FACTORS INFLUENCING THE LOCUS
OF INNOVATION ACTIVITY LEADING
TO SCIENTIFIC INSTRUMENT
AND PLASTICS INNOVATIONS

by

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Alan J. Berger

Submitted to the Alfred P. Sloan School of Management on May 9, 1975, in partial fulfillment of the requirements for the degree of Master of Science.

ABSTRACT

The importance of the locus of innovation activity as an innovation process variable has recently been explored in studies conducted by von Hippel at M.I.T. The M.I.T. investigation has shown, through an analysis of innovation in the scientific instrument industry, that the major share of development activity need not always take place within the commercializing firm. It was found that innovation process activity is strongly dominated by users in the field of scientific instruments.

In an effort to determine factors which may influence the locus of innovation, the present study explores an industry, engineering thermoplastics, which has been found to exhibit a locus different from that found in the von Hippel investigation.

Based on the assumption that the locus of innovation is dependent upon the characteristics of underlying factors in the environments of the innovating industries, a comparison was made, between the scientific instrument and engineering thermoplastics industries, seeking factors which differ in characteristics. This comparison indicates that a dramatic difference exists in the materials and equipment cost required in user innovation. The impact of this factor upon the locus of innovation activity in the scientific instrument industry is then explored.

Thesis Advisor: Eric von Hippel
Title: Assistant Professor of Management
ACKNOWLEDGMENTS

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The Perkin-Elmer Corporation and the Natick Research Laboratory of the U.S. Army Quartermaster Corp very generously made available their libraries which greatly aided this study.

A very special word of appreciation is extended to all of those involved in the research project into innovation activity at the Sloan School of Management at M.I.T. Without Professor Eric von Hippel's intellectual stimulation, advice, and support this thesis could not have been completed. Any errors in the work are the sole responsibility of the author.
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Chapter I

Introduction

Recent studies into the industrial good innovation process, conducted by von Hippel at M.I.T., have revealed the importance of the "locus of innovation activity" as an innovation process variable. It has been demonstrated, through an investigation of innovations in the scientific instrument industry, that the dominant share of innovation process activity does not always take place within the commercializing firm. This finding differs with what has been the conventional wisdom in the field and suggests that this locus varies among industries. The variance of this locus has broad implications for those interested in stimulating industrial good innovation through funding and for those researchers interested in describing the innovation process. The purpose of this paper is to establish the existence of a locus of innovation activity different from that found in the scientific instrument industry and to offer speculation regarding possible factors that influence the variable.

It is important at the outset to make clear exactly what is meant by the notion of a "locus of innovation activity". The concept views the innovation process as a series of discrete stages or roles (see framework following) played out by various actors (i.e. users, materials suppliers, manufacturers). The following is a schematic representation of the stages in the process. Here the innovation process is viewed as proceeding in six discrete and sequential stages beginning with a "Recognition" stage and ending in the commercial introduction of a new product into the market place, "Utilization & Diffusion:"
Figure 1

STAGES IN THE INNOVATION PROCESS

<table>
<thead>
<tr>
<th>Innovation Process Stage</th>
<th>Recognition</th>
<th>Idea</th>
<th>Problem</th>
<th>Solution</th>
<th>Utilization &amp; Diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Capsule Stage Descriptions)</td>
<td>(Recognition of technological and demand feasibility of an innovation and potential demand for it)</td>
<td>(Fusion of feasibility and desirability perceptions into a design concept)</td>
<td>(R &amp; D activity)</td>
<td>(Invention)</td>
<td>Pre-Commercial</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Commercial</td>
</tr>
</tbody>
</table>

Commercial".

After completion of the process, the actor, who has taken on the greatest number of roles, is described as dominant. Within his sphere is the "locus" of innovation activity. In order to give the reader a clearer understanding of this concept, examples of innovations, taken from the von Hippel study of the scientific instrument industry, with different loci of activity, are presented below.

