Cooperation Between Rivals: Informal Know-How Trading

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ABSTRACT

"Informal" know-how trading is the extensive exchange of proprietary know-how by informal networks of process engineers in rival (and non-rival) firms. I have observed such know-how trading networks to be very active in the US steel minimill industry and elsewhere, and they appear to represent a novel form of cooperative R&D.

When one examines informal know-how trading in the framework of a "Prisoner's Dilemma", real-world conditions can be specified where this behavior both does and does not make economic sense from the point of view of participating firms. Data available to date on the presence and absence of such trading seem to be roughly in accordance with the predictions of this simple model.

Although presently documented only as a firm-level phenomenon involving the trading of proprietary technical know-how, informal know-how trading seems relevant to (and may currently exist in), many other types of situation. Indeed, it may be applicable to any situation in which individuals or organizations are involved in a competition where possession of proprietary know-how represents a form of competitive advantage.

Cooperation Between Rivals:
Informal Know-How Trading

1.0: Introduction

It has long been recognized that it is difficult for an innovating firm to fully appropriate the benefits arising from its innovations, and that desired research might therefore not be performed (1). One sometimes possible solution to this dilemma is cooperative R&D conducted by firms who share the costs and benefits of particular R&D projects (2).

In this paper I explore a novel type of cooperative R&D: the informal trading of proprietary know-how between rival (and non-rival) firms. I have observed this behavior to be widespread in one industry. I propose that the phenomenon makes economic sense, and that it may be present in many industries. Indeed, it may be applicable to any situation in which individuals or organizations are involved in a competition where possession of proprietary know-how represents a form of competitive advantage.

I begin by briefly characterizing informal know-how trading as I have observed it to date (section 2). Next, I present a case study of the phenomenon involving the trading of proprietary process know-how among US steel minimill firms (section 3). Then, I explore whether and when technology trading between direct competitors is an economically advantageous form of cooperative R&D from the viewpoint of participating firms (section 4). I then place know-how trading in the context of other forms of R&D cooperation (section 5) and, finally, I discuss how the phenomenon may apply beyond the arena of interfirm trading of R&D-related knowledge (section 6).

2.0: A General Description of Informal Know-How Trading

Know-how is the accumulated practical skill or expertise which allows one to do something smoothly and efficiently. The know-how which 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, an engineer typically cannot find what he needs in publications either: Much is very specialized and not published anywhere. He must either develop it himself or learn what he needs 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 firms which make similar products or use similar processes are the people most likely to have that needed information. But are such professional colleagues willing to reveal their proprietary know-how to employees of rival 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 which I have observed to date appears to involve informal trading "networks" which develop between engineers having common professional interests. Network formation begins when, at conferences and elsewhere, an engineer makes private judgements as to the areas of expertise and abilities of those he meets, and builds his personal informal list of possibly useful expert contacts. Later, when "Engineer A" encounters a product or process development problem he finds difficult, he activates his network by calling Engineer B, an appropriately knowledgeable contact who works for a directly competing (or non-competing) firm, for advice.

B makes a judgment as to the competitive value of the information A is requesting. If it seems to him vital to his own firm's competitive position, he 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 - B will answer his request as well as he can and/or refer him to other experts of his acquaintance. B may go to considerable lengths to help A: He may, for example, run a special simulation for him on his firm's computer system. At the same time, A realizes that in asking for and accepting the help, he is incurring an obligation to provide similar help to B - or to another referred by B - at some future date. No explict accounting of favors given and received is kept in instances studied to date, but the obligation to return a favor seems strongly felt by recipients - "... a gift always looks for recompense" (3).

3.0: Case Study: Informal Trading of Proprietary Process Know-How Among US "Minimill" Steel Producers

To date, information on informal know-how trading between rivals is most complete in the instance of process know-how trading in the US steel minimill industry. I present it here as an existence test of the general phenomenon we are discussing, and as a means of conveying its flavor.

Minimills, unlike "integrated" steel plants, do not produce steel from iron ore. Rather, they begin with steel scrap which 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 US steel minimill firms to compete extremely effectively against the major integrated US steel producers in recent years. Indeed, they have essentially driven US integrated producers out of the market for many commodity products.

