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THE KNOWLEDGE-LEVERAGING PARADOX: HOW TO ACHIEVE SCALE WITHOUT MAKING KNOWLEDGE IMITABLE

RUSSELL W. COFF
Emory University

DAVID C. COFF
Xtelesis

ROGER EASTVOLD
e-Diagnostic Network

Tacit knowledge, one of the most promising resources, is among the toughest to leverage. It is important because it is often inimitable. However, increasing its scale may require codification, which may make it imitable. We explore and illustrate an approach to applying information technologies to leverage scarce expertise without codifying or transferring knowledge. Such technology may allow individuals to further specialize and generate more tacit knowledge, preserving the strategic properties of knowledge while scaling up.

Tacit knowledge has strategic significance because of its potential to be valuable, rare, and hard for rivals to imitate or acquire (Barney, 1991). That is, the fact that the knowledge is hard to transfer may help firms sustain an advantage. However, this creates management dilemmas within firms wishing to achieve an advantage using this resource (Coff, 1997; Zander & Kogut, 1995). Once valuable tacit knowledge is identified, firms must transfer and replicate it to increase the scale and meet the demand for the scarce resource (Tsai, 2001). This, in turn, often requires face-to-face communication and protracted learning curves (Polanyi, 1966; Teece, 1977). Firms are therefore apt to face an internal shortage of talent, hampering efforts to build a strategy that involves leveraging tacit knowledge.

While information technology might be posed as a solution to this problem, there are many hurdles to be overcome. The first is that information technology often requires the knowledge to be codified and/or transferred—a very difficult task by definition (Teece, 1977). Furthermore, should this be accomplished, the codified knowledge might be easier for rival firms to acquire or imitate, thereby limiting the sustainability of the advantage (Lado & Zhang, 1998). Thus, the very property that grants strategic value also makes knowledge a very hard resource to leverage.

We first highlight the paradox in the extant literature that tacit knowledge has great strategic value but that it must be codified to exploit that value. We then develop theory about how information technology can be applied to leverage tacit knowledge without transferring or codifying the knowledge, suggesting new research directions for the information technology literature. We explore this using two vignettes in which information technology was applied to leverage expertise: (1) silicon wafer manufacturing and (2) a rural hospital in West Texas. In both cases the technology allowed experts to work remotely and leverage their skills and knowledge across multiple locations. In this way, a highly specialized and well-honed expertise was leveraged without codifying, transferring, or even engaging in face-to-face communication. However, in the latter case, the

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knowledge was not rare or unavailable to rivals and did not appear to confer an advantage. Indeed, the hospital ultimately underwent a major management shake-up owing to its poor performance.

In the next section we describe theoretical dilemmas in the use of information technology to leverage tacit knowledge. We then develop propositions about how such technology might be applied to accomplish this and illustrate these concepts using the vignettes. Finally, we discuss implications for using information technology in support of resource-based advantages.

THE KNOWLEDGE-SCALING PARADOX

The Problem of Acquiring Tacit Knowledge

In order to understand the dilemma of leveraging tacit knowledge with information technology, we begin by reviewing broader problems associated with tacit knowledge. It is widely accepted that knowledge creation and management can be a source of sustained advantage (Barney, 1991; Grant, 1996). Tacit knowledge is especially promising because, although it may be closely tied to a valuable capability (e.g., a cost or differentiation advantage), it may also be hard for rivals to imitate or acquire.

These isolating mechanisms that prevent rivals from obtaining the resource also pose dilemmas for firms wishing to acquire resources. Such assets cannot generally be acquired externally for the same reasons that rivals cannot obtain the knowledge in labor markets. First, such tacit knowledge is often firm specific and must be developed internally—there may be no market for the skills (Dierickx & Cool, 1989). Second, if the expertise is available, it may be abundant and thus might not serve as a source of advantage. Third, the tacit nature of the knowledge may make it hard for the firm to identify job seekers with the desired knowledge. Such labor markets may function like Akerlof's (1970) markets for lemons, in that those seeking jobs will be disproportionately lower-quality employees (Chiang & Chiang, 1990). Finally, if the expertise is rare but easily identifiable, the individuals who own it may be in a strong position to extract most of the rent (Coff, 1999). Much of the literature on the resource-based view stops with the acknowledgment that knowledge may be an important source of competitive advantage and that knowledge-based capabilities must typically be built rather than purchased externally (Dierickx & Cool, 1989).

The Dilemma of Scaling Up Knowledge to Meet Demand

However, obtaining the resource is only the first of many knowledge management challenges. If a firm is fortunate enough to obtain such assets, those assets will still probably be scarce, even within the firm. For example, if an individual has valuable tacit knowledge that attracts customers, the demand for his or her time will quickly exceed supply (Teece, 1982). Thus, to leverage tacit knowledge into a *significant* advantage, the firm must be able to "scale up" to meet demand for the resource.

This is distinct from the corporate strategy literature, which focuses on leveraging knowledge across businesses. That context assumes that there is excess capacity in strategic resources that cannot be fully utilized within a single business unit (Montgomery & Wernerfelt, 1988)—a very different problem from the scaling dilemma at issue here, in which the knowledge is in short supply.