Case 1: Manufacturer-dominated Innovation Process

Well-Regulated High-Voltage Power Supplies for Transmission Electron Microscopes

The first electron microscope and the first few pre-commercial replications used batteries connected in series to supply the high voltages they required. The major inconvenience associated with this solution can be readily imagined by the reader when we note that voltages on the order of 80,000 volts were required - and that nearly 40,000 single cell batteries must be connected in series to provide this. A visitor to the laboratory of Marton, an early and outstanding experimenter in electron microscopy, recalls an entire room filled with batteries on floor-to-ceiling racks with a full-time
technician employed to maintain them. An elaborate safety inter-lock system was in operation to insure that no one would walk in, touch something electrically live and depart this mortal sphere. Floating over all was the strong stench of the sulfuric acid contents of the batteries. Clearly, not a happy solution to the high voltage problem.

The first commercial electron microscope, built by Siemens of Germany in 1939, substituted a 'power supply' for the batteries but could not make its output voltage as constant as could be done with batteries. This was a major problem because high stability in the high voltage supply was a well-known prerequisite for achieving high resolution with an electron microscope.

When RCA decided to build an electron microscope, an RCA electrical engineer, Jack Vance, undertook to build a highly stable power supply and by several inventive means, achieved a stability almost good enough to eliminate voltage stability as a constraint on high resolution microscope performance. This innovative power supply was commercialized in 1941 in RCA's first production microscope.

In this case, it is clear that the manufacturer played the dominant role in the innovation process. Five of the six steps in the process, from "Idea Formulation" through "Utilization & Diffusion", were completed by him. (It is not clear in this case that the manufacturer is totally responsible for the recognition of the demand potential for the innovation. This demand potential may have been transferred to the manufacturer from users of the instrument.)

By contrast, below, the user completed the first five stages of the process. The manufacturer was responsible for only the last stage, "Utilization & Diffusion: Commercial".

Case 2: User-dominated Innovation Process
Spinning of a Nuclear Magnetic Resonance Sample

Samples placed in a nuclear magnetic resonance spectrometer (NMR) are subjected to a strong magnetic field. From a theoretical understanding of the NMR phenomenon, it was known by both NMR users and personnel of the only manufacturer of NMR equipment at that time (Varian, Incorporated; Palo Alto, Ca.) that increased homogeneity of that magnetic field would allow NMR equipment to produce
more detailed spectra. Felix Bloch, a professor at Stanford University and the original discoverer of the NMR phenomena, suggested that one could improve the effective homogeneity of the field by rapidly spinning the sample in the field, thus, 'averaging out' some inhomogeneities. Two students of Bloch's, W. A. Anderson and J. T. Arnold, built a prototype spinner and experimentally demonstrated the predicted result. Both Bloch's suggestion and Anderson and Arnold's verification were published in Physical Review, April, 1954.

Varian engineers went to Bloch's lab, examined the prototype sample spinner, developed a commercial model and introduced it into the market by December of 1954. The connection between Bloch and Varian was so good and Varian's commercialization of the improvement so rapid, there was little time for other users to build homebuilt spinners prior to that commercialization.

When a large proportion of the innovations within a given industry are dominated by a particular actor, the innovation process in that industry is described as "actor-dominated" (e.g. "user-dominated", "manufacturer-dominated", etc.) For example, von Hippel's investigation of innovations in the scientific instrument industry revealed a striking pattern of "user" dominance. The magnitude of this pattern is shown in the following table taken from the study. Here, 31% of those major improvement innovations studied were dominated by users.

It is clear from these findings that the locus of innovation activity can vary within a given industry. It has also been suggested that this locus may vary among industries. The present study, in an effort to understand more about this variable, will isolate an industry displaying a pattern different from that found in scientific instrumentation. After establishing the existence of such a constrasting locus, speculation will then be made regarding possible factors which influence the locus.

