5

Testing the Relationship Between the Functional Source of Innovation and Expected Innovation Rents

In chapter 4 I proposed that it would often be possible to predict the functional sources of innovation on the basis of differences in potential innovators' expectations of innovation-related rents. Now it is time to test this hypothesis. I begin by testing the hypothesis against five samples and find it supported in these instances. Then I draw on the evidence presented to propose that general rules may underlie innovators' expectations of rent.

Five Empirical Tests

In order to test the hypothesis that the functional source of innovation and innovators' expectations of rent are related, we need data on both these factors. Since the work described in chapters 2 and 3 has already provided reliable innovation source data for nine quite diverse innovation types, I found it efficient to create the data base for this test by adding rent expectation data to these same innovation samples where possible. After investigation I found that I could obtain these additional data for five of the nine samples (listed in Table 5–1). These became the basis of the five empirical tests of the hypothesis I have carried out to date.

The inability to use four innovation samples due to data problems is unfortunate. However, the reasons for exclusion do not appear to bias our test of the hypothesis. In the instance of semiconductor process innovations, a single innovation caused multiple product and process impacts whose value I could not isolate and estimate. In the instance of plastics additive innovations and the sample of wire termination equipment innovations, needed data were simply not available from innovating firms or from published sources. Finally, the scientific instrument innovation sample could not be used here because

TABLE 5–1. Summary of Functional Source of Innovation Data

	Innovations Developed by					
Innovation Category	*User*	*Manufacturer*	*Supplier*	*Other*	*NA (n)*	*Total (n)*
Pultrusion process	90%	10%	0%	0%	0	10
Tractor shovel–related	6	94	0	0	0	11
Engineering plastics	10	90	0	0	0	5
Industrial gas–using	42	17	33	8	0	12
Thermoplastics–using	43	14	36	7	0	14

the innovation-related benefits expected by instrument users and instrument manufacturers were different in kind and could not be readily compared. (This is a problem of general interest and I will return to it at the end of the chapter.)

My hypothesis requires that I estimate the rents firms could reasonably expect if they had decided to develop specified innovations. This is not an easy task because expectations of rent are not based on some straightforward calculation. Rather, those who plan to innovate know they must struggle for gain against the sometimes unpredictable actions of competitors, the possible emergence of competing innovations, and other events.

In the battle for innovation-related rents, each firm with an interest in an innovation devises strategies that may help it to minimize innovation costs and maximize its returns from innovation. For example, if Boeing decides to develop a new, more fuel-efficient plane, it will try to lower its innovation costs by shifting some project development expenses to component suppliers and by demanding some advance payments from buyers. Also, it will try to increase its share of the rents generated by the plane by, for example, raising its price to capture some of the fuel savings benefit that users expect to reap. At the same time, of course, suppliers and users are trying to resist these moves and to carry out profit-increasing strategies of their own (e.g., General Electric may attempt to charge more for the fuel-efficient jet engines that it supplies to Boeing).

Given this complex reality, my general strategy for estimating rents that firms might reasonably expect if they were to develop specific types of innovations has been to study several innovation categories in detail and to try to understand the thinking of and options open to potential innovators in these fields.

Innovators capture temporary rents from their successful innovations by first establishing some type of monopoly control over their innovation and then using this control to increase their economic return. A successful innovator's rents may come in the form of cost savings and/or increased prices and/or increased sales obtainable during his period of temporary and partial monopoly. Unfortunately, the available data do not allow us to assign values to these individual components of expected rents or to properly sum and discount them with respect to time. Therefore, in each test that follows I will first summarize information bearing on firms' relative abilities to capture innovation-related rents and then will build a test of reason from this data.

The logic behind my tests of reason will be self-evident, I think, with the possible exception of some of the elements I use to estimate relative abilities to establish monopoly control over an innovation. Let me therefore elaborate a little on the latter before proceeding to a discussion of the tests themselves.

Recall from chapter 4 that we found that innovators typically could not expect to obtain rents from their innovations by licensing them to others because both the patent grant and trade secrecy legislation did not typically allow innovators the type of monopoly control necessary to achieve this. Therefore, innovators must typically benefit by excluding imitators from obtaining rent from their own innovation-related outputs.

The patent grant, trade secret legislation, and response time are the only mechanisms I have observed to date that are exclusively available to innovators and may potentially give an innovator the control over his innovation that he needs to exclude would-be imitators. (This seems a short list, but note that it is not of fixed length. Mechanisms for enhancing an innovator's innovation property rights are social inventions and their number or design has no inherent limit. For example, in the United States one can currently observe the extension of copyright protection to include software writings.)

In chapter 4 we saw that the patent grant generally offers only weak protection to innovators in the context of licensing. I find no apparent reason why it should be any more effective in allowing an innovator to prevent others from imitating his innovation without permission. However, trade secret protection can be much more effective in preventing imitation than it was seen to be in enabling licensing. The difference is that, as a practical matter, licensing of trade secrets requires that they be revealed to licensees, and a secret shared may not stay secret very long. In contrast, a secret kept by an innovator for his own exclusive use need only be known within his factory walls and can often be well protected there.