To some extent, the broad problem of scaling may be generalizable to other firm-specific assets. If a firm owns a firm-specific technology, the extent of any resulting advantage may be constrained by whether the resource can be scaled up to meet demand. It may or may not be possible to invest further to increase the scale of the core technology without making it available to rivals. If the technology generates rent, the firm should have financial resources to invest further. However, the firm-specific nature of the resource will limit the role of outside suppliers or markets. This, along with the fact that rivals cannot easily deploy the idiosyncratic technology, may help to sustain an advantage, even while the firm increases the scale on which it is applied.

This leveraging problem is especially difficult for tacit knowledge, because the act of scaling up may make the resource imitable and, thus, may erode the advantage. Typically, the firm must replicate the tacit knowledge by transferring it among employees so that the tacit knowledge is more widely shared and is therefore available to meet demand (Tsai, 2001). Furthermore, knowledge creation requires that different bodies of knowledge be integrated across the firm to create new knowledge (Grant, 1996; Nonaka, 1994). However, knowledge transfer generally requires some degree of codification (Zander & Kogut, 1995; Zollo & Winter, 2002). Indeed, the problem of knowledge stickiness (e.g., why it is hard to transfer) is a central challenge explored in the knowledge management literature (Szulanski, 1996).

The knowledge-scaling paradox, then, is that in transferring and codifying knowledge to achieve the requisite scale, it may lose strategic properties that keep it from rivals (Lippman & Rumelt, 1982; Rivkin, 2001). That is, if the knowledge is codified, rivals may gain access to it more easily by hiring away employees or acquiring the codified knowledge in some other form, such as written documents or an expert system (Barney, 1991). We are left with a somewhat troubling accepted view that knowledge is a promising source of competitive advantage, but its promise must be diminished in order to exploit the resource. Our contribution is to explore boundary conditions surrounding this assertion.

Rivkin (2001) argues that firms must balance the need to replicate tacit knowledge internally with the desire to keep the knowledge tacit so that rivals cannot imitate. At very high levels of tacitness, firms fail to replicate the knowledge internally and cannot realize a significant competitive advantage. At low levels of tacitness, rivals are able to imitate the knowledge fairly easily, and any advantage is short-lived. Accordingly, he suggests that moderate levels of tacitness are most promising because they balance the challenges apparent at each extreme.

Specificity of Tacit Knowledge and the Scaling Dilemma

The assumption underlying Rivkin's (2001) case for moderate levels of tacitness is that the firm has better information than rivals about the capability. As such, moderate levels of tacitness pose more of a barrier for rivals wishing to imitate than for firms wishing to replicate the capability internally. Rivkin (2001) identifies the role of hands-on experience in conferring an advantage to replicators over imitators. Put another way, the originating firm is assumed to have greater absorptive capacity to replicate moderately tacit knowledge in a new unit than rivals have in importing and imitating the knowledge from scratch.

However, this implicitly assumes that all tacit knowledge has the same strategic relevance. If the knowledge is embedded in firm-specific experiences, it will certainly be much more readily available within the firm than to those outside the firm. In fact, this is an important basis for the knowledge-based theory of the firm (Kogut & Zander, 1992). Thus, tacitness alone is insufficient to predict the strategic impact of a knowledge base in terms of sustainability.

Figure 1 illustrates this interaction between tacitness and firm specificity. Quadrant I depicts the situation in which knowledge is highly tacit and firm specific. Accordingly, neither the originating firm nor its rivals can easily parlay the knowledge into an overwhelming competitive advantage. This is the outcome that Rivkin (2001) associates with high levels of tacitness.

In contrast, Quadrant II illustrates a context in which knowledge is tacit but broadly applicable. For example, most readers of this paper would have difficulty absorbing and utilizing knowledge about the physics underlying carbon nanotubes—microscopic tubular structures made from pure carbon (like diamonds) have important mechanical and electrical properties that make them promising for producing composite materials. However, nuclear physicists in many different organizations have the requisite background to comprehend this. While the first patent in nanotubes was issued in 1987, by January of 2004, 152 patents had been issued, 274 patents were pending, and there were 6,026 papers published on the topic in scientific journals (deHeer, 2004).

Based on this, it is clear that there is a burgeoning community of researchers who have the requisite background to absorb new knowledge on this topic. Despite being tacit, for the most part, this knowledge is not firm specific. In this case, firms imitating may not face the disadvantage that Rivkin (2001) associates with highly tacit knowledge. The knowledge may flow more easily to rivals who have the requisite absorptive capacity than to pockets of the originating organization that are not grounded in this knowledge base. Thus, replicators would not necessarily enjoy an advantage over imitators at moderate levels of tacitness. Despite the tacitness, such "industry recipes" are unlikely to confer a durable competitive advantage to the originating firm (Spender, 1989).