Resin development in the plastics industry was chosen as an area of investigation for the isolation of a different locus of innovation activity. The study and its findings will be presented in Chapter II. Chapter
Table 1

USER-DOMINANT LOCUS OF INNOVATION ACTIVITY:

SCIENTIFIC INSTRUMENTS

<table>
<thead>
<tr>
<th>Major Improvement Innovations Affecting</th>
<th>% User Dominated</th>
<th>User</th>
<th>Manufacturer</th>
<th>NA</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Chromatography (GC)</td>
<td>82%</td>
<td>9</td>
<td>2</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance (NMR)</td>
<td>79%</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Ultraviolet Spectrophotometry (UV)</td>
<td>100%</td>
<td>4</td>
<td>0</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Transmission Electron Microscope (TEM)</td>
<td>79%</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>81%</strong></td>
<td><strong>35</strong></td>
<td><strong>8</strong></td>
<td><strong>3</strong></td>
<td><strong>46</strong></td>
</tr>
</tbody>
</table>

* We define the process leading to an ultimately commercialized innovation as 'user-dominated' only if a user performed all of the following innovation-related tasks prior to commercial manufacture of the device: invention, reduction to practice, first field use, publication of detailed experimental methods used and results obtained. The data indicates that when a user does one of these tasks, he tends to carry out the entire set. Where he fails to carry out any one of them, however, we take a conservative stand relative to the user-dominant pattern we are exploring and code that case as manufacturer-dominated.

III will deal with an examination of the forces underlying the process of innovation in thermoplastics and scientific instruments in a speculative attempt to uncover possible reasons for the difference between them. The speculation will be continued in Chapter IV, in an effort to outline the interaction of factors influencing the variable.
Chapter II
The Plastics Study

2.1 The Sample

The plastics industry was chosen as an area of investigation because anecdotal information suggested that a large proportion of innovation activity in this industry was carried out by the resin manufacturers. The results of a study of the innovation process here, it was hoped, would contrast with the results found in the field of scientific instruments.

Because the plastics industry embraces many types of materials such as films, rubbers, foams, etc. and because previous work has shown that characteristic patterns in the innovation process can vary as a function of the type of good involved, it was decided to focus only on a portion of it. One first step in this direction was to decide to limit the investigation to the so-called engineering thermoplastics. *

Preliminary investigation into engineering thermoplastics was conducted through literature search and interviews with polymer chemists, and resin producers and users. The investigation revealed that innovation in the basic material can occur in essentially three broad areas: entirely new resins can be developed; two or more basic resins can be

*An "engineering" plastic is broadly defined as any plastic material which is primarily used as a substitute for metal. The metals replaced by such materials find application in such areas as housings for electrical appliances, and under-hood use in automobiles. The word "thermoplastic", refers to the material's reprocessability. Sufficient heating melts the material and thus allows for refabrication. This class of plastics is distinguished from thermosets which cannot be reprocessed because of molecular cross-linking.
compounded, forming either a chemical or mechanical bond; and additives can be used to enhance the properties of a given plastic.* Again, on an arbitrary basis, it was decided to limit the current investigation to an exploration of the process of innovation in the development of new resins. Here either a new monomer, the basic building block of a plastic, is synthesized or a new molecular configuration is developed for an already-existing monomer. Both the synthesis and the change in molecular configuration can yield new plastics with unique sets of properties.

The sample of engineering thermoplastic resin innovations ultimately selected for study was further constrained by the application of three additional criteria:

1. The plastic must necessarily have been developed within the United States,
2. The plastic must have been commercialized within the past twenty years,
3. The plastic must have been commercially successful.

The first two criteria were established simply to aid the research process; language barriers and the sheer distance of potential information sources, greatly hindering the research effort, prevented the inclusion of plastics developed outside of the United States. Because it was felt that the input of key individuals (those that had been instru-

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* Additives, here include not only chemicals such as bacteriostats but also reinforcing materials such as glass fibers.
mental in the development and commercialization of the plastics) would be lost if the sample included basic resins commercialized too far back in time, the twenty year parameter was arbitrarily set. Since almost all of the major developments in this family of resins took place in the United States, the sample size was unaffected by the first criterion. Only one plastic, nylon, (developed and commercialized by DuPont in the 1930s), was eliminated from the sample due to its not having satisfied the second criterion.

Commercial success of the plastic, the third criterion, was defined as the continued production and offering for sale of a resin from the time of its commercialization until the present day, and a production volume of at least ten million pounds per year during the past year. Expert opinion guided the establishment of this production figure as a sample selection parameter. A consensus among experts (here the opinions of resin producers and academic consultants to the plastics industry were sought), revealed that resins produced in amounts less than ten million pounds per year are considered relatively insignificant by industry standards. Several engineering thermoplastic resins were not included in the sample due to the requirements of this additional selection parameter.

