3

Variations in the Functional Source of Innovation

We have seen that users sometimes innovate. But do they always? Or does the functional source of innovation vary in some manner between users, manufacturers, suppliers, and others? To be able to answer these questions, we must have data on the sources of innovation characteristic of at least a few more types of innovation. Therefore, my students and I undertook the six brief studies I will describe in this chapter.

Each of the six studies examines a different type of innovation. The first four I will review consider innovation categories chosen to match my own areas of technical knowledge and those of the graduate students participating in our project. The choice of topics for the last two studies I will review was made on a different basis, which I will spell out when discussing them.

Each study uses identical methods, so that their results are commensurable, and each is tightly focused on a single issue: What are the sources of innovation? These studies find that the functional source of innovation differs strikingly across the several types of product and process innovation I have explored.

Users as Innovators: Pultrusion

Pultrusion is a valuable process for manufacturing fiber-reinforced plastic products of constant cross-section. It is well suited to the production of high-strength composites with reinforcement material that is aligned in known directions—just what is needed for demanding structural applications such as those in aerospace vehicles and sports equipment. Although pultrusion sales at the time of the study were relatively small, they had been growing rapidly and were expected to continue to do so.[1]

The pultrusion process is performed from start to finish on a single ma-

TABLE 3–1. Pultrusion Process Machine Innovations

Basic Innovation: Original batch pultrusion process	
Major process machinery improvements	
Intermittent pultrusion process	Tractor pullers
Tunnel oven cure	Cut-off saw
Continuous pultrusion process	Radio frequency augmented cure
Tooling innovations	
Preforming tooling	Improved dies
Hollow product tooling	

chine. The process starts when reinforcing material such as fiberglass is pulled simultaneously from a number of supply rolls and into a tank containing a liquid thermoset resin such as polyester. Strands of reinforcement material emerge from the tank thoroughly wetted with resin and then pass through preforming tooling that aligns and compacts the strands into the desired cross-section. The compacted bundle of glass and liquid resin is then pulled through a heated die where the resin is cured. Next the cured product moves through pullers, which are the source of the considerable mechanical force needed to draw reinforcing material and resin through the steps just described. Finally a saw cuts the continuously formed product into sections of the desired length.

The Sample

The basic pultrusion process was developed in the late 1940s. Since that time, there have been major improvements to pultrusion process machinery and to the resins and reinforcement materials used in the pultrusion process as well. The sample (Table 3–1) focuses on pultrusion process machinery only. It contains all machinery innovations that resulted in major improvements to the pultrusion process when judged relative to the best practices obtaining at the time each innovation was first commercialized.[2]

In addition, the sample contains three tooling innovations. These are not strictly part of a general-purpose pultrusion machine. Rather, they are accessories to the machine (sometimes also called jigs or fixtures) that are designed especially to aid in the manufacture of a particular product. (The ones in the sample are each useful for a large category of pultruded product. Each is described in detail in the appendix.)

All innovations studied were very successful and spread through much of the user community in the form of user-made and/or commercially produced equipment.

Findings: The Sources of Pultrusion Equipment Innovation

As can be seen in Table 3–2, almost all significant pultrusion process machinery innovations were developed by machine users (producers of pultruded products).

TABLE 3–2. Sources of Pultrusion Process Machinery Innovations

		Innovation Developed by			
Innovation Type	*% User*	*User*	*Manufacturer*	*NA*	*Total*
Original process	100%	1	0	0	1
Major improvements	86	5	1	0	6
Tooling innovations	100	3	0	0	3
TOTAL	90	9	1	0	10

This finding follows the pattern of earlier studies, but in this case the user-innovators appear much less technically sophisticated than those we encountered earlier. Innovating users of pultrusion process equipment were emphatically not high-tech firms. They were essentially job shops making fiberglass products by pultrusion and, often, by hand-layup methods as well. (Readers who remember repairing the bodywork on their cars as teenagers will have had firsthand experience with the hand-layup process. It simply involves wetting fiberglass fabric or roving with a liquid plastic, shaping the wet material as desired, then curing the plastic.)

These user firms had no formal R & D groups and, typically, no one with formal technical training in plastics or plastics fabrication. If an order came in for a part of novel shape, the foreman on the factory floor or one of the workers would make up a mold to aid in shaping it. If the first design worked, production would commence. If not, the mold and patterns of fiberglass layup would be tinkered with until they did work acceptably. The more parts needed of a given shape, the greater the effort put into making molds and other aids to speed the layup process.