FIGURE 1
The Interaction of Tacitness and Firm Specificity

		Firm specificity: High	Firm specificity: Low
Tacitness	High	**I. Small durable advantage** Potentially durable source of advantage but hard for the originator to replicate in order to increase the scale. Example: Learning curve/experience or firm-sponsored training	**II. Industry recipe** The tacit knowledge requires absorptive capacity to utilize but is readily diffused to firms that have the requisite knowledge base. Example: Complex knowledge arising from education/professional training
	Low	**III. Substitution limits durability** Originator can easily increase scale. Specificity forces rivals to seek substitutes (e.g., their own firm-specific routines). Example: Firm-level standard operating procedures and routines	**IV. Common knowledge** The knowledge is quickly replicated internally but also diffused throughout the industry. It becomes the "ante" required to compete. Example: Standardized, widely available skills/general human capital

In Quadrant IIII the knowledge is firm specific but not tacit. This means that rivals can comprehend the knowledge but cannot apply it directly in their context. However, the fact that they understand the knowledge spurs them to search for comparable substitutes. In other words, they will most likely seek their own firm-specific knowledge that accomplishes the same end. Such knowledge may confer an advantage, but its duration will be bounded by rivals' ability to find comparable substitutes.

Finally, Quadrant IV depicts knowledge that can easily be replicated and imitated because it is codifiable and general in nature. Accordingly, it should diffuse rapidly throughout the industry and form no basis for a competitive advantage—even one of a temporary nature.

From Figure 1 we see that none of the quadrants yields a highly promising source of a sustainable competitive advantage. Accordingly, there would be tremendous potential value to be realized if a firm could figure out how to scale up highly tacit and firm-specific knowledge (quadrant 1). This is truly a thorny problem for the strategy literature.

Knowledge Leveraging and the Theory of the Firm

This scaling challenge highlights a core problem in organizational theory. Clearly, one way to leverage an individual who has tacit knowledge is through hierarchy or specialization of labor. For example, researchers leverage their knowledge by hiring research assistants for mundane tasks. Similarly, doctors and lawyers often delegate tasks to paraprofessionals (nurses, paralegal assistants, secretaries, etc.). In this case, the knowledge may not be transferred if the principal provides proper incentives and monitoring. This may leverage individuals without codifying, replicating, or transferring the tacit knowledge. As such, this may be the oldest solution to the knowledge-scaling paradox. Indeed, this harkens back to Adam Smith's (1776) use of a pin factory to underscore his observation that specialization of labor can enhance efficiency.

It is also one of the foundations of the knowledge-based theory of the firm, which seeks to explain the scope and boundaries of the firm using the knowledge management process. The existing literature suggests that hierarchies emerge because of the need for a common language or routines to facilitate knowledge transfer (Kogut & Zander, 1992; Nelson & Winter, 1982) or because there is a need to supervise or coordinate those with distinct knowledge bases (Arrow, 1974; Conner & Prahalad, 1996).

Either way, it is assumed in existing research that tacit knowledge accumulates at the lower levels of the hierarchy (Castanias & Helfat, 1991). This differs from knowledge leveraging, in which those in authority positions tend to be repositories of tacit knowledge and attempts to transfer the knowledge are minimal. Nevertheless, we consider this to be otherwise consistent with the knowledge-based theory of the firm.

However, hierarchy, as a means to leverage tacit knowledge, has a number of limitations. First, agency problems arise if it is hard to provide powerful incentives or monitoring. Anyone who has had a research assistant afflicted with "senioritis" can attest to the potential for motivational problems. If the tasks are hard to measure or observe directly, the principal may be restricted in his or her ability to delegate. A second factor is that since there is a limit to how many subordinates an individual can manage (Barnard, 1938), this method may not achieve the desired scale before hitting the point of declining marginal returns.

Limits of Using Information Technology to Leverage Tacit Knowledge

Arguably, the second oldest form of knowledge leveraging involves the application of technology. Simple tools may increase an individual's productivity considerably. In the case of knowledge management, parchment and a quill offered a breakthrough innovation thousands of years ago. However, writing involves codifying knowledge by definition—that is, putting it into words. In this way, many technological solutions carry the same limitation as other knowledge management techniques: the potential value of the knowledge must be diminished through codification in order to achieve scale.

This general observation is apparent in the information technology literature. Alavi and Leidner (2001) describe the role of information technology in facilitating knowledge creation, knowledge storage, knowledge transfer, and knowledge application. They identify groupware, communication, and intranet technologies as tools that may be useful in facilitating all of these processes by enhancing communication and coordination in organizations. Other technologies are specific to knowledge management processes. For example, knowledge repositories are specific to storage, whereas expert systems are specific to knowledge application.

However, most of these applications manipulate codified knowledge so that it can be transferred and used by many in the firm, or even by multiple firms. Indeed, the knowledge management system literature focuses on database-driven applications designed to store explicit knowledge. Consider the knowledge management systems used by many large consulting firms to codify, store, retrieve, and transfer knowledge about how to conduct various types of projects. Here, a consultant might document the key elements of a complex project proposal so that others who must develop similar proposals can retrieve them and borrow from them as needed. This type of knowledge management system is designed specifically to manage the codifiable portion of the knowledge to be leveraged. In practice, managers often use such systems to identify others who can help them with a particular problem; in short, such a system facilitates social network formation to a greater extent than the storage of tacit knowledge.

Other knowledge management techniques are even more aggressive in codifying tacit knowledge. Expert systems require that an expert be interviewed to translate tacit heuristics into a codified set of decision rules. These rules then form the outline of the application. Specifically, the end user enters the critical parameters indicated by the expert. The system then applies the decision rules to generate an analysis and, ultimately, a recommendation. Here, there is a conscious attempt to codify tacit knowledge in order to make it available to nonexperts (Gill, 1996).