The sample of engineering thermoplastic resin innovations available for study after the application of the above criteria consists of:

**Acetal Homopolymer**

*General Electric in the U.S. and Farbenfabriken Bayer in Germany, independently developed polycarbonate resins in the 1950s. The plastic was commercially introduced by both companies at approximately the same time.*
2.2 Data Collection Methods

Data was sought in four major areas:

1. Nature of the innovation—a description of the properties of the plastic and its functional significance for the user;

2. First commercializing firm's contribution to the innovation;

3. Innovation-related inputs (including both technological and need inputs) transferred to the first commercializer;

4. The nature of, reason for, and focus of any innovation-related, pre-commercial work done outside of the commercializing firm and later transferred to it.

Data sources included industry trade journals, scientific articles, and both in-person and telephone interviews. Whenever possible, those individuals instrumental in the development of a plastic (including corporate managers, research and development scientists, and marketing managers) were interviewed. The information for each innovation was written up on data sheets, called "keys", subdivided into the four ma-
jor headings described above. If the first commercializer of a given plastic was the sole contributor* to the innovation, (this was the case with all of the plastics studied), headings 3 and 4 were left open and all information regarding the impetus for the innovation, including need inputs transferred to the initial commercializer, was written up under heading 2.

The following are examples of completed keys. (Those interviewed have verified the accuracy of the information cited in the "keys" and have permitted its reproduction.)

Sample key for PPO8

1. **Nature of the Innovation**

   Initial Commercialization of Polyphenylene Oxide, PPO

   An engineering thermoplastic "characterized by outstanding dimensional stability at elevated temperatures, broad temperature use range, outstanding hydrolytic stability, and excellent dielectric properties over a wide range of frequencies and temperatures."

   **Data Reference:**


   Applications for the plastic include electrical connectors and components, appliance housings, pumps and plumbing fixtures, and parts for automotive grilles and trims.

---

* Sole contribution to an innovation refers to the fact that no functional technological input is transferred to the commercializing organization from the outside. In the case of the development of Acetal Homopolymer, for example (see p. 19 of this report), the fact that polymers of formaldehyde had been known in the literature before the DuPont innovation had no real functional bearing on DuPont's development of high molecular weight, thermally-stable polymers of this chemical.
Best predecessors: Polycarbonate and acetal resins.

Data Reference:
Modern Plastics Encyclopedia, p. 51.

2. Contribution of First Firm to Commercialize Innovation


In 1955, A. S. Hay joined the organic chemistry section of General Electric's Research Laboratory. While in graduate school, Hay had formulated some ideas for direct oxidation of organic compounds. (These ideas were basic in nature, there was no commercial end-product or process in mind.) He was encouraged by G. E. to try out his ideas. The end-result of Hay's work was an entirely new method of synthesizing plastics, "Polymerization by oxidative coupling". This development occurred in 1956. (G. E. received a patent for the process in 1962.)

The first plastics synthesized by oxidative coupling made use of an expensive and relatively uncommon monomer (2,6-xylenol) and did not perform well under high temperature use. Scientists at General Electric began looking for less expensive monomers in order to exploit the process's commercial potential. Development work, utilizing scientists from both the Research Laboratory at Schenectady, N.Y., and the Chemical Development Operation at Pittsfield, Mass., continued until December of 1964 when G. E. announced its interest in commercializing a plastic material based on this unique process.

Key scientists at G. E. were:

A. S. Hay  
S. B. Hamilton  
J. R. Elliot  
R. P. Anderson  
R. Gutoff

The monomer for this new resin was phenol, a relatively inexpensive and available compound. (G. E. had been a major producer of phenolic
resins which are also synthesized from this monomer.)

Data Reference:


The marketing department at G. E. anticipated that the new material, because of its high heat distortion temperature, would find application in under-hood use in the automotive industry, in military aircraft, and in computer equipment.

PPO was introduced in 1965 and was first used in surgical instruments, battery cases, and appliance parts. By 1967 the material appeared to be a commercial failure. It was difficult to process, requiring specialized machinery, and high temperature molds.