Typically, important pultrusion innovations were triggered when a user firm received a large order for a part of uniform cross-section such as hundreds of feet of one structural shape or thousands of feet of rod to be used for fiberglass fishing poles. Faced with a massive task of this sort, a creative person on the factory floor was sometimes inspired to innovate, using an innate sense of engineering design and machine parts lying around the factory. In a few instances, these efforts resulted in process equipment innovations of general value.

Manufacturers as Innovators: The Tractor Shovel

The tractor shovel is a very useful machine often used in the construction industry. Initial conversations with experts in construction led us to suspect that users would in fact be innovators in tractor shovels. Everyone had a story to tell about a construction firm that, facing an unusual challenge and a tight deadline, performed an overnight modification to some item of construction

TABLE 3–3. Sample of Tractor Shovel Innovations

Basic Innovation: Original tractor shovel	
Major improvements	
Side lift arm linkage	Double-acting hydraulic cylinders
Power steering	Four-wheel drive
Hydraulic bucket control	Torque converter
Fluid transmission coupling	Articulation
Planetary final drive	Power shift transmission
Significant special-purpose accessories	
Lenthened boom arms	Attachment coupler system
Log grapple	Steel-shod tires
Bottom dump bucket	

equipment that solved the problem and saved the day. In fact, however, tractor shovel manufacturers turned out to be the dominant source of commercially successful tractor shovel innovations.

The tractor shovel can be visualized as a four-wheeled, rubber-tired machine with a large, movable scoop mounted at the front end. It is normally used for excavation and other construction tasks as well as for the general handling of bulk materials, ranging from coal to chemicals to soybeans. Householders who live in states with severe winters may have a clear visual image of tractor shovels: They are typically the machines that dig out roads after ordinary trucks have been halted by deep snow.

Tractor shovels are built in many sizes. Today, one can find large tractor shovels with massive, 20 cu-yd scoops working in open-pit mines loading ore into trucks; one can also find small tractor shovels working in warehouses shifting various materials from place to place 1 cu yd at a time. Approximately 41,000 tractor shovels of all sizes were manufactured in the United States in 1980, with an aggregate value of $1.5 billion dollars.[3]

The Sample

The basic tractor shovel was developed in 1939. The sample consists of that basic innovation plus all significant improvements to the tractor shovel commercialized prior to 1970.[4] The major improvements category in Table 3–3 consists of innovations that are installed in virtually all tractor shovels and that are of value to essentially all users. For example, articulation, an innovation that hinges the tractor shovel in the middle and greatly improves steering and traction, is valuable to essentially all users and is now incorporated in almost all tractor shovels. In contrast, the special-purpose accessories listed are innovations that are only of value in some specialized tasks. Thus, the lengthened boom arms are used primarily by those who load high-sided trucks, whereas the log grapples are primarily used by lumber companies in their logging operations. Of course, many other special-purpose accessories exist, ranging from asphalt pavers to snow blowers. The five chosen for study serve relatively large user groups.

TABLE 3–4. Sources of Tractor Shovel Innovations

	Innovation Developed by					
Innovation Type	*% Manu-facturer*	*Manu-facturer*	*Allied Manu-facturer*	*User*	*NA*	*Total*
Basic shovel	100%	1	0	0	0	1
Major improvements	100	10	0	0	0	10
Major accessories	80	2	2	1	0	5
TOTAL	94	13	2	1	0	16

Findings: The Sources of Tractor Shovel Innovation

As can clearly be seen in Table 3–4, almost all of the innovations studied were developed by tractor shovel manufacturers. In two instances these innovating manufacturers were what is known in the trade as allied manufacturers or allied vendors. These are firms that make a specialty of manufacturing attachments for tractor shovels and similar machines. Sometimes they are simply equipment dealers who run a small manufacturing operation on the side. (Tractor shovel manufacturers will often cooperate with such firms because the accessories they build enhance the utility of the basic tractor shovel by tailoring it to various specialized users.)

Only one innovation studied was completely developed by a user: the attachment coupler system, which was developed by a farmer for use on his farm. But users did some innovation work related to some of the other special attachments studied (see the appendix). For example, before steel-shod tires were developed by a manufacturer (they are used to protect tractor shovel tires from cuts), some tractor shovel users were protecting the tires of their machines by wrapping them with heavy steel chains.