These applications may be problematic from a strategic standpoint, since the knowledge becomes codified in the process of applying the information technology. This means that the knowledge may become imitable and/or available to rival firms (Lado & Zhang, 1998; Mata, Fuerst, & Barney, 1995). That is, in applying the technology, the knowledge will have lost some of its value-generating properties, at least in terms of the sustainability of the advantage. In fact, there is very little discussion in the literature about applications of information technology to facilitate knowledge management that do not involve codifying and/or transferring the knowledge.

However, some information technology applications rely relatively less on codification. For example, virtual teams and groupware may also be tools for facilitating knowledge creation. Such electronic coordination is valuable but may alter the nature of the knowledge created by emphasizing explicit elements of knowledge that are more easily shared in electronic communication channels (Griffith, Sawyer, & Neale, 2003). Tacit knowledge may be transferred in electronic media, but it often must be codified to a greater extent. Thus, the technology makes explicit knowledge more available and may shift emphasis away from relatively tacit components that require face-to-face communication. This, in turn, lessens the focus on developing tacit knowledge that has greater strategic significance.[1] Therefore, the following proposition integrates perspectives from the knowledge, information technology, and strategy literature.

> *Proposition 1: Other things being equal, the more technology requires knowledge to be codified, the more imitable the knowledge will become.*

This would appear to cast doubt on the efficacy of applying information technology to leverage knowledge into a sustained competitive advantage. However, some technologies are not specifically oriented toward codifying. For example, telecommunications technology may require relatively little codification per se. Firms rely heavily on voice and, increasingly, video telecommunications applications that may help convey tacit knowledge (e.g., through tone or facial expression). Although these channels are relatively rich compared to text-based media, they are clearly not as rich as face-to-face communication.

Although these may not diminish the strategic value of the underlying knowledge in the way that text-based communication does, they have been a focus primarily in the context of knowledge transfer. Transfer is, by definition, a difficult and time-consuming task for tacit knowledge (Szulanski, 1996; Teece, 1977). Thus, one might think that an effective tool would allow for a more rapid or efficient transfer of tacit knowledge. These technologies, however, may not speed this task so much as reduce the amount of face-to-face contact required to transfer knowledge. Indeed, substituting communication technology for face-to-face communication may cause the knowledge transfer to be more lengthy and/or inefficient (Alavi & Leidner, 2001). This may allow functions to be more geographically distributed than would otherwise be the case, but the task of knowledge transfer remains formidable.

Limiting Codification and Knowledge Transfer

The discussion above assumes that technology may be applied primarily to assist in the codification and transfer of knowledge; indeed, this has been a major thrust in the information technology literature (Alavi & Leidner, 2001; Lado & Zhang, 1998; Mata et al., 1995). However, given that codification may reduce the strategic value of the knowledge and technology may not enhance the speed or efficiency of knowledge transfer, how useful is information technology as a tool for leveraging knowledge as a strategic asset?[2]

We believe that information technology can be very valuable in this context but that it requires a departure from the usual approaches to applying technology to leverage knowledge. We propose an alternative that may avoid or limit codification and transfer but still apply technology to leverage knowledge. In so doing, this will preserve the strategic properties of the knowledge and generate a more sustainable advantage.

Technology has long been used to enhance individual productivity. For example, personal computers, such as the one used to write this paper, ease the process of writing. Similarly, we suggest that it is possible to use technology so that individuals can leverage their tacit knowledge without transferring or codifying that knowledge. In short, technology can be used to make individuals more productive, limiting the need to replicate, transfer, or codify the knowledge. Since this retains the strategic properties of the tacit knowledge, the advantage may be even more sustainable than through traditional

[1] Note that we hold constant the degree of protection afforded by other isolation mechanisms, such as intellectual property rights (Teece, 1986).

[2] For the moment we set aside the value of establishing geographically dispersed networks.

applications of information technology to knowledge management.

One might ask what type of technology might leverage those with tacit knowledge while minimizing the codification required. We begin with an example of tacit knowledge in the form of pattern recognition, where an expert can observe a set of stimuli, discern patterns, and translate them into recommendations (Simon, 1987). While this type of knowledge might be amenable to expert systems, were it codified and reduced to a set of decision rules, as discussed, that might reduce the strategic properties of the knowledge. However, technology might still be used to organize and track information. This would leave the key task of spotting trends in the information uncodified. However, the information that a decision maker would use could be collected and displayed in an interface that facilitated interpretation. In this way, a decision maker could become more productive without codifying or transferring the most critical knowledge—how to interpret patterns in the data.

Such a system is likely to increase firm-specific investments in a number of ways. First, the technology itself may be idiosyncratic, since it is customized to the knowledge management task at hand. Second, over time, the system will become embedded in the firm's routines, since it collects and organizes data that are specific to decisions requiring tacit knowledge (Birkinshaw, Nobel, & Ridderstrale, 2002; Nelson & Winter, 1982). For example, as described earlier, some consulting firms have designed and implemented idiosyncratic knowledge management systems. These systems are then integrated into such routines as the proposal development process, which may involve scanning the system for similar projects and consulting project managers across the firm for advice (e.g., access to tacit knowledge). Such systems also require individuals to routinely contribute information about projects to make it available to others in the firm. Accordingly, individuals invest in firm-specific knowledge to use the system effectively. This, in turn, may enhance strategic properties of the knowledge, since firm specificity may act as a barrier to imitation (Peteraf, 1993). Thus, the knowledge may actually have stronger strategic properties after the application of technology than before.

