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Cooperation Between Rivals: The Informal Trading of Technical Know-how

We have seen that variations in the functional sources of innovation can sometimes be explained in terms of potential innovators' relative expectations of economic rents. Since this is so, it becomes worthwhile to think about developing a more general understanding of patterns in the sources of innovation on the basis of a more general understanding of rents and how innovators may seek to maximize them. In this chapter I begin this process by focusing on a mode of cooperative R & D that I call informal know-how trading.

I begin by describing informal know-how trading in general terms. Next, I document how it operates in the field of steel minimill process know-how. Then, I explore how one might explain this form of cooperation in terms of patterns in the rents obtainable from innovation-related knowledge.

Informal Know-how Trading

Know-how is the accumulated practical skill or expertise that allows one to do something smoothly and efficiently. The know-how I focus on here is that held in the minds of a firm's engineers who develop its products and develop and operate its processes. Often, a firm considers a significant portion of such know-how proprietary and protects it as a trade secret.

A firm's staff of engineers is responsible for obtaining or developing the know-how its firm needs. When required know-how is not available in-house, engineers typically cannot find it in publications either: Much is very specialized and not published anywhere. They must either develop it themselves or learn what they need to know by talking to other specialists. Since in-house development can be time consuming and expensive, there can be a high incentive to seek the needed information from professional colleagues. And often, logically enough, engineers in competing firms that make similar products or use similar processes are the people most likely to have that needed information. But are these professional colleagues willing to reveal their proprietary know-how to employees of competing firms? Interestingly, it appears that the answer is quite uniformly yes in at least one industry—and quite probably in many.

The informal proprietary know-how trading behavior I have observed to date can be characterized as an informal trading network that develops between engineers having common professional interests. In general such trading networks appear to be formed and refined as engineers get to know each other at professional conferences and elsewhere. In the course of such contacts, an engineer builds his personal informal list of possibly useful expert contacts by making private judgments as to the areas of expertise and abilities of those he meets. Later, when Engineer *A* encounters a difficult product or process development problem, *A* activates his network by calling Engineer *B*—an appropriately knowledgeable contact who works at a competing (or noncompeting) firm—for advice.

Engineer *B* makes a judgment as to the competitive value of the information *A* is requesting. If the information seems to him vital to his own firm's competitive position, *B* will not provide it. However, if it seems useful but not crucial—and if *A* seems to be a potentially useful and appropriately knowledgeable expert who may be of future value to *B*—then *B* will answer the request as well as he can and/or refer *A* to other experts. *B* may go to considerable lengths to help *A:* for example, *B* may run a special simulation on his firm's computer system for *A*. At the same time, *A* realizes that in asking for, and accepting, *B*'s help, he is incurring an obligation to provide similar help to *B*—or to another referred by *B*—at some future time. No explicit accounting of favors given and received is kept, I find, but the obligation to return a favor seems strongly felt by recipients—" . . . a gift always looks for recompense."[1]

Informal know-how trading can occur between firms that do and do not directly compete. Informal but extensive trading of information with competitive value between direct competitors is perhaps the most interesting case, however, because if we can explain that phenomenon, we can more easily explain trading with less competitive impact. Therefore, I focus much of the ensuing data and discussion on the case of informal know-how trading between direct competitors.

Case Study: Informal Trading of Proprietary Process Know-how Between U.S. Steel Minimill Producers

To date, my data on informal know-how trading between competitors are most complete in the instance of process know-how trading in the U.S. steel minimill industry. I offer this data here as an existence test of the phenomenon and as a means of conveying its flavor.

Minimills, unlike integrated steel plants, do not produce steel from iron

TABLE 6–1. U.S. Steel Minimill Sample

Steel Minimill Firm	*Melt Capacity*[a] *(tons per year, 000)*
Four largest firms	
Chaparral, Midllothian, Texas	1400
Florida Steel, Tampa	1578
North Star, Salt Lake City, Utah	2300
Nucor, Charlotte, North Carolina	2000
Other (randomly selected)	
Bayou Steel, LaPlace, Louisiana	650
Cascade Steel Rolling Mills, McMinnville, Oregon	250
Charter Electric Melting, Chicago, Illinois	130
Kentucky Electric Steel, Ashland	280
Marathon Steel, Tempe, Arizona[b]	185
Raritan River Steel, Perth Amboy, New Jersey	500
Specially selected outlier	
Quanex, Houston, Texas	

[a]*Source:* Nemeth, "Mini-Midi Mills," Table 1, pp. 30–34.
[b]Firm closed in July 1985.

ore. Rather, they begin with steel scrap that they melt in an electric arc furnace. Then, they adjust the chemistry of the molten steel, cast it in continuous casters, and roll it into steel shapes. Modern facilities and relatively low labor, capital, and materials costs have enabled U.S. steel minimill firms to compete extremely effectively against the major integrated U.S. steel producers in recent years. Indeed, they have essentially driven U.S. integrated producers out of the market for many commodity products.