Finally, an interesting and often effective additional mechanism—response time—became visible in the course of my investigations of innovators' strategies for protecting their innovation-related knowledge. I define response time as the period an imitator requires to bring an imitative product to market or to bring an imitative process to commercial usefulness once he has full and free access to any germane trade secrets or patented knowledge in the possession of the innovator.

Response time exists because many barriers in addition to lack of knowledge must be overcome in order to bring any product or process—even an imitative one—to commercial reality. Engineering tooling must be designed, materials and components ordered, manufacturing plants made ready, marketing plans developed, and so on. During the response-time period an innovator by definition has a monopoly with respect to the innovation and is in a position to capture rent from his innovation-related knowledge.[1]

When an innovator is seeking to protect his innovation from imitators, he may be able to use any or all three mechanisms—patents, trade secrecy, and response time—to prolong his period of exclusive use, his lead time. Whether any or all of these are usable or offer an advantage to a given class of potential innovator is a function of situation-specific factors that will be discussed in the context of the cases that follow.

I begin each case discussion by identifying the types of firm best positioned to capture rents from the category of innovations under study. Next I describe and compare four rent-related elements of the real-world situation facing each type of firm. These are (1) the relative abilities of firms holding different functional relationships to an innovation to establish some monopoly control over it; (2) the nature and amount of innovation-related output generated by innovating and noninnovating firms; (3) the anticipatable cost of innovation; (4) the displacement of existing business that a firm undertaking the innovation studied might expect. Finally, I draw on this information to assess the reasonable preinnovation rent expectations of potential innovators. In this final step I use a very conservative test with respect to my hypothesis. I simply *rank* such rent expectations and count the hypothesis as supported only if the functional source of innovation is populated by firms with the highest preinnovation expectations of rent. (I will return to this point at the end of the chapter.)

Pultrusion Process Machinery: Innovation and Innovation Rents

As we saw in chapter 3, users are the source of all sampled pultrusion process machinery innovations save one. Therefore, the hypothesis I am testing may be stated for this sample as: Innovating users of pultrusion process machinery had higher preinnovation expectations of rent from their innovations than did all firms holding other functional relationships to those same innovations.

There are many classes of firm that have some sort of functional relationship to pultrusion process machinery innovations ranging from inventor to user to manufacturer to distributor. However, it is not necessary to precisely determine the reasonable rent expectations of all of these in order to test the hypothesis. The only noninnovators who can represent a challenge to the hypothesis are those with rent expectations that might conceivably equal or exceed those of the innovating firms. It is therefore efficient to begin this test with a simple inspection of the many extant functional relationships between innovator and innovation and exclude all from further analysis that on the face of it cannot reasonably expect a level of rent from pultrusion process machinery innovations that is anywhere near that of the innovating process users.

In the instance of pultrusion process machinery innovations, I have determined, by means of interviews with industry experts, that the only two functional categories of firm likely to gain significant rent from innovations that improve pultrusion process machinery are process machine users and process machine manufacturers.* I therefore explore the relative ability of these two functional types of firms to capture such rent in what follows.

Relative Ability to Establish Monopoly Control

On the basis of both interview data and reason, it appears to me that innovating users of pultrusion process equipment are better able than innovating manufacturers to establish temporary monopoly control over their innovations. The key source of this difference is the ability of equipment users to hide their innovations for a period of time as trade secrets. This option is not open to manufacturers, who must display their innovations to customers in order to sell them.

Patents and response time were both considered ineffective in this industry by interviewees. Innovators sometimes applied for patents and sometimes received some modest licensing income, but it was understood by all that the patents did not really provide effective protection. Innovators typically would not even attempt to contest infringement of their patents and expected only the naive or exceedingly cautious to honor them. Response time in the instance of pultrusion innovations is only months and is not considered to be of significant value to either user or manufacturer innovators.

Relative Innovation-Related Output

The innovation-related output of the users of pultrusion process equipment innovations is, of course, pultruded product. In general, the effect of the innovations we have studied was to make it possible to extend the pultrusion process to new types or sizes of product. This in turn allowed user firms to create cheaper or better substitutes for products made by other methods or other materials.

*Field investigation showed that the licensing of innovation-related knowledge was (and was considered to be by industry participants) of minor importance in pultrusion processing. Innovators' general inability to appropriate rents from the licensing of knowledge led me to eliminate both independent inventors and suppliers of materials used in pultrusion as potential recipients of significant innovation-related benefit. Independent inventors were eliminated because they only have nonembodied innovation knowledge to sell. Suppliers of materials used in pultrusion were eliminated because pultrusion used 2% or less of the huge amount of polyester resin and fiberglass consumed annually in the manufacture of fiberglass-reinforced plastics during the period of the innovations studied (William G. Lionetta, Jr., "Sources of Innovation Within the Pultrusion Industry" [SM thesis, Sloan School of Management, MIT, Cambridge, Mass., 1977], Table III, p. 41). These innovations needed only commodity plastic resin and fiberglass reinforcement products to implement. Therefore, the suppliers too could not embody innovation-related knowledge in their outputs, and would also be dependent on the licensing of nonembodied innovation knowledge for their innovation-related rents.

Other functional relationships between innovator and pultrusion process innovations—wholesaler and so forth—were eliminated from further consideration after discussion with industry personnel showed innovation benefit potentially accruing to these was clearly much less than that potentially accruing to users and manufacturers.

