that accounted for the change in environment (MacCormack 1997). Another important setting is when changes in competitors' actions affect the payoffs of the focal firm's actions. In this section, we explore how introducing such change affects the optimal strategy for managing know-how. A marked result of §3 was that the firm will record at most one best practice. We now show how this may be different when the actions' performance may change over time, e.g., when changes in the environment or in competitors' actions can make formerly successful methods less effective or even obsolete.

To capture in a straightforward manner the idea that performance may change over time, we will assume that at the beginning of each period, each action's performance is redrawn with independent probability q . That is, with probability q , v_{a_j} is redrawn from distribution G at the beginning of period t , whereas with complementary probability $1 - q$, it remains the same as in period $t - 1$. The firm

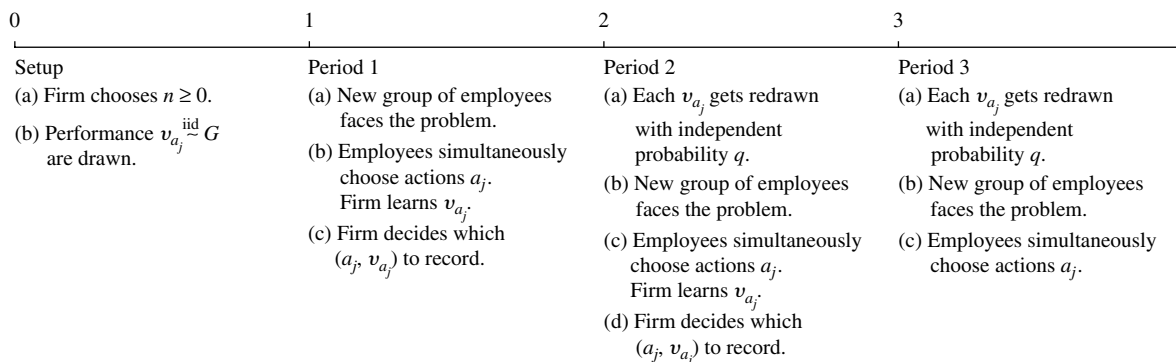
and employees do not directly observe whether a payoff has been redrawn (although they will learn this fact when the action is tried again). The timing of the modified game is shown in Figure 2.

To keep the analysis tractable, we add the parametric assumption that G is a Bernoulli distribution with parameter p and support $\{0, 1\}$. This corresponds to a situation in which each potential solution either solves the problem, resulting in a success with payoff 1, or does not solve the problem, resulting in a failure with payoff 0. Ex ante, however, it is not known which are the successful solutions. All employees share a common prior that each potential solution has an independent probability p of being successful. We can think of $(1 - p)$ as the difficulty of the problem, i.e., high p is an easy problem whereas low p is a difficult problem. We will also assume that $\delta = 1$. This is exactly the model of §2 but with more specific assumptions on G and δ .

We find that if an action's performance may change over time, the firm may want to record more than the best-performing action, i.e., the optimal size $n^* > 1$, because the additional information serves as backup for when the best practice becomes obsolete. In our yacht design example, elements of the keel design of the winning Team New Zealand boat in the 2000 America's Cup were previously investigated in 1995, but deemed suboptimal at that time. Whereas the Italian team did not revisit these design options in their 2000 design, Team New Zealand did and found that they were more suitable to the sailing conditions in 2000. We find that such backup information will be most useful when the rate of change is intermediate: When change is fast (q is large), yesterday's know-how is less valuable today, limiting the benefit of such extra information; when change is slow (q is small), there is no need to remember more than only the best practice, because the probability that this practice becomes obsolete is small.

Second, we also find that a formal knowledge system is most likely for low rates of change (low q) and

Figure 2 Time Line of Model with Changing Environment



moderately difficult problems (medium p). As the rate of change increases, the information becomes more quickly obsolete, and the value of storing information thus decreases. For very easy problems (high p), the solution becomes so obvious that a knowledge system is unnecessary; for very difficult problems (low p), the probability of discovering a solution becomes so small that there is typically not much to record.

Finally, the value of backup solutions also increases in firm size because there are again scale effects in both experimentation and exploitation. Larger organizations thus record more backup information.