There are approximately 60 steel minimill plants (and approximately 40 producers) in the United States today.[2] The most productive of these have surpassed their Japanese competitors in terms of tons of steel per labor-hour input, and they are regarded as among the world leaders in this process.

Methods

The sample of minimills I studied is a subset of a recent listing of U.S. firms with one or more minimill plants.[3] I selected the four firms with the largest annual molten steel production capacity (melt capacity) from this list and then added six others selected at random from the same list. Later, some interviewees in these firms suggested that I also study Quanex Corporation because it was viewed as an industry outlier in terms of trading behavior; so I also added this firm. All firms included in the study sample are identified in Table 6–1.

Interviews were conducted with plant managers and other managers with direct knowledge of manufacturing and manufacturing process engineering at each firm in the study sample. The questioning, mostly conducted by tele-

TABLE 6–2. Know-how Trading Patterns

Steel Minimill Firm	*In-house Process Development*	*Know-how Trade*
Four largest firms		
Chaparral	Major	Yes
Florida Steel	Minor	Yes
North Star	Minor	Yes
Nucor	Major	Yes
Other		
Bayou Steel	Minor	Yes
Cascade Steel Rolling Mills	Minor	Yes
Charter Electric Melting	Minor	Yes
Kentucky Electric Steel	Minor	Yes
Marathon Steel	Minor	Yes
Raritan River Steel	Minor	Yes
Quanex	Minor	No

phone, was focused by an interview guide and addressed two areas primarily: (1) Has your firm/does your firm develop proprietary know-how that would be of interest to competitors? If so, give concrete examples of process or product improvements you have developed and some estimate of their value. (2) Do you trade proprietary know-how with competitors? With whom? Do you hold anything back? What? Why? Give concrete examples.

The source of major, well-known innovations claimed by interviewees was cross-checked by asking interviewees in several firms, "Which firm developed *x?*" The accuracy of self-reported trading behavior could not be so checked. I, nevertheless, have confidence in the pattern found because interviewees in all but one of the sampled firms provided independent, detailed discussions of very similar trading behavior.

Results

Personnel at all firms except Quanex (selected for study specifically because its behavior differed from the norm) did report routinely trading proprietary process know-how—sometimes with rivals.

Interestingly, reported know-how trading often appeared to go far beyond an arm's-length exchange of data at conferences. Interviewees reported that, sometimes, workers of competing firms were trained (at no charge), firm personnel were sent to competing facilities to help set up unfamiliar equipment, and so on.

Of course, the firms that report informal know-how trading with competitors in Table 6–2 do not trade with every competitor and do not necessarily trade with each other. (The interviewed firms differ widely in technical accomplishment and, as we will see later, a firm will only offer to trade valuable know-how with those who can reciprocate in kind.)

TABLE 6–3. Minimill Costs per Ton (Wire Rod, 1981)[a]

Cost Category	*$ per Ton*	*Percentage of Total*
Labor	$60	21%
Steel scrap	93	33
Energy	45	16
Other operating[b]	65	23
TOTAL OPERATING	$263	
Depreciation	11	4
Interest	7	2
Miscellaneous tax	3	1
TOTAL COSTS[c]	$284	100

[a]*Source:* Barnett and Schorsch, *Steel: Upheaval in a Basic Industry,* Table 4–3, p. 95.
[b]Includes alloying agents, refractories, rolls, and so on.
[c]Excluding any return on equity.

Before turning to consider why the trading of proprietary process know-how occurs in the steel minimill industry, let me examine that behavior in more detail under three headings: (1) Did minimills studied in fact develop/have proprietary process know-how of potential value to rivals? (2) Did firms possessing know-how trade with rivals? (3) Was know-how in fact traded, as opposed to simply revealed without expectation of a return of similarly valuable know-how?

Valuable Know-how?

Since many minimill products are commodities, it is logical that process innovations that save production costs will be of significant value to innovating firms and of significant interest to competitors. Barnett and Schorsch[4] report U.S. minimill 1981 costs to manufacture wire rod (a reasonably representative commodity minimill product) to be as shown in Table 6–3.

On the basis of Table 6–3 data, it seems reasonable that all minimills would have a keen interest in know-how that would reduce their labor and/or energy costs. And, indeed, all those interviewed reported making in-house improvements to methods or equipment in order to reduce these costs. In addition, some reported making process innovations that increased the range of products they could produce.