Pultrusion process machines vary in size, and early machines tended to be smaller and slower than later ones. In 1975 the output of a single average pultrusion machine working a single shift was about 200,000 lb of pultrusions annually. At the 1976 market price of $1.70/lb, this means that a single innovative pultrusion machine could produce $340,000 of novel pultruded product during each year of that machine's service life.

The innovation-related output of a pultrusion machine manufacturer is the incremental hardware on the pultruder that embodies a pultrusion improvement innovation. However, it is more conservative with respect to the hypothesis we are testing to regard innovation-related output as the entire machine embodying such an innovation. Early pultrusion machines tended to be smaller and cheaper than later ones. In 1975 the price of a commercial pultruder of average capacity was $75,000 to $85,000.[2]

Until 1966, all pultrusion process equipment was made by the firms that used it. Then, in 1966 Goldsworthy Engineering began to manufacture a standard line of pultrusion process machines. (Of course, prior to that year there were many manufacturing firms that did produce other types of plastics processing machines and were fully capable of producing pultruders.) By the 1970s each of the largest three user firms had 15 to 20 pultrusion machines each and were making machines for internal use at roughly the same rate as Goldsworthy was making them for the external market. In 1976, pultruder operators reported that about 30 of the 175 pultruders operating in the United States had been built by an equipment builder. The rest were built by users in-house. In that year, pultruders built by users in-house cost less than the commercial equivalent.[3]

Relative Costs of Innovating

The pultrusion process machinery innovations examined were built by both users and manufacturers using general-purpose machine shop equipment that both types of firm had on-site. No organized R & D effort was used to develop these innovations: They consisted of good ideas that, once grasped, could be implemented on the shop floor. Thus it can be assumed that innovation costs would be similar in magnitude for both users and manufacturers of these machines.

Relative Amount of Displaced Sales

No potential innovator in this field had reason to anticipate that pultrusion process innovations would result in a significant displacement of his present sales. In some instances, as can be seen in the innovation cases presented in the appendix, users developed process improvements to reduce their costs of production. In other cases, pultrusions were displacing metals, typically, in high-performance applications. Neither the pultrusion process equipment users nor the equipment manufacturers had any position I am aware of in such displaced products or processes.

Discussion

Now I must speculate. Is it reasonable that even an optimally situated manufacturer of pultrusion machines could expect to gain as much or more rent as innovating users? I do not think so. We have seen that a user has a basis to expect some degree of monopoly control over his innovation, but that a manufacturer does not. Further, I see no relative disadvantage that an innovating user might have with respect to an innovating manufacturer that might offset the user advantage in monopoly control. Users and manufacturers contemplating innovation could expect similar costs, and neither needed to fear displacement of existing business as a result of the type of innovation studied. Further, the possible impact of increasing returns to scale in production of the machines embodying the innovation would be trivial at the levels of production involved here. Even if a single manufacturer produced all of the machines needed by the market (say, 20 per year) his direct per machine costs would only be on the order of 10% less than those of a user producing only a single machine.[4]

In sum, then, the evidence leads me to conclude that the rents that process machine users could reasonably expect prior to an innovation exceed those that a pultrusion process machine manufacturer could expect if he contemplated the same innovation opportunity. Therefore the hypothesis is supported in this instance: Pultrusion process users, the functional type of firm that I judge to have the highest reasonable expectations of innovation-related rent, are also the type of firm that my data show most active in developing pultrusion process equipment innovations.

The Tractor Shovel: Innovation and Innovation Rents

Since, as we saw in chapter 3, manufacturers are the source of almost all tractor shovel innovations, the hypothesis I am testing may be stated for this sample as: Firms that hold the functional relationship of manufacturer to the sampled tractor shovel innovations are also the type of firm best positioned to capture rents from such innovations.

As in the previous study, my first step in testing the hypothesis here was to identify by inspection the few functional types of potential tractor shovel innovators positioned to appropriate significant innovation rents. I found tractor shovel users and tractor shovel manufacturers were clearly the two functional categories of firm most favorably positioned in this regard,* and I will therefore only attempt to rank the relative rent expectations of these two types of firms here.

*My findings here precisely parallel those presented earlier regarding the pultrusion process machinery study. As was the case in that field, innovation benefit was almost never captured from the licensing of nonembodied knowledge. Further, industry participants had no illusions that this could be done, given the general weakness and unenforceability of patents in the field of mechanical invention. As a consequence, I judged that independent inventors were unlikely to be able to

Relative Ability to Establish Monopoly Control

Tractor users and tractor shovel manufacturers apparently are in an equally poor position to establish monopoly control over a tractor shovel innovation they may undertake. Patents did not offer effective protection to innovators in this field. Also, neither user nor manufacturer could expect to protect tractor shovel product innovations as trade secrets. Tractor shovels are used on open construction sites, and any innovations by users and/or manufacturers will be open to the view of would-be imitators. Response times in the instance of tractor shovel innovations are on the order of one year. That is, either a user or a manufacturer of a tractor shovel who had good mechanical skills could imitate a tractor shovel innovation he was able to inspect in a year or less.