Manufacturers as Innovators: Engineering Thermoplastics

Engineering plastics are triumphs of organic chemistry and most were created after World War II. The term engineering plastic simply means a plastic that can be used in demanding engineering applications. Examples of such applications are parts placed under mechanical stress or mechanical shock (e.g., gears or mallet heads) or parts placed in demanding temperatures and/or chemical environments (e.g., parts used in automobile engines). Prior to the advent of engineering plastics, such parts could only have been made of a material like metal or glass. Now they can often be made better and more cheaply from plastic.

All engineering plastics are produced in low volume but with a relatively high selling price when judged against such bulk plastics as polyethylene. In 1976

TABLE 3–5: Engineering Thermoplastics Sample

Innovation (Trade Name)	*U.S. Consumption for Structural Uses*[a] *Millions of Pounds*	*Millions of Dollars*
Polycarbonate (Lexan)	150	143
Acetal homopolymer (Delrin)	20	15
Acetal copolymer (Celcon)	60	47
Polysulfone	12	22
Modified polyphenylene oxide (Noryl)	9	90

[a] 1976 data (James A. Rauch, ed., *The Kline Guide to the Plastics Industry* [Fairfield, N.J.: Charles H. Kline, 1978], 55–58 and Table 3–11).

engineering plastics counted for about 2% by volume of all plastics produced but accounted for about 6% of the total value of all plastics produced.[5]

The Sample

The sample of engineering plastics innovations consists of all commercially successful engineering thermoplastic monomers* introduced to the market after 1955 that achieved sales of at least 10 million lbs annually by 1975. (This definition of commercial success was suggested by plastics manufacturer interviewees.) The five engineering thermoplastics innovations that met these sample selection criteria are identified in Table 3–5.

Findings: The Sources of Engineering Thermoplastics Innovation

As can be seen in Table 3–6, "four and one-half" of the five engineering plastics in the sample were developed by plastics manufacturers. Thus, this very small sample shows a strong manufacturer-as-innovator pattern.

The innovation coded as 50% user developed and 50% manufacturer developed was polycarbonate resin (Lexan), which was developed by General Electric in 1960. GE is both a major producer and a major user of polycarbonate. In the period immediately following commercialization when production capacity was low relative to that of today, GE personnel estimate that as much as 50% of GE polycarbonate production was consumed internally. Currently, GE consumes only a small percentage of annual polycarbonate production. (See the appendix for further details.)

Happily, cases such as GE, where a single firm holds more than one functional role with respect to an innovation, are very rare in our samples. When

*Engineering plastics are characterized as thermoset or thermoplastic resins, with thermoplastics being more commonly used. The two types of plastics are distinguished by the way in which they cure into usable plastic parts. Thermoset plastic forms molecular bonds when molded under high temperature and pressure, and the process is irreversible. Thermoplastics, in contrast, simply "freeze" into a shape on cooling, a process that can be reversed by the simple application of sufficient heat. Monomers are the basic molecular building blocks of plastics.

TABLE 3–6. Sources of Engineering Thermoplastics Innovations

	Innovation Developed by				
Innovation Type	*%Manufacturer*	*Manufacturer*	*User*	*NA*	*Total*
Engineering plastics	90%	4.5	0.5	0	5

dual or multiple roles are held by the same innovating firm or individual, severe coding problems emerge. Often, one cannot determine which role the innovator was "really" motivated by during the development work.

Manufacturers as Innovators: Plastics Additives

Plastics additives are used to modify the properties of a basic polymer in desired ways. An enormous number of additives exist, and they are generally categorized according to the function they perform. Thus, there are coloring agents, flame retardants, fungicides, filling materials, reinforcing materials, and so on. Each of these categories contains a number of materials of varying properties to serve the specified function.

I decided to examine the sources of innovation in two categories of plastics additives: plasticizers and ultraviolet (UV) stabilizers. These two additive types address markets of very different size. (In 1983 more than 600,000 metric tons of plasticizers of all types were sold.[6] In that same year, approximately 2300 metric tons of UV stabilizers of all types were sold.[7] I do not have data on dollar volumes in these two categories: Ultraviolet stabilizer prices are typically somewhat higher than plasticizer prices, however.)