Nucor and Chaparral conduct major and continuing in-house process development efforts (conducted, interestingly, by their production groups rather than by separate R & D departments). Thus, Nucor is now investing millions in a process to continuously cast thin slabs of steel. If successful, this process will allow minimills to produce wide shapes as well as narrow ones and also will perhaps double the size of the market open to minimills producers—an advance of tremendous value to the industry.

The in-house know-how development efforts of other interviewed minimills are much less ambitious, consisting mainly of relatively small refinements in process equipment and technique. For example, one firm is experimenting with a water-cooled furnace roof that is more horizontal (has less pitch) than that of competitors. (The effect of the flatter furnace roof is expected to be increased clearance and faster furnace loading times, a cost advantage.) Other firms develop modified rollers for their rolling mills that allow them to make better or different steel shapes, and so forth. Although many such process refinements have only a small individual impact on production costs, their collective impact can be large.[5]

In sum, then, most steel minimill firms do appear to develop proprietary know-how that would be of significant value to at least some rivals.

Rivals?

Our next question is: Are steel minimill firms that trade know-how really rivals (direct competitors)? If they are not, of course, the know-how trading behavior we observe becomes more easily explicable: Noncompetitors cannot turn traded proprietary know-how to one's direct disadvantage.*

Many minimills do compete with each other today, although this was not always the case. When minimills began to emerge in the late 1950s to late 1960s, they were usually located in smaller regional markets and were protected by transportation costs from severe competition with other minimills. Today, however, there are many minimill firms and significant competition between neighboring plants. In addition, the production capacity of minimill plants has steadily increased and the larger facilities "define their markets as widely as do integrated [steel mill] facilities."[6]

Some minimill interviewees report that they do trade know-how with personnel from directly competing plants. Others report that they try to avoid direct transfer to rivals, but they are aware that they cannot control indirect transfer. (Since traders cannot control the behavior of those who acquire their information, the noncompeting firms they select to trade with may later transfer that information to competitors.)

Is It Really Trading?

Proprietary know-how is only a subject for trading if free diffusion can be prevented. Therefore, I asked interviewees: Could the proprietary know-how you develop in-house be kept secret if you wanted to do this?

In the instance of know-how embodied in equipment visible in a plant tour, free diffusion was considered hard to prevent. Many people visit minimill plants. Members of steelmaking associations visit by invitation, and association members include competitors. In principle, such visits could be prevented, but the value of doing so is unclear since two other categories of visitors could not be as easily excluded. First, suppliers of process equipment

*Firms that produce identical products may not be rivals for many reasons. For example, firms may be restricted to a regional market by the economics of transport (as with liquified industrial gases or fresh milk products) or by regulation (as with banks and utilities).

often visit plants for reasons ranging from sales to repair to advice. They are expert at detecting equipment modification and are quick to diffuse information around the industry. Second, customers often request plant tours in order to assure themselves of product quality and may notice and/or request information on process changes.

On the other hand, interviewees seem to believe that they can effectively restrict access to know-how if they really want to, and there is evidence for this on a general level. Thus, Nucor and Chaparral both attempt to exert some control over their process innovations, and interviewees at other firms think they have some success. Quanex does not allow plant visits at all and feels it effectively protects its know-how thereby.

Data on this matter are also available at the level of specific innovations, although I have not yet collected them systematically. As an example, however, a firm with a policy of being generally open reported that it nevertheless was able to successfully restrict access to a minor rolling innovation for several years. That firm reported gaining an "extra" $140/ton because it was the only minimill able to roll a particular shape desired by some customers. It apparently only lost control of its innovation when production people explained it to a competitor at a Bar Mill Association meeting.

Interviewees, including top management, were aware of know-how exchange patterns in their industry and emphasized that they were not giving know-how away—they were consciously *trading* information whose value they recognized. Thus, Bayou Steel: "How much is exchanged depends on what the other guy knows—must be reciprocal." Chaparral: "If they don't let us in [to their plant] we won't let them in [to ours]—must be reciprocal." These statements are convincing to me because most interviewees who did engage in information exchange had clearly thought about whom to trade with and why. When asked, they were able to go into considerable detail about the types of firms they did and did not deal with and why dealing with a given firm would or would not involve a valuable two-way exchange of know-how.

Know-how trading in the steel minimill industry was not centrally controlled beyond the provision of general guidelines by top management. Also, no one was explicitly counting up the precise value of what was given or received by a firm, and a simultaneous exchange of valuable information was not insisted on. However, in an informal way, participants appeared to strive to keep a balance in value given and received, without resorting to explicit calculation. On average over many transactions a reasonable balance was probably achieved, although individual errors in judgment are easy to cite. (E.g., in the instance of the minor rolling innovation mentioned above, the innovating firm's sales department was furious when, in their view, engineering "simply gave" the unique process know-how and the associated monopoly rents away.)