Relative Innovation-Related Output

The innovation-related output of tractor shovel manufacturers consists of hardware embodying such innovations. The advantage of the sampled major improvement innovations over previous best practice was such that they were immediately embodied in most or all of the units sold by the innovating firm. Therefore, total tractor shovel sales of the innovating firm in the first post-innovation year is a reasonable indicator of the units of output embodying the innovation in that year.[5]

In the instance of the development of the tractor shovel itself, first-year innovation-related sales were about $250,000 (50 units were sold). All improvement innovations were developed by manufacturers producing at least hundreds of tractor shovels in the year the innovation was commercialized. The major improvement innovations in the sample all added functional capabilities to the tractor shovel at some increase in complexity and cost.

The function of a tractor shovel is to excavate and/or move bulk materials. From a user's point of view, the innovation-related output of a tractor shovel innovation is the increase in productivity that the innovation provides. I estimate the improvement that an innovating user could expect from embodying one of the improvement innovations studied on one tractor shovel is an increase in output of on the order of 20%. This translates into an operating savings of perhaps $1000 annually per machine.[6]

Even the largest users of tractor shovels contemplating an innovation could not expect to incorporate their innovation on more than a very few tractor shovels. Today, with the exception of the U.S. Army and some municipalities, even the major, national account users have a fleet of only 8 to 10 tractor

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appropriate significant innovation benefit from any tractor shovel innovations they might attempt. The same reasoning suggests that suppliers of components used to implement the innovations were also unlikely to innovate. Components used to achieve an innovative effect when applied to tractor shovels were not themselves novel and were typically available from a number of suppliers as off-the-shelf items.

Industry experts contacted all judged that users and manufacturers ranked highest in the list of fuctional types of firms able to appropriate innovation benefit from tractor shovel innovations.

shovels—and that of mixed models and vintages. Presumably fleets of this size were even more unusual in the period when the innovations we studied were commercialized.

Relative Costs of Innovating

I estimate that user innovation costs would be somewhat higher than those of innovating manufacturers because the equipment and engineering skills needed for innovation are utilized by tractor shovel manufacturers in the course of routine manufacturing and are therefore in place if needed for innovation. In contrast, tractor shovel users have no routine need for such equipment or related engineering skills and may need to acquire them especially for innovation-related tasks.

Relative Amount of Displaced Sales

In the instance of the tractor shovel, users might find that the development of an improvement slightly reduced the value of older tractor shovels and other functionally similar construction equipment that they had in inventory. In contrast, with the exception of Clark Equipment Company (a tractor shovel manufacturer that developed one of the sampled innovations), none of the innovating equipment manufacturers also made construction equipment of similar function, such as bulldozers. Therefore, these manufacturers would anticipate no displaced sales as a result of developing tractor shovel innovations.

Discussion

On the basis of the above discussion, I reason that both users and manufacturers of tractor shovels could only expect to have a monopoly of a year's duration if they chose to develop a tractor shovel innovation. However, it also seems clear that a tractor shovel manufacturer's ability to capture rent on the basis of this period of temporary monopoly is greater than that of any user.

Tractor shovel manufacturers inform me that they generally tend to try to increase sales on the basis of an innovation rather than to increase prices. They feel that they may gain a significant advantage over competitors in a year, possibly selling hundreds of additional tractor shovels due to the presence of the innovation. And, even after imitators enter, innovators' first-to-market reputation may continue to give them a marketplace advantage.[7]

In contrast, it is not clear to me or to users how a year's monopoly on a tractor shovel innovation might significantly benefit innovating users beyond the small operating savings discussed earlier. Because there are many substitute ways to move materials, a given user's unique possession of an innovation would not seem to give him monopoly control over any unique capabilities that would possibly command a high rent from the market.

In this industry, users appeared to have no plausible offsetting advantages that might raise their expectations of rent relative to manufacturers. Indeed, significant returns to scale obtainable from hardware embodying the innovations studied in the tractor shovel market were available to manufacturers but not users.[8]

In sum, then, I conclude that tractor shovel manufacturers are both the functional type of firm likely to have the highest preinnovation expectations of innovation-related rent and also the functional type of firm that in fact did innovate. Thus, I find support for my hypothesis in this sample.

Engineering Plastics: Innovation and Innovation Rents

Since, as we saw in chapter 3, the manufacturers of engineering plastics are the source of almost all innovations sampled in that field, my hypothesis may be stated here as: Manufacturers of the sampled engineering plastics innovations are also the functional type of firm best positioned to capture rents from such innovations.

On the basis of inspection and discussion with industry experts, I concluded that firms with either a user or a manufacturer relationship to engineering plastic resin innovations are most likely to gain significant rents from them.* Therefore, I focus on assessing the relative rents appropriable by each of these two functional groups in this test.

Relative Ability to Establish Monopoly Control

In the instance of engineering plastics, all the innovators studied could and did protect their innovations effectively through patents. This observation fits the general evidence regarding the high effectiveness of patents in the field of chemical inventions[9] and discussion with industry personnel shows that such protection is an important part of the commercial strategy of innovators in the field.

Recall from our earlier discussion in chapter 4 that any innovator could expect similar amounts of rent from a given innovation, given that he had perfect, costlessly enforceable property rights to it. To the extent that the patent protection available in the engineering plastics field has these characteristics, the reasoning applies here and I would expect user and manufacturer innovators to have roughly similar expectations regarding the rents they might obtain from engineering plastics innovations.