The term minimill is not precisely defined, and is becoming less so as "minimill" plants grow in size and complexity. 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 1,000,000 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" (4).

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

3.1 Methods

The sample of minimills studied here is a subset of a recent listing of minimill plants published in Iron and Steel Engineer. This listing (5) contained 45 US firms with one or more minimill plants. 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 know-how trading behavior) and so I also added this firm. All firms included in the study sample are identified in Table 1.

Table 1: US Steel Minimill Firm Sample

STEEL MINIMILL FIRM	MELT CAPACITY[a] (Tons/Year,000)
Four Largest Firms	
Chaparral, Midllothian, TX	1,400
Florida Steel, Tampa, Fla	1,578
North Star, Salt Lake City, UT	2,300
Nucor, Charlotte, NC	2,000
Other (Randomly Selected)	
Bayou Steel, LaPlace, LA	650
Cascade Steel Rolling Mills, McMinnville, OR	250
Charter Electric Melting, Chicago, IL	130
Kentucky Electric Steel, Ashland, KY	280
Marathon Steel, Tempe, Ariz[b]	185
Raritan River Steel, Perth Amboy, NJ	500
Specially Selected Outlier	
Quanex, Houston, TX	

[a] Source: Edward L. Nemeth, "Mini-Midi Mills - U.S., Canada and Mexico", Iron and Steel Engineer 61:6 (June 1984), Table 1, pp. 30-34.

[b] Firm closed in July, 1985.

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

3.2: Results

Personnel at all firms except Quanex (selected for study specifically because its behavior differed from the norm) reported routinely trading proprietary process know-how - sometimes with direct competitors. This finding strikes me as impressive, because conventional wisdom might suggest that know-how trading between rivals is rare.

Table 2: Know-How Trading Patterns

Steel Minimill Firm	**In-House Process Devel?**	**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	Minor	Yes
Charter Elec	Minor	Yes
Kentucky Electric	Minor	Yes

Marathon Steel	Minor	Yes
Raritan River	Minor	Yes
Quanex	Minor	NO

Interestingly, reported know-how trading often appeared to go far beyond an arms-length exchange of data at conferences. Interviewees reported that, sometimes, operating employees of competitors were trained (at no charge), firm personnel were sent to the plants of competitors to help set up unfamiliar equipment, etc.

Of course, the firms which report informal know-how trading with competitors in Table 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, it is reasonable that a firm will only offer to trade valuable know-how with those who can reciprocate in kind.)

Before turning to consider why the trading of proprietary process know-how occurs in the steel minimill industry, let us 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 direct competitors; (2) did firms possessing know-how sometimes trade it with direct competitors (rivals); and (3) was know-how in fact "traded", as opposed to simply revealed without expectation of a return of similarly valuable know-how?

3.2.1: <u>Valuable Know-How?</u>

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

Table 3: Minimill Costs Per Ton (Wire Rod, 1981)

Cost Category	Dollars per Ton	Percent of Total
Labor	$60	21%
Steel Scrap	93	33%
Energy	45	16%
Other Operating[a]	65	23%
Total Operating	$263	
Depreciation	11	4%
Interest	7	2%
Misc. Tax	3	1%
TOTAL COSTS[b]	$284	100%

Source: Donald F. Barnett and Louis Schorsch, Steel: Upheaval in a Basic Industry (Cambridge, MA: Ballinger, 1983), Table 4-3, p.95.

[a] Includes alloying agents, refractories, rolls, etc.

[b] Excluding any return on equity.

On the basis of Table 3 data, it seems reasonable that all minimills would have a keen interest in know-how which would reduce their labor and/or energy costs. And, indeed, all interviewed reported making in-house improvements to methods or equipment in order to reduce these costs. In addition, some reported making process innovations which increased the range of products which 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 will perhaps double the size of the market open to minimill 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 which is more horizontal (has less pitch) than that of other minimill firms. (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 which allow them to make better or different steel shapes, and so forth. While many such process refinements have only a small individual impact on production costs, their collective impact can be large (7).

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

3.2.2: Direct Competitors?