Plasticizers are materials that are incorporated into plastics to improve properties such as workability and flexibility. Without plasticizers, plastics such as polyvinyl chloride (PVC) would be hard and brittle. Ultraviolet stabilizers are added to plastics to protect them from the effect of ultraviolet light such as that present in sunlight. Without such protection, susceptible plastics would quickly discolor, become brittle, or show other undesirable changes.

The Sample

The sample of plasticizer and ultraviolet stabilizer innovations included all commercialized compounds that met four criteria. First, the additive was appropriate for use with at least one of the four largest plastics in commercial use: polyethylene, polyvinyl chloride, polystyrene, and polypropylene. Second, the additive must have been first commercialized after the World War II—a requirement added under the assumption that data on more recent innovations would be of high quality. Third, the additive must have been commercially successful, that is, it had to have been sold on the open market and regarded as a successful product by expert interviewees in the additives

TABLE 3–7. Sample of Plastics Additives Innovations

Plasticizers	
Butyl benzyl phthalate	Tri melitates
2 ethyl hexyl di phenyl phosphate	Tri isopropyl phenyl phosphates
Citroflex type	Epoxidized soybean oils
Di N undecyl phthalate	Long chain aliphatic polyesters
Ultraviolet (UV) stablizers	
2:4 dihydroxy benzophenone	2:4 di t butyl phenyl 3:5 di t butyl phenyl 4 hydroxy benzoates
Ethyl-2-cyano 3:3 diphenylacrylate	Zinc oxide and zinc diethyl dithio carbamates
2 hydroxy 4 dodecyloxy benzophenone	Benzotriozoles
Nickel complexes	
P methoxy benzylidene malonic acid dimethyl esters	

industry. Fourth, the additive was included only if it represented an improvement over previously commercialized additives on a property of importance to users other than cost, for example, decreased toxicity or increased ease of use.

The sample of plasticizers and ultraviolet stabilizers selected as meeting these criteria is identified in Table 3–7.

Findings: The Sources of Plastics Additives Innovation

As can be seen in Table 3–8, more than 90% of the plastics additives innovations studied were developed by firms that manufactured them. (Interestingly, two UV stabilizer innovations coded as manufacturer developed showed a pattern I had not found before: A single manufacturer did not develop the innovation on its own. Instead, an association of manufacturers funded the required R & D work at a private research firm.)

Suppliers as Innovators

Up to this point in the research on the functional sources of innovation, my students and I had conducted six studies in total and had only observed innovation by users and/or manufacturers. But experience gained in these studies was leading me to speculate as to the *cause* of the striking variations in the functional source of innovation that we had been observing.

I will discuss this matter in the next chapter. For present purposes, however, let me just say my speculation was that innovation appeared to be "caused" by potential innovators' relative preinnovation expectations of innovation-related benefit. And, therefore, it seemed to me that innovation in any number of functional loci should exist, given only the proper level and distribution of benefit expectations.

So, Pieter VanderWerf (Ph.D. candidate) and I set out deliberately to find

TABLE 3–8. Sources of Plastics Additives Innovations

	Innovation Developed by					
Additive Type	*%Manufacturer*	*User*	*Manufacturer*	*Supplier*	*NA*	*Total*
Plasticizers	100%	0	5	0	3	8
UV stabilizers	86	1	6	0	1	8
TOTAL	92	1	11	0	4	16

innovation in a third functional locus, suppliers. (Suppliers are firms or individuals whose relationship to an innovation is that of supplying components or materials required in the innovation's manufacture or use.) It seemed reasonable in a rough way that suppliers might develop an innovation that they did not expect to use or sell if that innovation would result in a large increase in demand for something they *did* want to sell. (Thus, gas utilities might develop novel gas appliances and give the designs away to appliance manufacturers, hoping to capture rents from increased gas sales, rather than from making or using the innovative appliance itself.) Based on this logic, we looked for innovation categories that might contain supplier innovation by looking for processes using a great deal of relatively expensive material or components as an input.

Three categories of innovation seemed likely candidates for supplier innovation on the basis of a preliminary inspection, and VanderWerf examined all of them. As the reader will see, all three showed supplier innovation as the hypothesis would predict.