However, as was also discussed earlier, in the real world even strong patents do not provide protection that is either perfect or costlessly enforced.

*Although patents offer effective protection in this field, licensing of engineering plastics innovations is unlikely for reasons to be discussed in the text. As a consequence, independent inventors and others without significant innovation-related outputs did not seem to me to be potential appropriators of significant innovation-related rents. Suppliers were eliminated from consideration as potential innovators because the materials used in the manufacture of the plastics studied were commodity chemicals, whose suppliers did not appear well positioned to obtain benefit from innovation-related knowledge through sale of a commodity output.

Indeed, an innovator cannot realistically expect to license his patent rights to others without risk or cost.

Relative Innovation-Related Output

The innovation-related output of an engineering plastics manufacturer is the novel plastic itself. Manufacture of each of the engineering plastics studied is highly concentrated. In my sample the innovator retained a dominant share of the market for his novel product for at least several years. In 1976 Du Pont (the innovator) produced 100% of acetal homopolymer (Delrin), Celanese 100% of acetal copolymer (Celcon), General Electric 100% of modified polyphenylene oxide (Noryl), and Union Carbide 100% of polysulfone. General Electric also produced 75% of all polycarbonate (Lexan) in 1976 and Du Pont produced 57% of all polyamides and 57% of all fluoropolymers.[10]

The innovation-related output of the user of engineering plastics is the products in which these plastics are embodied. I have no data on the volume of engineering plastics consumed by individual users. However, I can report that there are literally thousands of users of each of the innovative engineering plastics studied and that no single user buys more than a small fraction of total production. (The sole exception I identified was in the early days of Lexan production when GE used as much as half of its pilot-plant production internally. This fraction quickly dropped to just a few percent when larger plants were brought on line.)

Relative Costs of Innovating

The costs for the actual innovating firms in this field were either equal to or lower than those that other would-be innovators could reasonably anticipate. All of the innovating firms had substantial ongoing research programs in organic chemistry and thus did not have the significant R & D start-up costs firms without such programs could expect. Some, but not many, users also had such programs in place.

The R & D investment that innovators expend to develop an engineering plastic is orders of magnitude higher than the R & D costs associated with other categories of innovation examined in this chapter. Du Pont's R & D and pilot plant expenditures for Delrin, for example, were $27 million in 1959 dollars.[11] Commercialization is also expensive, because engineering plastics manufacture requires special-purpose plants. Thus, the cost of the first commercial plant for Delrin was $15 million[12]; for Celcon $15 to $20 million[13]; and for Lexan $11 million.[14]

Relative Amount of Displaced Sales

Engineering plastics are intended to be substitutes for other engineering plastics or more traditional engineering materials such as metal and glass.

Potential innovators who currently produce such materials do risk displacement of sales of existing products if they innovate. However, the problem can be minimized or eliminated by proper selection of the properties of the innovative material so that it is not a substitute for the innovator's existing products.

Discussion

As mentioned above, patent protection in this field is good, but there is no reason to expect licensing to be either costless or risk-free for an innovator attempting it. As a consequence, I reason that potential innovators would expect somewhat higher rates of rent for innovation-related output produced by the innovator's own firm. Taken by itself, this fact would not create a higher rent expectation for either user or manufacturer innovators. However, important economies of scale issues tip the balance toward the manufacturer.

Major engineering plastics such as those I studied are manufactured in single-purpose, continuous-flow plants that have significant economies of scale associated with them. As an approximation, processing costs per pound in a plant sized to produce 1 million lb of plastic a year are 10 times those in a plant sized to produce 100 million lb annually.[15] Consider the impact of this factor on a user contemplating developing a new engineering plastic. Since any individual user represents only a small portion of the total demand for an engineering plastic, a user firm considering innovation could not expect to achieve attainable economies of scale by producing for in-house use only. If a user, nonetheless, built a plant sized to fill in-house demand only, it would be in a risky position: Any manufacturer that came up with a functional substitute for the user innovation and produced it in a plant sized to serve the entire market could render the user plant and material uneconomic.

In effect, therefore, both users and manufacturers in this industry are both in a position to control the rights to an innovative engineering plastic that they may develop. But only a manufacturer (or a user who becomes a manufacturer) is in a position to exploit the significant economies of scale associated with engineering plastics manufacture. Given that this is so, a manufacturer that innovates is the only functional type of firm that does not have to incur the cost and risk of licensing this type of innovation to a manufacturer. The consequent saving in licensing-related cost and risk results in a higher expectation of net innovation-related rent for an innovating manufacturer than that which an innovating user might expect.

Process Equipment Utilizing Industrial Gases and Thermoplastics: Innovation and Innovation Rents

The final two tests of the hypothesis were conducted by VanderWerf.[16] These studies were designed precisely to test the hypothesis that rent expectations and the functional sources of innovation are linked and therefore they do not require extra data or analyses to serve my purposes. As a consequence, the review I will present can be relatively brief.