Our next question is: Are steel minimill firms which trade know-how in fact direct competitors (rivals)? If they are, we have found informal know-how trading to exist under conditions where, on the face of it, it would seem least likely. Direct competitors would seem to be the type of firm most able to turn traded proprietary know-how to a trader's direct disadvantage.

Many minimills do compete directly with each other today, although this was not always the case. When minimills began to emerge in the late 1950's to late 1960's, 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" (8).

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 such rivals - but 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 direct competitors.)

3.2.3: 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 in fact be kept secret if you wanted to do this?"

In the instance of know-how embodied in equipment and 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 direct 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 often visit plants for reasons ranging from sales to repair to advice. They are expert at detecting equipment modification, and are quick to diffuse such 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 we have not yet collected it 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 per 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 direct competitor at a professional 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 <u>trading</u> information whose value they recognized. Thus, Bayou Steel: "How much is exchanged depends on what the other guy knows - must be reciprocal". Chaparral Steel: "If they don't let us in [to their plant] we won't let them in [to ours] - must be reciprocal". Such statements appear to me to have weight 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 is not centrally controlled beyond (sometimes) the provision of general guidelines by top management. Also, no one appears to be explicitly counting up the precise value of what is given or received by a firm, and a simultaneous exchange of valuable information is not insisted upon. However, in an informal way, participants seemed to strive to keep a balance in value given and received, without resorting to explicit calculation. On average over many transactions, a reasonable balance may in fact be achieved, although individual errors in judgment are easy to cite. (For example, 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 profit, away.)

3.2.4: Quanex, The Exception

Quanex was the sole exception to the minimill trading norm which I found. The firm was not on the list of minimills which I used to generate the study 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 competing 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 real rivals 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. (I 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.)

3.3: Other Empirical Evidence Regarding Know-How Trading

Is know-how trading unique to the US 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 these tend to suggest that informal know-how trading exists in many industries.

First, my students and I have now conducted pilot interviews in several US 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 Allen, et al. (9), of a sample of Irish, Spanish and Mexican firms appears consistent with what I am calling informal know-how trading. Allen examined the "most significant change, in either product or process" which 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 implemention. 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".

T. 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 plant visit by representatives 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 (10).

Finally, Robert Allen (11) reports on a phenomenon he calls "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 1850-1875 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. Thus, it appeared that some firms revealed data of apparent competitive value to both existing and potential rivals, a phenomenon which he called collective invention.

The essential difference between know-how trading and collective invention is that know-how trading involves an exchange of valuable information between traders which is at the same time kept secret from non-traders. In contrast, collective invention requires that all competitors and potential competitors be given free access to proprietary know-how (12). 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 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 to me to be possible. Allen deduced that technical data was 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 via written records but are, in fact, part of the trading behavior of present-day firms.)

4.0: 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 rivals in terms of maximizing the profits (rents) which firms reap from it. (Although I will not consider the matter here, benefits and costs experienced by individuals who actually do the trading within firms can also be relevant. I will return to this issue in section 6.) 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 referring to the small amount of real-world information currently available to us.

4.1: Know-How Trading as a Prisoner's Dilemma

Consider know-how trading between rivals as an example of 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 (14). 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 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 (e.g., $2r > t + s$).

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 knowhow prior to a given trade. The total rent, R_{total}, which a firm (player) possessing that knowhow reaps from it can then be expressed as:

$$R_{total} = R + \text{delta } R$$

Here, R is the rent which 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 knowhow. Delta R is the extra increment of rent which the firm can expect to garner if it does <u>not</u> 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 post-trade, R will be a duopoly rent and delta R will be the monopoly rent associated with exclusive possession of the know-how minus the duopoly rent.)

A Base Case

As a base case, assume that in each play of the game, two firms each 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 delta R associated with it. Then, each firm starts with proprietary know-how having a pre-play 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 post-trade, and each having the post-trade rent:

$$R_{total} = 2 \ R$$

That is, post-trade each will have lost that increment of rent, delta R, which was associated with a more exclusive possession of its own knowhow 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, and s = R.