Proposition 2: When technology is used to leverage tacit knowledge without codification, firm-specific resources (both technology and knowledge) are created that may enhance sustainability of an advantage.

Although increased firm specificity may make an advantage more durable, it may also tend to enhance the power of those with essential tacit knowledge, since their knowledge would become even more valuable. These individuals would become even more critical to rent production once the technological intervention was in place. This is an important contrast to methods of leveraging requiring the codification or transfer of knowledge and would therefore reduce the power and influence of those who possessed the tacit knowledge.

Indeed, Osterloh and Frey (2000) note the importance of cooperation and motivation in the knowledge transfer process. Furthermore, resistance to change is often the most significant obstacle when implementing new technologies (Heracleous & Barrett, 2001). Thus, choosing technologies that minimize codification might ease implementation considerably.

This increase in power may encourage individual experts to cooperate relative to alternative knowledge management methods. However, it may also grant central individuals considerable bargaining power (Coff, 1999). That is, employees might seek compensation for the risk they would be assuming in investing in narrow firm-specific knowledge that has limited value to other firms. Such knowledge normally forms the basis for a bilateral monopoly (Williamson, 1975). In other words, the individual has power through his or her ability to limit or stop rent production. At the same time, he or she may not be able to offer a credible threat to cease production if the knowledge is firm specific and, therefore, is not valuable to other firms (Becker, 1964). Using information technology to leverage an individual without codification would tend to retain this basic structure but would increase the stakes. Thus, one would expect the firm and individual to split the gains achieved through the application of information technology.

But what split might be obtained? To the extent that the technological change results in more firm-specific knowledge, it may reduce the external demand for the experts while increasing their value internally. This may hinder their ability to offer a credible threat of exit, thereby reducing the portion of the rent that the experts can appropriate. While these experts might seek compensation for this risk before making the investment, they would lose bargaining power once the initial investment was made. If so, while initial pay may be high, pay increases might not keep pace. Accordingly, the longer the experts' tenure, the less rent they would be able to appropriate.

> *Proposition 3: As technology-leveraged individuals increase the firm-specific component of their knowledge over time, they lose power to appropriate rent.*

VIGNETTES ON USING INFORMATION TECHNOLOGY TO LEVERAGE TACIT KNOWLEDGE

The propositions above may at first seem simple and yet unrealistic. The information technology literature has focused so heavily on the codification and transfer of knowledge that the notion of avoiding these elements seems quite foreign. In this section, however, we offer two brief vignettes that illustrate how this might work in practice. We do not use these examples to test propositions so much as to suggest that they are not unrealistic and should be tested.

The first vignette is drawn from over twenty unstructured interviews with KLA-Tencor Corporation managers charged with implementing a system that allowed experts in manufacturing yield management to leverage their scarce knowledge across many locations. The interviews took place throughout the planning and implementation phases of the project. The second example is drawn from the literature on physicians' use of information technology to diagnose and treat patients remotely. In both cases information technology was used to leverage individuals in very knowledge-intensive tasks.

Leveraging Yield Management Expertise in Silicon Wafer Manufacturing

Several factors inherent in the semiconductor industry drive the need for comprehensive yield management. This refers to generating the maximum output from each silicon wafer (e.g., minimizing waste). Among the most significant drivers behind the demand for yield management solutions are increasing device complexity, reduced product life cycles, and increased competition. To meet market needs, the semiconductor industry is constantly increasing the functions incorporated into a single device, while simultaneously reducing device size.

These challenges are further complicated by competition within the semiconductor industry, which drives an expectation for declining prices, despite increasing product complexity. Thus, chip manufacturers simultaneously face continuing pressures for profitability, shorter product cycles, and increasing manufacturing complexities. As chip prices drop, cost effectiveness becomes the key to superior profitability. Chip manufacturers increasingly turn to a few firms that provide yield management equipment and expertise to enhance efficiency. One of these, KLA-Tencor, offers products, software, analysis, services, and expertise to help manufacturers manage yield throughout the wafer fabrication process—from R&D to production.

Scarce tacit manufacturing knowledge. Knowledge is the primary asset being leveraged, for a variety of reasons. First, given the rapid pace of innovation in manufacturing equipment and processes, yield management support professionals must be well versed in the most current chip manufacturing technologies. Second, the most important knowledge tends to be tacit. By the time defects are readily apparent in a plant's output, the process will have already entered a "death spiral," requiring the facility to be shut down for repairs. Accordingly, the central task is to identify problems from very subtle signs that may be amplified over time absent managerial intervention. Experts require considerable hands-on experience to develop this tacit knowledge; the early signs of a chip manufacturing process gone awry cannot be fully codified and, therefore, are hard to teach others.

This is further complicated by the fact that customer factories are miles or even continents apart and are equipped with a multitude of highly complex tools. Historically, firms in this industry have stationed engineers at customers' plants so they can manage performance using their proprietary monitoring "tools." These tools are a combination of hardware and software used to measure the manufacturing process.