Recall from chapter 3 that by the time VanderWerf began his research, he and I had the hypothesis reported on here in mind. It seemed on the basis of that hypothesis that materials suppliers might be found to innovate under the right conditions. As a consequence, VanderWerf elected to focus on categories of process machinery innovations that used large amounts of material as input *and* where an innovating supplier might hope to have some level of monopoly control over that input material. Under such circumstances it appeared possible that materials suppliers might benefit from and develop innovative process equipment that used their material—even if they did not plan to build or use the innovative equipment themselves. Thus, in the instance of these two studies, we were attempting to predict the functional source of innovation on the basis of assumptions regarding the likely functional source of highest innovation rents. As the reader will see, this experiment worked well.

The Studies

VanderWerf's first sample consisted of innovations in process machines that utilized large amounts of industrial gases as an input, whereas his second sample consisted of innovations in process machines that used large amounts of specific thermoplastics as an input. He began his research by determining, by means of discussions with industry experts, that process machine users, manufacturers, and suppliers of materials processed on the innovative machines all had some reasonable expectations of innovation-related rents. Next, he compared the levels of such benefit that these three functional categories of firm might reasonably expect.

VanderWerf estimated the benefit firms could potentially appropriate from each innovation under study by studying the actual commercial history and innovation-related behavior of users, manufacturers, suppliers, and others. By means of discussions with industry participants, he then estimated the relative appropriable benefits (rent), innovation costs, and the new business fraction (a measure that serves the same function as my displaced sales) each class of would-be innovators could reasonably expect if they had been able to accurately foresee the commercial results actually attained by the various innovations. Possible error in these estimates was compensated for by resolving ambiguity in a direction against the hypothesis under test.

Discussion

For each innovation, VanderWerf ranked four functional categories of innovator (user, manufacturer, supplier, and other) in the order of their expected

TABLE 5–2. Test of Hypothesis; The Source of Innovation Benefit and Innovation Activity Compared[a]

	(A) Industrial gas-using innovations: Predicted probability of innovation			
	Highest	*Second*	*Third*	*Lowest*
Innovator	8	4	0	0
Noninnovator	4	8	12	12
			(chi² $p < .01$)	

	(B) Thermoplastics-using innovations: Predicted probability of innovation			
	Highest	*Second*	*Third*	*Lowest*
Innovator	12	1	1	0
Noninnovator	2	13	13	14
			(chi² $p < .01$)	

[a]VanderWerf, "Explaining the Occurrence of Industrial Process Innovation by Materials Suppliers," 65–66.

level of benefit from that innovation. In the top (bottom) rows of Table 5–2(A) and 5–2(B), VanderWerf positions each firm that actually did (did not) develop each innovation in that expected benefit ranking. As can be clearly seen in Table 5–2, these two samples also strongly support the hypothesis under test.

Conclusions and Discussion

The hypothesis I set out to test was that the functional sources of innovation could be predicted on the basis of potential innovators' expectations of innovation-related rents. We now see that this hypothesis is supported in the instance of the five samples examined (Table 5–3). These test data are encouraging but clearly cannot prove the matter beyond dispute. Nevertheless, I myself find the results encouraging enough to warrant moving ahead to both further research and practical applications.

It would be interesting, for example, to use expectations of rents to predict and empirically explore functional sources of innovation in addition to the user, manufacturer, and supplier sources documented in this book. Thus, wholesale or retail distributors of innovative products, processes, or services should have high expectations of innovation-related rents under some conditions, and they probably will be found to innovate where these pertain.

I speculate that the model will be applicable to industrial products, processes, and services—a very considerable universe. It will also be quite practical in these fields: It requires data on variables that innovators and policymakers in firms may already have at hand.

TABLE 5–3. Is There a Relationship Between the Functional Source of Innovation and Reasonable Expectations of Innovation Rent?

		Number of Innovations found in sources with expected rent rank			
Innovation Type	*Relationship*	*Highest*	*2nd*	*3rd*	*4th*
Pultrusion process	Yes: $p < .02$[a]	9	1		
Tractor shovel–related	Yes: $p < .02$[a]	13	3		
Engineering plastics	Yes: $p < .2$[b] (NS)	4	1		
Industrial gas–using	Yes: $p < .01$[c]	8	4	0	0
Thermoplastics–using	Yes: $p < .01$[c]	12	1	1	0

[a]Chi[2] test. The null hypothesis used in these tests was that innovations would be found equally distributed between the two loci of highest expected rents.
[b]Binomial test (used due to very small sample size). The innovation coded 50% user and 50% manufacturer in Table 3–6 is coded conservatively with respect to the hypothesis here (i.e., coded as 100% *not* in the locus of highest expected rents).
[c]Chi[2] test. Same as note (a) except that VanderWerf was able to rank expected rents reasonably anticipatable by members of four functional loci with respect to each innovation (see Table 5–2).

However, the model will not be practicable in fields where all potential innovators do not measure the rents they expect in commensurable ways. This is so simply because the hypothesis that underlies the model requires that one compare levels of expected rents across functional groups in order to predict the functional source of innovation. And this is only possible in fields where all classes of potential innovators with a significant potential interest in an innovation use commensurable measures. Two examples will illustrate the problem.