Quanex, the Exception

Quanex was the sole exception to the minimill trading norm I found. The firm was not on the list of minimills I used to generate our sample, and I only became aware of it and its outlier status because I routinely asked each firm interviewed if it knew of any firm whose trading behavior differed from its own.

When contacted, Quanex explained its behavior by saying that, first, it did not trade because it felt it had nothing to learn from rival firms (a contention disputed by some interviewees). Second, it said that, while it did produce steel by a minimill-like process, it produced specialty steels and considered its competitors to be other specialty steel producers (e.g., Timkin) and not minimills. And, Quanex reported, it was *not* an outlier with respect to specialty steel producers where, it said, secrecy rather than trading was the norm. (We think this latter point very interesting, but will not pursue it here. If confirmed, it suggests that know-how trading patterns may differ between closely related industries. This in turn opens the way to empirical study of the underlying causes of know-how trading under well-controlled conditions.)

Other Empirical Evidence Regarding Know-how Trading

Is know-how trading unique to the U.S. minimill industry? Or is it a significant form of R & D cooperation in many industries? At the moment, I am aware of only three sources of empirical data on this important matter, and all tend to suggest that informal know-how trading exists in many industries.

First, my students and I have now conducted pilot interviews in several U.S. industries in addition to steel minimills. And, on an anecdotal basis, I can report that we have found informal know-how trading apparently quite common in some industries and essentially absent in others. Thus, self-report by interviewees suggests that trading is widespread among aerospace firms and waferboard manufacturing mills, but rare or absent among powdered metals fabricators and producers of the biological enzyme klenow. Interestingly, however, trading seems a more quasi-covert, secretive activity by engineering staffs in some of these industries than was the case in steel minimills. In minimills, top management was typically aware of trading and approved. This does not seem to be necessarily the case in all industries where significant trading is present.

Second, data in a study by Thomas J. Allen et al.[7] of a sample of Irish, Spanish, and Mexican firms appear consistent with what I am calling informal know-how trading. Allen examined the "most significant change, in either product or process" that had occurred in each of 102 firms during recent years. Interviews were conducted with innovation participants to determine the source of the initial idea for the innovation and important sources of help used in implementation. Coding of the data showed that approximately 23% of the important information in these categories came from some form of personal contact with "apparent competitors" (firms in the same industry).

T. J. Allen elaborates on the behavior observed:

> In a typical scenario, the manager from one of these firms might visit a trade show in another country, and be invited on a plant visit by representa-

tives of a foreign firm. While there he would encounter some new manufacturing technique that he would later introduce into his own firm. In other cases managers approached apparently competing firms in other countries directly and were provided with surprisingly free access to their technology.[8]

Third, Robert C. Allen[9] reports "collective invention" in the nineteenth-century English steel industry—and I think that what he has observed might in fact be an example of informal know-how trading. Allen explored progressive change in two important attributes of iron furnaces during 1850–75 in England's Cleveland district: an increase in the height of furnace chimneys and an increase in the temperature of the blast air pumped into an iron furnace during operation. Both types of technical change resulted in a significant and progressive improvement in the energy efficiency of iron production. Next, he examined technical writings of the time and found that at least some who built new furnaces reaching new chimney heights and/or blast temperatures publicly revealed data on their furnace design and performance in meetings of professional societies and in published material. That is, some firms revealed data of apparent competitive value to both existing and potential rivals, a phenomenon that he called collective invention.

The essential difference between know-how trading and what R.C. Allen calls collective invention is that know-how trading involves an exchange of valuable information between traders that is at the same time kept secret from nontraders. In contrast, collective invention requires that all competitors and potential competitors be given free access to proprietary know-how.[10] Allen finds that this free access requirement presents interpretive difficulties, however.*

As will be seen later when I discuss the causes of know-how trading, the difficulty R. C. Allen notes is not present if the iron manufacturers he examined were actually engaged in know-how trading rather than in collective invention. This seems likely to me. Allen deduced that technical data were made available to all because he observed that much was published and presented to technical societies. Certainly, what was published was public: But know-how with trading value might well have been withheld from publication and/or published only when it had lost proprietary status with the passage of time. Both of these suggested behaviors would be difficult to discern in written records but are in fact part of the trading behavior of present-day firms.

*The interpretive difficulty reported by R. C. Allen: "It is extremely puzzling why firms released design and cost information to potential entrants to the industry. If (as we continue to assume) the industry was competitively organized, it would appear that this action could only rebound to the disadvantage of the firm. To the degree that the information release accelerated technical progress, the price of the product would decline and so would the net income of the firm that released the information" (R. C. Allen, "Collective Invention," 16).