We therefore find that both condition 1 (t > r > p > s) and condition 2 (2r > t+s) required for a sitution 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, since at this point I have only anecdotal data to use in testing, 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 is often the case in the real world, I suggest. To understand why, it is important to first understand a little more about the actual nature of most (not all) proprietary know-how.

"Know-how" may have the ring of something precious and nonreproducible to the nontechnical reader. In fact, however, 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 such "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, one 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 direct competitors who use an identical process machine. An industrywide policy of noncooperation among competitors 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 which 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 which might affect who wins the contract stops. Later, after the contract has been awarded, the same know-how which was recently closely guarded will apparently again be traded freely.

The reported behavior seems reasonable. Much aerospace know-how has the characteristics discussed in the previous section: 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 > R, for such know-how, and that know-how trading would therefore 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 delta R 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 delta R 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 which 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 non-rivals. 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 non-rivals to rivals) and would predict it to occur. Anecdotal evidence available to this point supports this prediction, but 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 Knowhow Has 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 that the establishment of uniform standards in a product category can sometimes enlarge markets and benefit all participating manufacturers. (Recent examples include 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 such as the recent sharing of information on the hazards of dioxin among rivals in the chemical industry.

<u>If Traders Have Different Amounts of Know-How</u>

Our pilot research investigations to date show several instances in which the large, relatively innovative firms in a product category examined appear to energetically suppress trading by their employees, while smaller producers of the same product types appear less restrictive. Examples are Kraft in cheese products, IBM in computers, P&G in paper goods. On the other hand, this pattern does not appear in the study of steel minimill firms, where the better-endowed firms seemed to simply pick trading partners who were equally well-endowed. Both patterns can be explained by the operation of either or both of the two following factors:

> (1) The firms which are better-endowed feel that they have all the know-how they need in-house. Therefore they would not receive any benefit from trading with rivals (or others) and do not do so.
>
> (2) A firm which has more proprietary know-how than potential trading partners will, assuming know-how of equal absolute value is exchanged in a trade, be worse off in percentage-of-unique-know-how-held terms relative to competitors than it was pre-trading. This could reasonably cause a relative reluctance by better-endowed firms to trade with those having less proprietary know-how.

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; (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 which 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 US 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 rents 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, one may say that 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, and 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, conditions 2 and 3 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 progress consists of small, incremental advances(7), 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 industry report that they 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

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 which I have presented in this paper 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 (16) has shown that scientists employed by non-profit laboratories (university and governmental) selectively revealed data to colleages 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 noted also that "Nearly every laboratory expressed a preference for giving information only to those who had something to return."(17)

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 (18) recently found a general pattern of rapid transfer of proprietary industrial information from the firms which generated it to others, and suggested that this might be caused by uncompensated "leakage" of such information to the detriment of the originating firms. But perhaps, instead, it is 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 which actually increases firms' ability to appropriate rent from technical knowhow.)

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 elaborated 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 which a trader needs - and some of these potential trading partners may be direct rivals and some not. I have focused on trading between rivals in this paper 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 non-rivals, because traded information may then have less or no competitive cost. (It may be possible to study this in an elegant manner by tracking <u>shifts</u> in information-trading behavior as a potential trading partner shifts from the status of non-competitor to that of direct rival or vice versa.)

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) innovation. Thus, US 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 stategies may exist which are possible because the substance of know-how trades is knowledge. For example, firms may find a strategy of relatively <u>rapid</u> 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: He 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 <u>and</u> the know-how developed by others (obtained from earlier trades) to firms which 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 in this paper 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 <u>may</u> differ from those of the firms which employ them. But they do not 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 colleages 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. 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 may provide us with a practical ability to predict know-how trading.

Studies of informal know-how trading patterns are interesting in their own right, but they may also serve as useful general tool for researchers and practitioners. Thus, if general patterns emerge in the types of know-how considered to be of high and low competitive importance, researchers may be able to develop and explore generic "efficient" competitive strategies which involve both competition and cooperation. And, if an increased understanding of efficient competition can allow firms to see some areas of R&D investment as not being of competitive value, or as offering only "redundant" competitive advantage, they might find it profitable to cooperate in more aspects of know-how development. This would lead to a drop in the cost of a given level of competition - a net social gain.

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