In scientific instruments, innovating scientist-users typically work in nonprofit institutions. Usually, their research is supported by governmental agencies who distribute grants on the basis of the expected scientific value of the proposed research rather than on its expected economic value. Therefore, neither users of scientific instruments nor their employers appear to have any reason to measure expected innovation-related benefit in economic terms. Rather, acknowledgement by peers of scientific accomplishment appears to be a major innovation-related incentive for this group.[17] In contrast, scientific instrument manufacturers are profit-making firms and presumably do measure their expected innovation-related benefit in economic terms. Similarly, in the field of consumer goods, consumers are known to evaluate innovations in part in terms of psychological benefits not easily measured in economic terms.[18]

In this chapter I have been able to assess the relationship between innovation and firms' expectations of innovation-related rents only by very careful attention to the details of industry structure and behavior that form such expectations. An important next step in this work, it seems to me, is to move toward generalization by seeking out real-world principles and common strategies—successful and unsuccessful—that underlie innovators' attempts to capture such rents.[19]

The empirical work I have done to date contains clues that might lead to such an ability to generalize. For example, note that the functional source of innovation was shown in the five studies to be populated by firms expecting the highest innovation-related rents (Table 5–3). Since the hypothesis itself proposes only that innovation will be found concentrated among firms who find their expected rents attractive, this result is striking. Perhaps it signals that expectations of rent will often differ significantly between firms holding different functional relationships to a given innovation opportunity. This seems to me to be possible because at the moment I can see two general reasons why the rent expectations of potential innovators could differ significantly as a consequence of the functional relationship they hold to an innovation opportunity.

First, the abilities of firms to protect and benefit from identical innovation-related information can differ as a consequence of functional role. For example, innovating users can often protect process and process machinery innovations as trade secrets better than any other type of innovator. This is so because only users can obtain rent from their innovations while keeping them hidden within their factory walls. Innovators with any other functional relationship to an innovation such as manufacturer or supplier must sell the innovation they develop or persuade others to adopt it before they can benefit. The process of selling or persuading typically involves revealing related secret knowledge to prospective innovation adopters and, as a practical matter, usually destroys the basis for trade secrecy protection.

Also, the risk users face in developing a cost-reducing innovation for their own use may typically be lower than that facing any other functional category of innovator. This is because only users do not have to market such innovations in order to derive rent from them—their own use constitutes a source of such rent. Therefore, the risk to users engaging in an innovation process is that the completed device will not work as intended or will be obsoleted by some other innovation or event. Manufacturers and all other nonusers considering developing that same innovation, on the other hand, face these same risks plus the risk that the innovation will not be accepted in the marketplace.

A second general reason why the rent expectations of potential innovators could differ significantly as a consequence of the functional relationship they hold to an innovation opportunity has to do with industry competitive structure. Firms having user, manufacturer, and supplier relationships to a given innovation often come from different industries. These industries may have different structures, for example, the industry that will manufacture an innovation may be more concentrated than the industry that will use it. Since a firm's innovation-related output is not likely to be determined entirely on the basis of a particular innovation, we can see that expectations of rent are likely to be affected by factors such as preinnovation concentration ratios.

A better general understanding of how firms capture innovation-related rents would have implications beyond innovation. For example, consider the possible impact on current views on when and why firms specialize.

Stigler[20] hypothesizes that "vertical disintegration" will occur as a new industry grows and matures. He reasons that many functions that firms in the new industry require have increasing returns to scale. Initially, the firms in the new industry might perform such functions for themselves because specialization is limited by the extent of the market and because total demand for a particular function might not be great enough to support a specialist firm. But, as the industry grew, demand would increase and eventually it would be reasonable for firms in the industry to spin such functions off to specialist firms that could carry them out on a larger scale and thus more cheaply.

It does seem reasonable to me that Stigler's hypothesis may explain real-world behavior under circumstances in which economies of scale and considerations of production cost are very important. However, different patterns will emerge when innovation-related rents (a factor not included in the Stigler hypothesis) are important—as they often are.

Consider, for example, that users may only be able to obtain rents on innovative process machinery if they build it in-house and protect it as a trade secret. Such rents might be far more significant than any scale-related economies potentially offered by a specialist process equipment manufacturer. Anecdotal evidence exists in support of this idea. Thus: "Most world class German and Japanese manufacturing companies have large, well-staffed, very active machine shops. Much of the success of these companies is a result of the proprietary production processes that are incubated in these shops and therefore unavailable to their competitors."[21]

Notes

1. In principle, if an imitator became aware of an innovator's protected knowledge at the moment he developed it, there would be no response-time protection for the innovator: both innovator and imitator could proceed with commercialization activities in tandem. Response time is an important innovation benefit capture mechanism in reality, however, because would-be imitators seldom become aware of an innovator's knowledge at the moment he develops it. Typically, in fact, an imitator only becomes aware of a promising new product when that product is introduced to the marketplace. Until that point the innovator has been able to protect his product from the eyes of interested competitors inside his factory. After that point, if the product is easily reverse engineered and has no patent protection, only the response-time mechanism can provide the innovator with some quasi-monopoly protection from imitators.

No formal studies yet exist, but the value of response time to innovators can be reasoned to be a function of various situation-specific factors. For example, consider the effect of the length of response time divided by length of the customer purchase decision cycle. A high value of this factor favors the innovator over imitators. Consider one extreme example: a consumer fad item (very short purchase decision time) that sells in high volume for six months only. Assume that the item can be readily imitated but can only be produced economically by mass-production tooling that requires six months to build. Obviously, response time here allows the innovator to monopolize the entire market if he can supply it with his initial tooling. At another extreme is an expensive capital-equipment innovation that customers typically take two years to decide to buy, budget for, and so on—and that competitors can imitate in one year. Obviously, response time in this instance affords an innovator little protection.