As the number of tools has increased (corresponding to manufacturing complexity), the task of maintaining them has become harder. On-site engineers can manage the routine situations that arise. However, on-site support professionals typically lack the deep knowledge to resolve complex or rare problems. In these cases, deeper, more specialized expertise is needed—particularly to identify problems before they are noticeable in the firm's output. Yet this type of expertise is expensive and is not necessarily needed for the routine problems at each plant location. Furthermore, it is difficult to transfer or replicate the tacit knowledge across such geographically dispersed sites. Accordingly, when these more complex problems have emerged, the firm has had to fly in experts from its headquarters in Silicon Valley.

While this is a more cost-effective way to maintain the depth of tacit knowledge and expertise, it complicates support in other ways. First, customers have to wait while experts are in transit. Second, other customers, who may have a similarly urgent need for expertise, must wait until the expert is available to visit their site. Third, unexpected trips take specialists away from product development, causing a ripple effect on the firm's ability to introduce new products. Finally, travel makes the specialists' job harder and less attractive, exacerbating the already difficult task of attracting qualified people.

Application of information technology. KLA-Tencor has addressed this problem by having highly specialized engineers manage the tools from a central location. They monitor all of the tools remotely to identify patterns associated with reduced process integrity. These experts are often able to diagnose and resolve problems without even notifying on-site engineers. In this way, the experts can respond immediately and can prevent inappropriate repair actions, lost time from travel, mistaken diagnoses, and, ultimately, the down time required for major repairs.

This system involves minimal codification of knowledge. Rather, the instrument readouts are made available for remote viewing and control. As such, experts interface much as they would were they using the tools to monitor the process on site. However, because they are colocated and no longer need to travel to remote locations, the experts have specialized more and developed additional tacit knowledge. Accordingly, the net effect of applying the technology has actually been to increase the firm's reliance on firm-specific tacit knowledge.

Implications for competitive advantage. KLA-Tencor is the world leader in the yield management market, with a 41 percent market share (Pitzer, Kumar, & Chin, 2004). Its next closest competitor has only about a 12 percent market share. Moreover, in the years 2000–2003, KLA-Tencor was the only one among its most direct peers that did not report losses in at least one year. Accordingly, the firm exhibits the type of performance one might attribute to a resource-based competitive advantage.

The system described here creates some very critical resources and capabilities embodied in the specialized engineers that support the company's advantage. First, the technology allows experts to be colocated and minimizes required travel. This, in turn, facilitates knowledge creation (Hedlund, 1994; Kogut & Zander, 1992; Nonaka, 1994), which produces the tangible result of enhanced product development on an ongoing basis. Thus, the use of information technology to leverage tacit knowledge has been quite successful here.

This has strategic significance because the capabilities created meet the criteria set forth in the resource-based view: valuable, rare, and unavailable to rivals (Barney, 1991). We begin with the question of value. As suggested, technology-enabled experts can solve customers' production problems more effectively and cheaply. By developing deeper, more tacit knowledge, experts are able to identify and correct problems before they lead to costly shutdowns or repairs. Arguably, this can be the biggest source of waste, so this knowledge development results in significant savings. KLA-Tencor is now using this customer support solution as a way to differentiate itself from rivals. This system is the first in the semiconductor equipment industry to combine all of these technological components for the purpose of leveraging tacit knowledge.

In addition, the system actually generates rare resources via hyperspecialization. Through this application of information technology, KLA-Tencor has been able to develop hyperspecialized expertise on how its own idiosyncratic tools operate. That is, individual experts have deep knowledge of a small subset of the firm's portfolio of tools. Therefore, the company is assured that the key resource—engineers with deep and narrow expertise—remains scarce, particularly outside the firm.

Finally, it is especially noteworthy that these resources are inimitable and unavailable to rivals. Not only has the intervention increased the tacitness of the knowledge, it has also made it more firm specific. Thus, as suggested in Proposition 2, it is possible to increase firm specificity if the technology applied minimizes codification. In this way, both the high levels of tacitness and the firm specificity act as isolating mechanisms—illustrating Quadrant I of Figure 1. KLA-Tencor's rivals (e.g., yield management consulting and semiconductor manufacturing equipment firms) are at a disadvantage in that KLA's employees have knowledge of the firm's idiosyncratic tools that will not easily transfer. Furthermore, each expert has knowledge of a small subset of the tools in the firm's portfolio and cannot convey enough knowledge for rivals to fully imitate its systems and tools. Accordingly, rivals have relatively little to gain by luring away KLA employees because their knowledge is so specific to KLA's proprietary tools and technologies.

Appropriability is a final issue in assessing the extent of advantage (Coff, 1999). In this case, the key resources are the information technology and those with deep expertise. As stated earlier, the experts have a bilateral monopoly owing to their firm-specific knowledge (Becker, 1964; Williamson, 1975). That is, their skills are extremely valuable, and they conceivably have the ability to hold up others to appropriate rent. However, at the same time, their skills are firm specific and may not be as valuable to rivals. Interestingly, this application has increased the firm-specific component of employees' knowledge, potentially reducing demand for them, which would tend to reduce employee bargaining power.