Allen proposes three possible explanations for such behavior (a firm's desire to publicize its accomplishment even at the penalty of lost profit, a firm's inability to keep the know-how secret even if it wished to, speculations regarding special conditions under which a firm might possibly find the open revealing of know-how to be profitable), but the puzzle is not convincingly laid to rest.

An Economic Explanation for Know-how Trading

I propose that it may be possible to explain both the presence and absence of informal trading of proprietary know-how between direct competitors in terms of economic rents accruing to trading firms. I begin by framing the phenomenon in the context of a Prisoner's Dilemma, and then initially explore the plausibility of such a model by reference to the limited amount of real-world information currently available to me.

Know-how Trading as a Prisoner's Dilemma

Let us consider know-how trading between rivals as a two-party Prisoner's Dilemma. It has been shown that the two parties involved in such a Dilemma are likely to achieve the highest private gain over many interactions (moves in the game) if they cooperate.[11] However, each player is continuously tempted to defect from cooperation because he will reap higher returns from a single move if he defects while his partner behaves cooperatively.

Two conditions must hold for a situation to be defined as a Prisoner's Dilemma. The first condition is that the value of the four possible outcomes must be $t > r > p > s$, where t is the payoff to the player who defects while the other cooperates; r is the payoff to both players when both cooperate; p is the payoff to both players when both defect; and, finally, s is the payoff to the player who cooperates when the second player defects. The second condition is that an even chance for each player to exploit and be exploited on successive turns of the game does not result in as profitable an outcome to players as does continuing mutual cooperation (i.e., $2r > t + s$).

Let me begin placing know-how trading in the context of a two-party Prisoner's Dilemma by observing that traded know-how is often possessed by more than one firm prior to a trade. Assume, therefore, that $n - 1$ firms possess a particular "unit" of know-how prior to a given trade. The total rent, R_{total}, that a firm (player) possessing that know-how reaps from it can then be expressed as:

$$R_{total} = R + \Delta R$$

Here R is the rent that a firm may expect from implementing a unit of know-how if it reveals it to its trading partner and, as a result, n firms possess that know-how. ΔR is the extra increment of rent that the firm can expect to garner if it does *not* trade the unit of proprietary know-how. In that case only $n-1$ firms possess that unit, and the player possessing it therefore gains extra competitive advantage from its use. (In instances when a given unit of know-how is possessed by only one firm prior to a trade and by two posttrade, R will be a duopoly rent and ΔR will be the monopoly rent associated with exclusive possession of the know-how minus the dupoly rent.)

A Base Case

As a base case, assume that in each play of the game two firms both start out with one unit of proprietary know-how unknown to the other. Assume also that each of these two units, although different, has identical R and ΔR associated with it. Then each firm starts with proprietary know-how having a preplay value of $R + \Delta R$.

Because knowledge is the good being traded here, a cooperative trade, r, between the two firms will result in each firm having both units of know-how posttrade, and each having the posttrade rent:

$$R = 2R$$

That is, posttrade each will have lost that increment of rent, ΔR, that was associated with a more exclusive possession of its own know-how unit, but will have gained the additional rent associated with an additional know-how unit. Similar reasoning allows us to work out the consequences of all four possible outcomes of a single play of the game by the two firms as:

$$t = 2R + \Delta R,\ r = 2R,\ p = R + \Delta R, \text{ and } s = R$$

We therefore find that both the first condition ($t > r > p > s$) and the second condition ($2r > t + s$) required for a situation to be defined as a Prisoner's Dilemma hold if $R > \Delta R$. Therefore, if $R > \Delta R$, a policy of know-how trading will usually pay better in the long run than any other strategy. On the other hand, both conditions fail and continuing defection or no exchange is the best option if $R < \Delta R$.

The simple model just given can obviously be brought into more precise alignment with the real world if we add refinements. But at this point I have only anecdotal data to use in testing, so it is reasonable to defer complexity. Instead, I will attempt to assess the intuitive plausibility of the simple model by reference to real-world examples.

When Proprietary Know-how Offers Little Competitive Advantage

In essence, $R > \Delta R$ holds when the exclusive possession of a know-how unit offers relatively little competitive advantage. This, I suggest, is often the case in the real world. To understand why, it is important to first understand a little more about the actual nature of most (but not all) proprietary know-how.

Know-how may have the ring of something precious and nonreproducible to the nontechnical reader. In fact, most proprietary know-how shares two characteristics: (1) it is not vital to a firm and (2) it can be independently developed by any competent firm needing it, given an appropriate expenditure of time and money. Consider two examples of typical proprietary know-how:

> An engineer at an aerospace firm was having trouble manufacturing a part from a novel composite material with needed precision. He called a professional colleague he knew at a rival firm and asked for advice. As it happens, that competitor had solved the problem by experimenting and developing some process know-how involving mold design and processing temperatures, and the colleague willingly passed along this information.