2. The source of figures in this section is William G. Lionetta, Jr., "Sources of Innovation Within the Pultrusion Industry" (SM thesis, Sloan School of Management, MIT, Cambridge, Mass., 1977), chap. 2.

3. A homebuilt machine of average capacity (i.e., a machine capable of pultruding product with a cross-section of 6 in. by 7 in.) had a direct cost of at most $60,000 in 1977 (Lionetta, "Sources of Innovation Within the Pultrusion Industry," 43) versus the price of $95,000 charged for an equivalent commercial machine. Presumably the user-built machines were cheaper because the user does not incur some expenses that the machine builder must, such as selling expenses.

4. C. F. Pratten, *Economies of Scale in Manufacturing Industry* (Cambridge: Cambridge University Press, 1971), Table 17–4, p. 173.

5. The primary exception was four-wheel drive. Although it offered advantages to all users, it was a costly feature most advantageous to those operating on difficult terrain and, so, penetrated the market more slowly. The inclusion of four-wheel drive in a tractor shovel added over $1000 in direct cost per unit at the time of the innovation.

6. This estimate of operating savings is derived in the following manner. Standard industry assumptions are that the life of a tractor shovel is five years and that it will operate 2000 hr/yr. Productivity savings primarily involve savings of labor and capital. If we assume an operator was paid $1/hr plus 50% fringe and overhead, which was average at the time of the innovations (Council of Economic Advisers Annual Report 1981, in *Economic Report of the President, Transmitted to the Congress, January 1981, Together with the Annual Report of the Council of Economic Advisers* [Washington, D.C.: U.S. Government Printing Office, 1981], 21–213), an innovation that made a tractor shovel 20% more productive—a reasonable estimate for the major improvement innovations studied—would involve a savings of 20% of an operator's salary (or $600/yr) and a savings of 20% the capital cost of a machine. Since, at the time of the innovations, tractor shovel prices ranged from $5000 to $10,000/unit (or a maximum of $2000 depreciated over five years straight line), total maximum annual savings to the user in capital and labor therefore were $1100/yr/machine/innovation.

7. Glen L. Urban et al., "Market Share Rewards to Pioneering Brands: An Empirical Analysis and Strategic Implications," *Management Science* 32, no. 6 (June 1986): 645–59.

8. Pratten, *Economies of Scale in Manufacturing Industry*, Table 17–4, p. 173.

9. C. T. Taylor and Z. A. Silberston, *The Economic Impact of the Patent System: A Study of the British Experience* (Cambridge: Cambridge University Press, 1973).

10. James A. Rauch, ed., *The Kline Guide to the Plastics Industry* (Fairfield, N.J.: Charles H. Kline, 1978), Table 3–4, p. 59.

11. Herbert Solow, "Delrin: Du Pont's Challenge to Metals," *Fortune* 60, no. 2 (August 1959): 116–19.

12. Ibid.

13. Marshall Sittig, *PolyAcetyl Resins* (Houston, Tex.: Gulf Publishing Company, 1963).

14. National Academy of Sciences, *Applied Science and Technological Progress*, A

report to the Committee on Science and Astronautics, U.S. House of Representatives, GP–67–0399 (Washington, D.C.: U.S. Government Printing Office, June 1967), 37.

15. Wickam Skinner and David C. D. Rogers, *Manufacturing Policy in the Electronics Industry: A Casebook of Major Production Problems,* 3rd ed. (Homewood, Ill.: Richard D. Irwin, 1968).

16. Pieter A. VanderWerf, "Explaining the Occurrence of Industrial Process Innovation by Materials Suppliers with the Economic Benefits Realizable from Innovation" (Ph.D. diss., Sloan School of Management, MIT, Cambridge, Mass., 1984).

17. Robert K. Merton, *The Sociology of Science: Theoretical and Empirical Investigations,* ed. Norman W. Storer (Chicago: University of Chicago Press, 1973).

18. Glen L. Urban and John R. Hauser, *Design and Marketing of New Products* (Englewood Cliffs, N.J.: Prentice-Hall, 1980).

19. Success at this task will allow us to lessen the amount of detail we need and exploit the possibilities of larger data bases such as those recently developed by Keith Pavitt and F. M. Scherer. Pavitt recently examined a data base of over 2000 British innovations to begin to map the origins and flow of technology between sectors of British industry ("Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory," *Research Policy* 13, no. 6 [December 1984]: 343–73). Scherer recently generated and studied a data base on the interindustry flows of technology based on data from 443 large U.S. industrial companies (*Innovation and Growth: Schumpeterian Perspectives* [Cambridge, Mass.: MIT Press, 1984], 51).

20. George J. Stigler, *The Organization of Industry* (Homewood, Ill.: Richard D. Irwin, 1968).

21. Robert H. Hayes and Steven C. Wheelwright, *Restoring Our Competitive Edge: Competing Through Manufacturing* (New York: Wiley, 1984), 381.