Supplier/Manufacturers as Innovators: Wire Termination Equipment

In a first study, VanderWerf[8] explored the source of innovations in process machines used in electrical wire and cable termination. The idea leading to this focus was simply that many connector designs are unique to particular connector suppliers. Thus, connector suppliers might have a strong incentive to develop machines that would make it more economical for users to apply their products.

Two types of wire termination machines were examined: those that simply cut a wire to length and strip the insulation from its ends; those that cut the wire and attach some sort of connector to one or both ends. Machines used for these purposes range from simple and inexpensive hand tools to complex machines costing as much as $100,000.

Some firms that manufacture wire and cable preparation process machines are equipment manufacturers only. Others manufacture equipment *and* the electrical terminal or connector supply items that the machinery applies to electrical wires. These latter firms have both a manufacturer and a supplier relationship to the process machinery innovations selected for study.

TABLE 3–9. VanderWerf Sample of Innovations in Wire Termination Equipment[a]

Wire type: Single-insulated (hookup) wire

Equipment function: Cutting and stripping

INNOVATIONS

- Automatic cut-and-strip machine
- Linear feed cut-and-strip machine

Equipment function: Nickless stripping

INNOVATIONS

- Thermal stripper
- Die-type hand stripper
- Semiautomatic die-type stripper

Equipment function: Attachment of terminals

INNOVATIONS

- Automatic lead-making machine
- Power crimp bench press
- Strip-fed crimp press

Wire type: Bundled single-insulated wires

Equipment function: Wire stripping

INNOVATIONS

- Rotary stripper

Equipment function: Attachment of terminals

INNOVATIONS

- Stripper-crimper
- Heat shrink-sleeve assembly racks (for soldered connectors)
- Crimp connector assembly machine
- Semiautomatic insulation-displacement terminator
- Automatic insulation-displacement harness maker

Wire type: Ribbon cable

Equipment function: Cutting and stripping

INNOVATIONS

- Automatic ribbon cable cutter
- Automatic ribbon cable cut-and-strip machine

Equipment function: Connector attachment

INNOVATIONS

- Pneumatic ribbon cable press
- Semiautomatic ribbon cable terminator
- Automatic ribbon cable harness maker

Wire type: Flat conductor cable

Equipment function: Attachment of cable terminals

INNOVATIONS

- Crimp stitcher

[a]VanderWerf, "Parts Suppliers as Innovators in Wire Termination Equipment."

The Sample

Different types of wire termination machines are needed to process different types of wire. VanderWerf focused on the machines used to prepare four

TABLE 3–10. Sources of Innovation in Wire Termination Equipment[a]

	Innovation Developed by					
Innovation Type	*%Supplier*	*Supplier*[b]	*User*	*Manufacturer*	*NA*	*TOTAL*
Machines that *do not* attach terminals or connectors	0%	0	1.5[c]	4.5[c]	2	8
Machines that *do* attach terminals or connectors	83	10	0.5[c]	1.5[c]	0	12
TOTAL	56	10	2	6	2	20

[a]VanderWerf, "Parts Suppliers as Innovators in Wire Termination Equipment."
[b]Innovating suppliers were found among connector manufacturers only, not wire manufacturers, except in the case of ribbon cable innovators when both connectors and cable were supplied by innovating firms.
[c]One innovation in this category was developed jointly by a user and a manufacturer, and attributed 50% to each.

types of wire frequently used in electronics equipment: single-strand hookup wire, multiwire round cable, ribbon cable, and flat conductor cable. He then identified an innovation sample that consisted of the first special-purpose equipment used to cut and strip and/or attach connectors to each type of wire as well as the major improvements to this equipment commercialized over the years.[9] This sample is shown in Table 3–9.

Findings

There are firms that specialize in manufacturing wire termination machinery. And, as can be seen from Table 3–10, VanderWerf found that these machine builders were the developers of almost all process machine innovations that did not involve attaching a connector to a wire.

In sharp contrast, almost all of the innovative machines that did attach connectors as part of their function were not developed by these machinery specialists. Rather, they were developed (and manufactured) by the major connector suppliers. We will be able to suggest an explanation for this interesting contrast later when we consider the causes of the variations we have observed in the functional sources of innovation.