It was certainly convenient for the firm now facing the difficulty to learn of a solution from the rival, but it was not in any way vital. First, it was possible to struggle along without solving the problem at all. The part was in fact being made but with a high scrap rate and much effort. Second, the engineer assigned to solve this problem was competent and could certainly develop a solution independently, given appropriate time and funds.

> Process engineers at a manufacturer of waferboard (a fabricated wood product somewhat like plywood) were having trouble involving frequent jamming of a production machine with wood being processed. As it happens, competitors had solved this problem by experimenting and developing some process know-how involving the regulation of wood moisture content. When contacted, they passed along what they had learned.

Again, it was convenient for the firm now facing the difficulty to know this solution, but it was not essential or even very important. First, the cost of struggling on without solving the problem at all was not exorbitant: Machine operators could continue to cope simply by stopping the troublesome machine and clearing it as often as necessary. Second, a competent engineer assigned to solve this problem could certainly solve it independently.

When proprietary know-how does have the attributes just described, we can perhaps intuitively see the plausibility of the model's prediction that rival firms will find it profitable to engage in know-how trading. Conceptually, the consequences of noncooperation in know-how sharing under such conditions are similar to those of a policy of not cooperating in sharing spare parts with rivals who use an identical process machine. An industrywide policy of noncooperation between rivals with respect to spares would under most circumstances not permanently deprive any firm of needed spares nor otherwise significantly affect the competitive position of rival firms in the industry. It would simply result in increased downtime and/or spares-stocking costs for all—a net loss for all relative to the consequences of a policy of cooperation.

When Proprietary Know-how Offers Significant Competitive Advantage

Sometimes, the competitive value of a unit of know-how is large, and $R < \Delta R$. According to the model, one would then expect that informal know-how trading would *not* occur. I can illustrate this possibility with an interesting example that appears to show know-how trading behavior shifting as the value of a given type of know-how shifts over time.

Aerospace engineer interviewees have informed my students and me that they freely exchange most know-how under normal conditions. But, when a competition for an important government contract is in the offing, the situation changes, and trading of information between rivals that might affect who wins the contract stops. Later, after the contract has been awarded, the same know-how that was recently closely guarded will apparently again be traded freely.

The reported behavior seems reasonable. Much aerospace know-how has the characteristics discussed earlier: It is not critical and under normal conditions it can be independently reproduced by competent engineers if need be. Therefore, it is likely that $R > \Delta R$ for such know-how, and that know-how trading would pay according to the model. But when a competition for an important government contract is near, conditions are not normal. Often, there will not be enough time to produce needed know-how independently, and therefore the ΔR value of a given piece of competition-related know-how could increase temporarily. If the increase reached the point where $R < \Delta R$, it is reasonable according to the model that know-how trading temporarily stop—the behavior in fact reported by interviewees. And, of course, after the contract is awarded, it is reasonable that the ΔR value of competition-related know-how will drop and trading resume—as interviewees report that it does.

In the example just given the know-how at issue could have been independently redeveloped by anyone who wanted it. But the know-how nonetheless yielded competitive advantage to its possessor because the time needed for independent redevelopment was simply not available. Sometimes, however, know-how that can yield a major competitive advantage cannot be routinely reinvented. (It may, for example, be the result of unusual insight and/or major research efforts.) Then, $R < \Delta R$ for years, and trading of that know-how may never be in the best interests of the firm possessing it.

When Proprietary Know-how Offers No Competitive Advantage

Unique possession of proprietary know-how offers essentially no competitive advantage to a firm with respect to nonrivals. Therefore I would expect know-how trading to be to the advantage of firms in such a situation (assuming that the traded information does not leak from nonrivals to rivals) and would predict it to occur. Anecdotal evidence available to this point supports this prediction, but it is certainly only of illustrative value. For example, on the basis of interviews, I find that electric and gas utilities (which serve different regions and are therefore not rivals) do appear to share know-how extensively.

When Diffusing Proprietary Know-how Has Competitive Value

In at least some real-world conditions it appears that competition is enhanced by wide sharing of some know-how. As an example consider the establishment of uniform standards in a product category that can sometimes enlarge markets and benefit all participating manufacturers (e.g., standards set for computer networks and compact audio disks). The establishment of such standards requires some sharing of know-how by participating firms. As a second example consider the sharing of proprietary information on safety hazards between rivals (e.g., on the hazards of dioxin among rivals in the chemical industry).