The following proposition formalizes these results. It determines the marginal benefit from an extra unit of capacity and derives the comparative statics for the optimal size n^* of the knowledge system. Let $\Pi(n)$ be the expected payoff per employee when information on n payoffs can be recorded and transferred from period $t - 1$ to period t . The marginal benefit of a unit of capacity is then $\Delta\Pi(n) = \Pi(n) - \Pi(n - 1)$.

PROPOSITION 5. *The benefit from adding an additional unit of capacity equals*

$$\begin{aligned} \Delta\Pi(1) &= [1 - (1 - p)^I](1 - q)(1 - p) \\ &\quad \cdot [2 - (1 - p)q + (1 - p)^I], \quad \text{and} \\ \Delta\Pi(n) &= \sum_{j=n}^I \frac{I!}{(I - j)!j!} p^j (1 - p)^{I - j} (1 - (1 - p)q) \\ &\quad \cdot (1 - p)^n q^{n - 1} (1 - q) \quad \text{for } n \geq 2. \end{aligned}$$

The marginal benefit $\Delta\Pi(n)$ increases in firm size I and decreases in capacity n for all n . For $n \geq 2$, $\Delta\Pi(n)$ is single-peaked (“quasi-concave”) in the probability of change q . For $n = 1$, $\Delta\Pi(n)$ strictly decreases in q and is strictly single-peaked (“strictly quasi-concave”) in problem difficulty p .

The optimal capacity of the knowledge system n^ is single-peaked (“quasi-concave”) in the probability of change q , and increases in firm size I . Moreover, there exists $0 < \underline{p} \leq \bar{p} < 1$ such that a knowledge system will be implemented if and only if $p \in (\underline{p}, \bar{p})$.*

The online appendix illustrates the quasi-concavity results of Proposition 5 with a numerical example.

These results also have interesting implications for the effect of competition.¹¹ In particular, the performance of an action may depend on what competitors are doing. As a consequence, the payoffs to the focal firm’s actions will change when competitors’ actions change. If we take these competitive changes as exogenous, then this model of change can give us some insights on how competition can affect optimal

knowledge management. In particular, the aforementioned results have two implications. First, and probably most important, knowledge systems are more likely in settings with low q , i.e., in settings where such competitive changes are limited in impact or even absent. This may be one reason why a lot of knowledge systems focus on internal operations and on the cost side of operations, where the confounding effect of competition is minimal or nonexistent. Second, in a setting where such competitive changes are prevalent but not too prevalent (i.e., intermediate q), firms would record more than one successful solution to a problem as a backup for when competitors’ actions change. An important qualification is obviously the assumption that competitive changes are exogenously given. More research is needed to study the effect of this assumption on these results and on, e.g., the link between the competency trap and incumbent inertia.

Empirically, this section adds two predictions. First, a firm is most likely to store multiple solutions for a problem when the environment in which the firm operates changes at an intermediate rate. Second, the theory also predicts that a firm is more likely to have a formal knowledge system when the rate of environmental change is low and its knowledge workers face problems of medium difficulty. A slightly stronger but empirically more convenient version of this last hypothesis is that the likelihood of having a formal knowledge system has an inverted-U relationship with the rate of success in solving the firm’s typical problems without the help of a knowledge system. For example, a hospital should be less likely to implement a knowledge system for procedures that nearly always succeed, such as measuring blood pressure, or that nearly never succeed, such as a full arm transplant. A hospital is more likely to implement knowledge systems for tough but feasible procedures such as heart surgery. This prediction, however, raises some challenges as an empirical test of the theory for three reasons. First, the measure of difficulty is often counterfactual. Second, there is an important truncation issue. Organizations will try to avoid (or, alternatively, may not survive) settings where the base rate of success is very low. Hospitals will simply not do any full arm transplants. This leads to a truncated distribution which would probably result in a positive relationship between the problem difficulty and the likelihood of having a knowledge system, although that conjecture requires further research.¹² The third issue is that it seems quite difficult to find a useful setting with identifying variation. In particular,

¹² A similar truncation issue may affect the results in function of the rate of change. Extremely rapidly changing environments are very tough for organizations to survive.