Suppliers as Innovators: Process Equipment Utilizing Industrial Gases and Thermoplastics

In a second study VanderWerf[10] examined two additional types of process machinery for evidence of supplier innovation: (1) process machinery that used a large amount of an industrial gas such as oxygen or nitrogen as an input and (2) process machinery that used a large amount of thermoplastic resin as

TABLE 3–11. Sample of Industrial Gas-using Innovations[a]

Basic innovation	Related major improvement
Basic oxygen process	Mixed gas blowing
Detonation gun coating	Electrical sequencing
Nitrogen heat treating	Oxygen probe control
Cryogenic food freezing	Conveyorized freezer
Pyrogenic oxidation	Direct digital control
Argon–oxygen decarburization	Argon–oxygen nitrogen decarburization

[a]VanderWerf, "Explaining the Occurrence of Industrial Process Innovation by Materials Suppliers," Table 5–4, p. 46.

an input. In each of these areas, it seemed reasonable on economic grounds that materials suppliers might develop innovative process machines they did not want to manufacture or use, instead, hoping to capture rents from sales of materials used in the process.

The Samples

For each of the two process areas he would study, VanderWerf chose a sample design consisting of a number of innovation pairs: a major process innovation and a related important improvement. He chose his sample of industrial gas–using process innovations by, first, identifying the 6 industrial gases with the highest U.S. production volume in 1978. Next, he asked experts to identify the single process innovation introduced after World War II that now used the highest volume of each of these 6 industrial gases. (The sample was restricted to post-World War II innovations so that one could collect innovation history data from individuals with a firsthand knowledge of innovation events.) Finally, the single most important improvement to each of these 6 "basic" innovations was also identified by discussions with experts. These were included in the sample as related major improvements. The 12 innovations identified in this way are shown in Table 3–11.

VanderWerf chose a sample of 7 pairs of thermoplastics-using process innovations by a similar procedure. First, the 6 thermoplastics with the greatest U.S. production volumes at the time of the study were identified. Then, the major forming processes used with each as reported by *Modern Plastics* in 1983 were examined, and 7 were found to have been developed post-World War II. These 7 basic innovations were included in the sample. Finally, experts were asked to identify the single most important improvement that had been developed for each innovation up to the present day, and these were included in the sample as related major improvement innovations. These 14 innovations are shown in Table 3–12.

Findings

Careful study showed that supplier innovation did indeed exist. As can be seen in Table 3–13, about one third of both innovation samples had been

TABLE 3–12. Sample of Thermoplastic-using Innovations[a]

Basic innovation	**Related major improvement**
Slush molding	Water bath gelling
Rotational molding	Three-arm RM machine
Direct foam extrusion	Tandem screw extruder
Foam casting	Continuous belt casting
Bead expansion molding	Automatic molding press
Foam closed molding	Cold mold process
Reaction-injection molding	Self-clearing RIM head

[a]VanderWerf, "Explaining the Occurrence of Industrial Process Innovation by Materials Suppliers," Table 5–2, p. 44.

developed by materials suppliers. These firms had only a materials-supply link to these process innovations: They did not themselves either manufacture or use the machinery they had developed.

Additional Evidence on Nonmanufacturer Innovation

The six studies I have just reviewed will be useful when we attempt to understand the causes of variations in the functional sources of innovation, because they have determined the *proportion* of innovations that fall into various loci. Other studies exist, however, to support the *fact* of nonmanufacturer innovation.

Corey[11] provides several case histories of important materials-using innovations developed by materials suppliers. Cases of supplier innovation Corey explores range from the development of vinyl floor tile to the development of fiber-reinforced plastic water piping.

Recently, Shaw[12] examined the role of the user in the development of 34 medical equipment innovations commercialized by British firms. He found that 53% of these were initially developed and proven in use by users. He also found users often aided manufacturers wishing to commercialize their innovations in this field, sometimes helping to design, test, and even market the commercial version.

TABLE 3–13. Sources of Materials-utilizing Process Innovations[a]

	Innovation Developed by					
Material Type	*%Supplier*	*Supplier*	*User*	*Manufacturer*	*Other*	*Total*
Industrial gas	33%	4	5	2	1	12
Thermoplastic	36	5	6	2	1	14
TOTAL	35	9	11	4	2	26

[a]Vanderwerf, "Explaining the Occurrence of Industrial Process Innovation by Materials Suppliers," Tables 8–1, p. 57, and 8–2, p. 58.