Informal Know-how Trading in Context

Informal technology trading can usefully be compared with and contrasted to two other forms of R & D exchange between firms: (1) agreements to perform

R & D cooperatively and (2) agreements to license or sell proprietary technical knowledge. As we will see, informal know-how trading can usefully be seen as an inexpensive, flexible form of cross-licensing. Under appropriate conditions, it appears to function better than either of these better-known alternatives.

Agreements to trade or license know-how involve firms in less uncertainty than do agreements to perform R & D cooperatively. This is because the former deals with *existing* knowledge of known value that can be exchanged quickly and certainly. In contrast, agreements to perform R & D offer *future* know-how conditioned by important uncertainties as to its value and the likelihood that it will be delivered at all. The value of the know-how contracted for is uncertain because R & D outcomes cannot be predicted with certainty. The delivery of the results of cooperative R & D projects to sponsoring firms is somewhat uncertain because such results are best transferred back to the sponsoring firms in the minds of employees participating in the cooperative research. Given the U.S. tradition of frequent job changes, participants run significant risk of losing the benefits of their investment by losing the employee(s) they assigned to the project.

Informal know-how trading such as that reported here has a lower transaction cost than more formal agreements to license or sell similar information. Transaction costs in informal know-how trading systems are low because decisions to trade or not trade proprietary know-how are made by individual, knowledgeable engineers. No elaborate evaluations of relative benefit or seeking of approvals from firm bureaucracies are involved. Although informal, each engineer's assessment of the relative likely value of the trades he elects to make may be quite accurate: An information seeker can tell on the basis of his first interaction whether the expert advice he is given is of good quality—because he will immediately seek to apply it. An information provider can test the level of the inquirer's expertise and future value as a source of information by the nature and subtlety of the questions asked. Also, although a particular informal judgment of the value of a trade may be quite incorrect, many small transactions are typically made. Therefore, the net value of proprietary process know-how given and received will probably not be strongly biased for or against any participating firm.

In general, informal know-how exchange between rival and noncompeting firms is the most effective form of cooperative R & D when (1) the needed know-how exists in the hands of some member of the trading network, when (2) the know-how is proprietary only by virtue of its secrecy, and when (3) the value of a particular traded module is too small to justify an explicit negotiated agreement to sell, license, or exchange. Taken together, the second and third conditions have the effect of insuring that the know-how recipient will be free to use the information he obtains without fear of legal intervention by the donor firm. Since much technical knowledge key to progress consists of small, incremental advances, the universe bounded by these three conditions is likely to be a substantial one.

Formal know-how sale or licensing is likely to be preferred when the know-how in question (1) already exists and (2) is of considerable value relative to the costs of a formal transaction. Experts in the oil and chemical industries report that they may engage in formal licensing and sale rather than informal exchange precisely because the value of the know-how in question is typically very high.

Agreements to perform cooperative R & D must be the form of cooperation of choice when (1) the needed information does not exist within any firm willing to trade, license, or sell, and when (2) individual firms do not find it worthwhile to develop modules of the needed know-how independently. This would occur when know-how modules have no profitable applications as modules. Perhaps this is often the case, but I am not sure. Perhaps most "new" know-how in fact consists largely of existing modules of know-how developed for other purposes.

Discussion

Up to this point, I have discussed informal know-how trading as a firm-level phenomenon involving the trading of innovation-related know-how between technical personnel. But the model of such trading that I have presented here contains no inherent restriction as to the nature of know-how traded or as to the nature of the trading parties. Perhaps, therefore, the phenomenon exists and makes sense for individuals and other types of organizations and for other types of know-how as well. A certain answer must await appropriate research, but there are intriguing suggestions that informal know-how trading may be quite general. For example, Collins[12] has shown that scientists employed by nonprofit laboratories (university and governmental) selectively revealed data to colleagues interested in know-how related to the TEA laser. He noted that individuals and laboratories made conscious and careful discriminations as to what know-how would be revealed to what recipient, and he noted also that "nearly every laboratory expressed a preference for giving information only to those who had something to return."[13]

In arenas where know-how trading is applicable, what is its significance? An answer to this question also awaits further research. However, it seems to me possible that it may be an important phenomenon in some arenas. For example, Mansfield[14] recently found a general pattern of rapid transfer of proprietary industrial information from the firms that generated it to others, and he suggested that this might be caused by uncompensated "leakage" of such information to the detriment of the originating firms. But is it perhaps, instead, an indicator of massive know-how trading? If the observed information transfer is indeed simple leakage without compensation to the information generator, then, as Mansfield suggests, innovators face very serious appropriability problems. If, on the other hand, the rapid transfer observed is the result of information trading such as that present in the steel industry, then we may be observing a phenomenon that actually increases firms' ability to appropriate benefit from technical know-how.