Interestingly, in this case, engineers have viewed the ability to limit their travel positively and have not sought additional compensation to encourage the investment in firm-specific human capital. This illustrates how nonfinancial benefits can substitute for pay (Coff, 1997). Therefore, it appears that employees have not appropriated a large portion of the rent (consistent with Proposition 3). Indeed, this may well be one source of KLA-Tencor's stable financial performance relative to its direct rivals.

Leveraging Physician Expertise with Information Technology

Information technology is increasingly applied to the field of medicine in a variety of ways, ranging from robot-assisted surgery (Gerhardus, 2003) to remotely delivered psychiatry (Vought, Grigsby, Adams, & Shevitz, 2000). All are attempts to leverage scarce medical knowledge to increase the quality of medical care. Accordingly, the second vignette is the application of telecommunications technology to leverage expertise from a Lubbock hospital to another located in rural West Texas. This vignette draws on a detailed published case study by Sykes and McIntosh (1999).

Scarce physician knowledge in West Texas. The Texas Tech Health Sciences Center (TTHSC) is charged with providing medical support and services for rural West Texas. A key challenge is the scarcity of professionals who wish to live in and serve these rural areas. To answer this challenge, the TTHSC was awarded a grant in 1990 to study the potential of telecommunications for rural health care. The project, known as MEDNET, used satellite and telephone lines to establish links with several rural West Texas hospitals. Through this system, doctors in these areas gained access to continuing education and interactive medical consultations with specialists. The hope was that providing this link would increase the viability of rural hospitals in several ways: (1) communication with experts at the TTHSC would reduce the isolation felt by rural physicians and would encourage more to remain in the area; (2) the continuing education units offered through TTHSC would help professionals retain their certification without traveling, important both for the convenience of the physicians and because, like the KLA-Tencor setting, the professionals were unavailable while in transit; and (3) the access to specialists would enhance health care and improve patient retention.

Although the nearest hospital was often hundreds of miles away, patients were willing to drive if they lacked confidence in their local facility and emergency care was not required. MEDNET would allow more complex or serious patients to be treated locally, where health care costs were lower. It was estimated that this would save more than $1,000 per consult over the costs to transport the patient and the higher fees in the city.

Sykes and McIntosh (1999) focus on the Big Bend Regional Medical Center, one rural hospital in the network. This hospital was under financial pressure, and it was hoped that MEDNET would strengthen its reputation and differentiate it. Certainly, the satellite link gave the facility access to more specialized medical expertise than any other facility within the 200-mile radius. Since this was a pilot study, the technology was not available to rival facilities. However, there was a possibility that it would eventually be rolled out more broadly should it be successful.

The system received publicity in 1990, when a doctor was able to save a baby in respiratory distress by videoconferencing with a neonatal specialist 300 miles away, in Lubbock, Texas (Stanley, 1991). The two-way video link allowed the specialist to "examine" the patient remotely and to view X-rays, along with other lab tests. The specialist concluded that the baby had inhaled waste in the amniotic fluid and prescribed a course of treatment that restored the baby's health. News of the event was amplified when technology providers, like Southwestern Bell Telephone, used the case in advertisements to show how telecommunications was transforming medicine.

Implications for competitive advantage. Like the KLA example, the objective of MEDNET was not generally to transfer tacit knowledge but to allow experts to work remotely. The technology involved little, if any, codification of knowledge. Finally, as the "miracle baby" example illustrates, the information technology was quite effective overall. Indeed, in addition to saving money, relative to the alternatives, the system allowed doctors to save a number of lives.

However, the overall result for the organizations involved was very different. The financial difficulties continued at the Big Bend Regional Medical Center, suggesting that, if any advantage was conferred, it did not have overwhelming economic value. The hospital continued to experience a shortage of professional staff, so recruitment and retention were not strongly influenced. Ultimately, Big Bend Regional Medical Center failed, and the assets were taken over by a large hospital chain, which fired the existing management team. Furthermore, the buyer did not implement the MEDNET system in any of its other facilities as a best practice to be emulated.

There were a number of important differences that may have contributed to this outcome. First, the knowledge, while tacit, was not firm specific. There were many specialists in different firms/hospitals who had comparable expertise. Accordingly, this example illustrates Quadrant II of Figure 1. While the new technology did not reduce tacit knowledge, it did not increase firm specificity. Patients retained the ability to drive the 200 miles and see a comparable specialist at a different facility. This distance may have been an inconvenience, but rival clinics remained a factor in all nonemergency cases where patients could afford the time to choose. As a result, the knowledge was valuable and somewhat scarce but remained available to rivals. Importantly, this was the perception of patients and the community as a whole. Thus, while the technology worked as planned, it could not serve as a basis for differentiating the facility and offered no competitive advantage.

From the standpoint of TTHSC, while the technology worked very well, its economic value was also questionable. It failed to divert very many patients to the technology-enabled rural hospitals and resulted in relatively little savings. The system was used to save lives in the context of medical emergencies and trauma, where travel to a larger facility was not possible. However, when feasible, patients still preferred to drive the extra miles to see a specialist directly. In the end, TTHSC specialists were not better utilized after the technology was implemented.

DISCUSSION AND CONCLUSION

Paradox Lost

These brief vignettes were not offered as tests of the propositions but, rather, to illustrate the efficacy of further exploration along these lines. Much of the work on the resource-based view extols the potential benefits of leveraging knowledge-based assets since they are hard for rivals to imitate or acquire (Hall, 1993; McEvily & Chakravarthy, 2002). Here, the tacitness of the knowledge contributes greatly to the sustainability of a competitive advantage. However, relatively little of the research has addressed how firms can achieve the desired scale with this type of resource.