Data Reference:


Because of the problems in marketing the new plastic, G. E. scientists, in a venture group headed by R. Gutoff, began looking for ways to modify the material. The group began work in 1963. In 1968, Noryl, a modified PPO (an alloy of the original material and Polystyrene) was introduced. The modified plastic was easier to handle and did not require high temperature molds in processing. (Conversations with people at G. E. indicate that the chemistry of PPO had a powerful attraction and modifying the pure molecule, "a piece of unique chemistry", was a difficult psychological problem.

Data Reference:

Phone Interview, S. M. Haycock
Sample Key for Acetal Homopolymer

1. **Nature of the Innovation**
   
   **Initial Commercialization of Acetal Homopolymer**

   The plastic has "regular structure and high crystallinity which gives parts made from them an unusual combination of physical properties that bridge the gap between those of metals and plastics. Those properties include high strength and rigidity, excellent dimensional stability, and resilience. Acetal homopolymer products retain many of these desirable engineering properties over a wide range of service temperatures and humidities, as well as solvent exposures".

   **Data Reference:**
   

   With the introduction of this resin, DuPont coined the term "engineering plastic".

   Best predecessor: Nylon.

   **Data Reference:**
   
   Phone interviews with H. Whitlock, K. J. Persak of DuPont

2. **Contribution of First Firm to Commercialize Innovation**

   First commercialized by DuPont in 1960. Solely a DuPont innovation.

   In the early 1950s DuPont chemists were involved in studies seeking purer forms of formaldehyde. (DuPont was a basic producer of this material.) According to Dr. H. Whitlock, after methods of producing purer forms of the chemical had been developed, a chemist on the research team found that this purer formaldehyde polymerized with good results. (Low molecular weight and thermally unstable polymers of formaldehyde had been synthesized years before.) Further development of the resin was transferred to the DuPont plastics division.
DuPont's great contribution was the synthesis of high molecular weight, heat-stable polymers of formaldehyde. This was accomplished by putting "caps" on the ends of the molecular chains to prevent unzipping of the molecule.

Data Reference:
Dr. H. Whitlock, DuPont
Dr. R. J. Prochaska, Celanese

There was an approximate time span of seven years from first synthesis to commercialization. Two and one half years of this time was spent in intensive market testing of the plastic. The market testing included use of the material by molders and extruders and end-use testing.

Data Reference:
K. Persak, H. Whitlock of DuPont
2.3 Results: The Innovation Process in Engineering Thermoplastic Resins

The principal finding of this investigation into the innovation process in engineering thermoplastic resins is that it is a manufacturer-dominated process. In 100% of the innovations studied, it is the resin manufacturer, not the resin user (fabricator) or other potential actor in the innovation process who:

---formulates (or investigates) the theoretical foundation for the development of a new resin;
---synthesizes the resin;
---proves the value of the material through experimentation;
---carries the development process through to commercialization.

In some instances, the user may contribute to the process by recognizing that a material improvement is required and transferring this information to the resin manufacturer. (Here, for example, fabricators using resin X continually urge the manufacturer to make it "more flexible". When additives can no longer satisfy this request, it is realized by the manufacturer that a demand exists for a new resin similar to X in most properties yet more flexible.) It is extremely difficult on the basis of retrospectively-gathered data, to determine the exact extent of user contribution to this stage in the innovation process.

On the other hand, there is evidence in the case of serendipitous syntheses for example, that the resin manufacturer may be forced to search out needs to fit the properties of a new material. Here, the role of need recognition is carried out by the manufacturer. The following is an example
of such a case.

A Case of Serendipity in Polymer Development: Polycarbonate Resin

In 1953 Dr. D. W. Fox, a chemist at G. E. working on a project involved in the development of a better wire insulation material, synthesized an interesting resin which proved to be unsuccessful as a wire insulator.

"Here is how Fox described what happened: 'I tried it and started making a polymer by ester-exchange with diphenyl carbonate and the melt became more and more viscous. Eventually I could no longer stir it. The temperature had reached 300°C, and I stopped at this point when the motor on the stirrer stalled. When the mass cooled, I broke the glass off and ended up with a "mallet" made up of a semi-circular replica of the bottom of the flask with the stainless steel stirring rod sticking out of it. We kept it around the laboratory for several months as a curiosity and occasionally used it to drive nails. It was tough.'