Whatever the generality of know-how trading turns out to be, I am sure that further study will also show it can be quite an elaborate phenomenon. Thus, we will surely find know-how trading strategies more complex than those envisioned in a simple, two-party Prisoner's Dilemma, and we may find multiple layers of trading incentives and strategies active in a single trading entity as well.

One obvious form of know-how trading strategy builds on the observation that many firms often have a unit of know-how that a trader needs—and some of these potential trading partners may be direct rivals and some not. I have focused on trading between rivals here simply because it is the costliest form of trade and thus potentially the hardest to explain as economically rational behavior. However, in the real world it is likely that firms would prefer to trade know-how with nonrivals because traded information may then have less or no competitive cost.

Second, consider that firms can form coalitions with respect to know-how trading and restrict that activity to only a subset of firms in their industry. This can be profitable under some conditions. For example, the members of such a club may collectively face a more elastic demand than is faced by the industry as a whole and therefore may gain greater returns from (cost-reducing) innovations. Thus, U.S. or Japanese semiconductor producers may decide it is to their advantage to trade know-how with other domestic firms but not with foreign firms—or vice versa.

Third, consider that strategies may exist that are possible because the substance of know-how trades is knowledge. For example, firms may find a strategy of relatively *rapid* know-how trading may pay dividends. Such a strategy is based on the assumption that a firm receiving know-how in trade does not care who originally developed it: The recipient only cares that it has value to him. Since only novel know-how is valuable to a recipient (there is no value in getting the same information twice), a strategy of rapid know-how trading might allow a firm to exchange its own know-how *and* the know-how developed by others (obtained from earlier trades) to firms that still find that know-how novel, a trading advantage.

As an example of multiple levels of trader existing within a given trading entity, consider that trading between firms such as that I have documented here must also involve a different level of trader—the individuals who actually conduct the trades. It is clear that the benefits to individuals actually engaged in the trading *may* differ from those of the firms that employ them. (But they do not necessarily differ. Consider that an engineer's motive in trading may be in part to improve his potential marketability to competing firms. In this case, a strategy of being helpful to colleagues employed by competitors without hurting the interests of one's present firm by revealing vital proprietary secrets might be optimal for the individual trader as well as for the firm since no one wants to hire someone with a penchant for betrayal.) Research may show that the benefits expected by the different active interests in a trading entity are correlated in important arenas. When this is the case, simple models such as the one presented here may provide us with a practical ability to predict the role of know-how trading in the distributed innovation process.

Notes

1. *The Havamal, with Selections from Other Poems in the Edda,* as quoted by Marcel Mauss in *The Gift: Forms and Functions of Exchange in Archaic Societies,* trans. Ian Cunnison (Glencoe, Ill.: Free Press, 1954), xiv. Mauss has studied patterns of gift giving in a number of cultures and finds the practice typically associated with strong obligations for recompense to be provided by the recipient of a "gift."

2. Early minimills were relatively small (50,000–150,000 tons per year capacity) and produced primarily commodity products such as the reinforcing bar used in the construction industry. Today, however, some individual plants approach 1 million tons annual capacity and many are reaching far beyond commodity products into forging quality, alloy steel, stainless steel, and "nearly any steel grade capable of being melted in an electric furnace" (Edward L. Nemeth, "Mini-Midi Mills—U.S., Canada, and Mexico," *Iron and Steel Engineer* 61, no. 6 [June 1984], 27).

3. Nemeth, "Mini-Midi Mills."

4. Donald F. Barnett and Louis Schorsch, *Steel: Upheaval in a Basic Industry* (Cambridge, Mass.: Ballinger, 1983).

5. Samuel Hollander, *The Sources of Increased Efficiency: A Study of Du Pont Rayon Plants* (Cambridge, Mass.: MIT Press, 1965).

6. Barnett and Schorsch, *Steel: Upheaval in a Basic Industry,* 85.

7. Thomas J. Allen, Diane B. Hyman, and David L. Pinckney, "Transferring Technology to the Small Manufacturing Firm: A Study of Technology Transfer in Three Countries," *Research Policy* 12, no. 4 (August 1983): 199–211.

8. Ibid., 202.

9. Robert C. Allen, "Collective Invention," *Journal of Economic Behavior and Organization* 4, no. 1 (March 1983): 1–24.

10. Ibid., 2.

11. Robert Axelrod, *The Evolution of Cooperation* (New York: Basic Books, 1984).

12. H. M. Collins, "Tacit Knowledge and Scientific Networks," in *Science in Context: Readings in the Sociology of Science,* ed. Barry Barnes and David Edge (Cambridge, Mass.: MIT Press, 1982), 44–64.

13. Ibid., 59.

14. Edwin Mansfield, "How Rapidly Does New Industrial Technology Leak Out?" *Journal of Industrial Economics* 34, no. 2 (December 1985): 217–23.