Furthermore, while the knowledge literature has focused on how firms might leverage such resources, the bulk of this literature presumes that knowledge management requires codification. It would appear that this contradicts resource-based assumptions about why tacit knowledge is such a valuable resource, but this paradox has rarely been explored directly (Rivkin, 2001, is an important exception).

Much of the information technology literature serves to exacerbate this paradox. Here, the need for codification is perceived to be even stronger, since information technology can be an especially powerful tool for manipulating and managing codified knowledge (Alavi & Leidner, 2001). Although this is consistent with the knowledge management literature, it could lead to the erosion of the value of knowledge-based resources from a strategic standpoint.

Interestingly, counter to trends in the literature, information technology can be deployed in a way that creates even more tacit knowledge, if the application does not require codification or knowledge transfer and increases the degree of specialization. In this way, information technology can allow firms to leverage knowledge while enhancing its strategic properties—the key knowledge management challenge.

This runs counter to Rivkin's (2001) suggestion that moderate levels of knowledge tacitness and complexity are most promising for a knowledge-based advantage. He suggests that, in this range, knowledge management dilemmas (transfer and codification) are balanced against the need to minimize knowledge spillovers that would allow rivals to imitate more easily.

In contrast, we suggest that it is possible to leverage relatively high levels of tacit knowledge into a competitive advantage. First, a high degree of tacitness can be coupled with firm specificity so that the risk of spillovers is quite limited. Furthermore, the dilemmas of replication and transfer can be avoided if the technology allows individuals to utilize their tacit knowledge more effectively. In short, individuals become more efficient, reducing the need to steep others in the knowledge base.

Implications for Further Research

Future research should explore the contexts in which such applications of information technology are most likely to add value. What are the boundary conditions under which this contributes to a competitive advantage? Our vignettes have described unique situations in which information technology has been used to leverage tacit knowledge. Unlike many applications, the technology applied in both cases involved relatively little codification. As such, the core knowledge remained tacit and embodied in the experts. In one context, it even allowed for greater specialization, which should have hindered imitation even more than before the information technology was applied.

However, our vignettes suggest that the locus of the advantage continues to reside with the knowledge and not with the information technology. In one case the technology appeared to create an advantage, whereas in the other it did not. The information technology can serve as an enabler or amplifier of strategic assets but is not, in itself, a source of competitive advantage. That is, if the knowledge is valuable, rare, and unavailable to rivals, technology might be used to achieve more scale without adversely affecting its strategic properties. Accordingly, there is much we can learn from these settings about how to develop technological solutions to knowledge management challenges that enhance strategic position.

That said, we have not explored the limitations on how much scale can be achieved through this type of technology. While there are generally declining returns to specialization, it would appear that the technology allows for greater specialization. However, it is not clear that this will be sufficient to achieve the desired scale in all settings. Rather, it adjusts the point at which declining returns to specialization are reached. Further research is needed to identify the bounds on when this type of solution is most likely to add value.

Thus far, our discussion has ignored the tacit knowledge and other intangible assets that may be associated directly or indirectly with implementing information technology. Indeed, applications of information technology can be a source of advantage when linked to knowledge and expertise (Bharadwaj, 2000). Put another way, firms often fail to implement technology effectively, and the ability to do so may confer an advantage if it is sufficiently valuable and rare. If the technology requires and creates additional tacit knowledge, there may be some component of an advantage more closely tied to the technology itself. Further research should explore whether this might extend competitive advantage even more.

Conclusion

We have contributed by integrating the strategy and knowledge management literature to understand how firms can effectively leverage knowledge into a resource-based advantage. Additional studies should focus more carefully on how firms can leverage knowledge effectively while preserving its most valuable strategic properties. Of course, we call for further research that directly tests our propositions. These strike at the very core of research on competitive advantage—but have nevertheless been under-researched.

Indeed, our propositions represent a very different research agenda for the information technology literature, since they suggest that technology might be applied to leverage knowledge without codification. We have focused on the need to leverage expertise across geographically dispersed units. This opportunity may be most promising for the types of telecommunications solutions that can convey tacit knowledge across great distances. The more traditional database-driven knowledge management systems appear to require more codification than this and may ultimately be of somewhat less strategic value. We anticipate that, if such applications prove to be viable, this will greatly enhance the strategic role that technology can play. In sum, this close alignment of the strategy, knowledge, and information technology literature carries some very strong potential benefits and offers fertile terrain for further exploration.

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Russell W. Coff (www.bus.emory.edu/RCoff/) is an associate professor of organization and management at Emory University's Goizueta Business School. He received his Ph.D. from UCLA. His research interests include the management of human assets, competitive advantage, and value capture from strategic capabilities.

David C. Coff is a client business manager at Xtelesis, where he helps clients improve network efficiency. Previously, he worked at AT&T for twenty-six years, where he served as a senior data/IP sales executive and IP specialist.

Roger Eastvold is the president of e-Diagnostic Network, where he helps clients apply technology to improve service operations. Previously, he served as vice president of technology at Brooks Automation and at KLA-Tencor.