¹¹ We thank the associate editor for suggesting this interpretation.

most settings with differing base rates of success are difficult to compare and therefore difficult to meaningfully include in one sample for an empirical test. Despite that, the result is still useful for a more informal evaluation of the theory and as a prescriptive result.

6. Limitations and Extensions

The analysis in this paper has concentrated on one particular setting and on a limited set of core issues to keep the analysis transparent and the discussion focused. This section considers some limitations and potential extensions of the model. It summarizes more extensive analysis presented in the online appendix.

The model assumed that employees try to maximize the payoff from their action, which captures the fact that many employees' compensation depends essentially on their on-the-job performance. But this does raise the question of how introducing explicit incentives to experiment would affect the results. We conjecture that there are three complementary reasons why the effects that we derive, in particular the competency trap, would probably persist even when explicit incentives are introduced. (1) The current solution without incentives is close to, or even equals, the first best solution (because there are no gains from recording mediocre practices that employees are not supposed to choose) so that the gains from introducing explicit incentives is limited. (2) Because incentives for experimentation often conflict with incentives for other purposes, strategically using the knowledge system to take care of experimentation gives the firm more degrees of freedom to get incentives right from these other perspectives.¹³ (3) Experimentation incentives require an ability to commit to policies that are often *ex post* suboptimal, such as rewarding failure, and are thus difficult or costly to implement (Manso 2007). Overall, we believe that even when such experimentation incentives are feasible, the effects identified in this paper would still play a role. However, a more formal approach is needed, not only to confirm this intuition but also to obtain comparative statics on the interaction between the incentive system and the knowledge system.

The model also focused on an isolated firm. Such a model is appropriate when competitive interactions have no impact on the knowledge system, for example, as an approximation for the internal operations of a firm. In other settings, however, competition may play an important role. The following are

some further implications of competition (beyond the ones discussed earlier). First, the competency trap may explain incumbent inertia: Because an incumbent typically has better current know-how than a potential entrant, its cost of experimentation (i.e., forgoing its current know-how) is higher than that of the entrant so that the incumbent will experiment and innovate relatively less. Moreover, competition also affects the trade-off between exploration and exploitation because it may exacerbate the cost of the competency trap. Finally, spillovers between competitors may decrease the benefits of exploration and thus the cost of the competency trap. One implication would be that firms in industries with lots of spillovers will still invest in knowledge systems but will have less restrictions on what information to record.

Finally, our paper has explored a particular setting where the nature of the know-how is codifiable, thereby allowing the transfer of knowledge through some sort of media. Clearly, there are many business settings where these characteristics do not apply. For example, negotiating a business deal requires tacit knowledge and "soft skills" that are probably best learned through personal experience and coaching. However, even if the nature of the know-how dictates that the firm relies on personal transfer of know-how, the firm needs a system to identify "experts" on recurring problems, and many of the issues identified in this paper would apply.

7. Conclusion

Lew Platt, a former chief executive officer of Hewlett-Packard (HP), famously said, "If HP knew what HP knows, we would be three times as profitable." For many firms, the ability to create, organize, and disseminate know-how is a key factor in how well they succeed. In this paper, we used an analytical model to study some basic strategic questions on the management of know-how. We identified factors—such as size, limited general knowledge, and high rates of turnover—that make it more attractive for a firm to invest in a formal knowledge system. We also identified some principles for the management of such a system, such as the relative informativeness of successes over failures, the importance of being selective to find the right balance between exploitation and experimentation, and the factors that should increase such selectivity.

Our focus on the transfer of know-how exclusively via a formal knowledge system makes the paper most relevant to settings such as global consulting firms or firms with multiplant operations. Settings where other means of transferring know-how are available may require more research to see whether or how our results apply. Analogously, the competitive interactions with other firms and the interactions between

¹³This second point applies more broadly to the interaction between a knowledge system and other systems and processes of the firm. The online appendix discusses informally complementarities between a knowledge system and a firm's hiring and retention policies, job rotation, and how a knowledge system may affect the market strategy of a knowledge-intensive professional firm.

the knowledge system and other systems in the firm also require more formal attention. We see these limitations as opportunities, and hope that our paper can contribute to a growing literature on the practical and strategic issues that firms increasingly face in managing know-how.

8. Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at <http://mansci.journal.informs.org/>.

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