Everett M. Rogers and his colleagues explored the diffusion of several innovations used in the public sector and observed that the version initially diffused was often modified by its users. In a study of 10 Dial-a-Ride operations (Dial-a-Ride is a form of shared taxi service), Rice and Rogers[13] report 77 modifications to the original concept in management, technology, or operation (service provided) by adopting users. A similar pattern of user modifications was found by Rogers, Eveland, and Klepper[14] in a study of the diffusion and adoption of GBF/DIME—an information-processing tool developed by the U.S. Census Bureau—among regional and local governments.

Notes

1. Stephen H. Pickens, "Pultrusion—The Accent on the Long Pull," *Plastics Engineering* 31, no. 7 (July 1975): 16–21.

2. Candidate innovations for inclusion in the sample were obtained from a group of experts working for both pultrusion process users and equipment firms. These experts were identified by a two-step process. First, individuals whose names were frequently cited in the technical literature on pultrusion were contacted. Second, the views of these individuals were sought as to the identity of experts in the pultrusion process who had a broad knowledge of the field from its inception to recent times. Individuals so identified (13 in all) were then contacted and asked to identify those innovations that would meet, in their view, the sample selection criteria stated in the text.

The experts polled regarding significant innovations in pultrusion were in substantial agreement with all except the first two innovations listed in Table 3–1. The dissenting experts felt that "true" pultrusion is a continuous process and that this characteristic was not achieved until 1948 with the third innovation listed in Table 3–1. In contrast, the view of other experts and (ultimately) of the author was that these two innovations displayed enough other pultrusion-like characteristics to qualify for inclusion. (See the appendix for further details on these and all other pultrusion innovations studied.) In any case, the decision to include these two innovations did not affect the findings with respect to the sources of innovation in pultrusion.

3. U.S. Department of Commerce, Bureau of the Census, *1977 Census of Manufactures*, vol. 2, *Industry Statistics* (Washington, D.C.: U.S. Government Printing Office, 1980).

4. Candidate innovations for the tractor shovel sample were identified by a two-step method. First, *Engineering News Record*, a widely read trade journal in the civil engineering field, was scanned for the period 1939–74 for mentions of possible candidate innovations. A list of possibilities developed by this method was then discussed with personnel who had a long history in the tractor shovel industry and who appeared to be both expert and knowledgeable as tractor shovel users or manufacturer personnel. Extensive discussion and numerous deletions from, and additions to, the initial list allowed us to reach a consensus on the innovation sample identified in Table 3–3.

5. James A. Rauch, ed., *The Kline Guide to the Plastics Industry* (Fairfield, N.J.: Charles H. Kline, 1978), 54.

6. "Chemicals & Additives '83: A *Modern Plastics* Special Report," *Modern Plastics* 60, no. 9 (September 1983): 69.

7. Ibid., 60.

8. Pieter VanderWerf, "Parts Suppliers as Innovators in Wire Termination Equip-

ment" (MIT Sloan School of Management Working Paper No. 1289–82) (Cambridge, Mass., March 1982). (Forthcoming in *Research Policy*, entitled "Supplier Innovation in Electronic Wire and Cable Preparation Equipment.")

9. The four wire types studied had annual sales ranging from $35 million to $250 million per year. Major improvements identified by industry experts all were found to provide users with at least a one and two-thirds improvement in labor productivity relative to best preceding practice extant at the time of their commercialization.

10. 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).

11. E. Raymond Corey, *The Development of Markets for New Materials: A Study of Building New End-Product Markets for Aluminum, Fibrous Glass, and the Plastics* (Boston: Division of Research, Graduate School of Business Administration, Harvard University, 1956).

12. Brian Shaw, "The Role of the Interaction Between the User and the Manufacturer in Medical Equipment Innovation," *R & D Management* 15, no. 4 (October 1985): 283–92.

13. Ronald E. Rice and Everett M. Rogers, "Reinvention in the Innovation Process," *Knowledge: Creation, Diffusion, Utilization* 1, no. 4 (June 1980): 499–514.

14. Everett M. Rogers, J. D. Eveland, and Constance A. Klepper, "The Diffusion and Adoption of GBF/DIME Among Regional and Local Governments" (Working Paper, Institute for Communications Research, Stanford University, Stanford, Calif.; paper presented at the Urban and Regional Information Systems Association, Atlanta, Ga., 31 August 1976).