"Early in 1954, A. Pechukas visited the research laboratory and saw the odd-looking polycarbonate 'hammer'. At that time he was general manager of the Chemical Development Department of G. E.'s Chemical and Metallurgical Division, Pittsfield, Massachusetts. Pechukas became very interested in Fox's discovery. Having just concluded an investigation, he was anxious to bring a promising new project into his department.

"Market research was carried out by the Chemical Development Operation at G. E. and 'the decision was made to develop a polycarbonate resin to be used as a molding material -- this was a crucial step because it was G. E.'s first attempt to enter a new material of its own in the thermoplastic molding material business.'

"Work progressed on the development of a polycarbonate of high molecular weight. This proved to be a false trial. 'We were the victims of some bad marketing information', Fox has since said. 'We wasted six months trying to get a product of high molecular weight when a product of one-half the molecular weight we thought we needed would have done the job. We just didn't have the marketing facts of life.'

"After discovering that a material of a lower molecular weight was acceptable for commercial use, and refining the
process to make it possible to use conventional pilot plant equipment, the project was back on the track."

Data Reference:

It is evident, in the development of this resin, that the manufacturer, not the user, took the initiative in the transferral of need information. Repeated market research was required, on the part of G. E. to clearly determine the existence of a market need for the new material.

When these findings are applied to the stages of the technical innovation process (see p. 8), one finds the locus of innovation activity centered in the manufacturer.

Figure 2

MAIN LOCUS OF INNOVATION ACTIVITY BY STAGE OF INNOVATION PROCESS

IN ENGINEERING THERMOPLASTIC RESIN DEVELOPMENT

<table>
<thead>
<tr>
<th>Innovation Process Stage</th>
<th>Recognition</th>
<th>Idea Formation</th>
<th>Problem Solving</th>
<th>Solution</th>
<th>Utilization &amp; Diffusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Capsule Stage Descriptions)</td>
<td>(Recognition of technological feasibility of an innovation and potential demand for it)</td>
<td>(Fusion of feasibility and demand perceptions into a design concept)</td>
<td>(R &amp; D activity)</td>
<td>(Invention)</td>
<td></td>
</tr>
</tbody>
</table>

Manufacturer

User
It is clear that the innovation process in plastics is very different from that found in scientific instrumentation. The following chapter will explore possible reasons for this difference.
Chapter III

Reason for the User-Dominant Locus
in Scientific Instruments
and
the Manufacturer-Dominant Locus
in Engineering Thermoplastic Resins: A Speculation

3.1 Method of Analysis

The fact that two industries have been shown to exhibit two very different loci of innovation activity permits a method of separating out those factors which may be important in influencing the locus of innovation activity as a variable. In a deductive sense, one interested in isolating factors which influence the variable can compare the two industries exhibiting the differing loci and consider those factors relating to the process of innovation which display differences in characteristics. Here a factor, for example, might be the number of manufacturers in an industry and its characteristics are many, few, over 1,000, etc. This logic assumes that the locus of innovation activity is a dependent variable, a kind of final output of the process of innovation. The locus is seen as dependent upon many factors underlying the process.

One such factor which displays dramatically different characteristics in the two industries studied is the cost of equipment and materials, (hereafter called "materials costs"), required by users seeking to innovate in order to satisfy internal needs. It is felt that this factor may be of major importance as a determinant of the locus of innovation in the two industries. This chapter will compare the
different characteristics of this factor in the two industries and will offer a speculation regarding the factor's influence upon the locus of innovation activity. Following this presentation, a discussion of some of the potential pitfalls involved in arbitrarily applying this comparative method of analysis will be discussed. Later, Chapter IV will explore the impact of materials cost upon the locus of innovation in the scientific instrument industry.
3.2 Materials Cost Characteristics, in the Scientific Instrument Industry

Because scientific instruments are tools, users desirous of developing new instruments or improving existing units are generally concerned with the creation of a single working prototype. (This fact is crucial to this analysis. As will be pointed out in the next section, the plastics user requires quantities of material in order to satisfy his internal needs.) In order to gain an understanding of the magnitude of materials cost required here, an analysis has been carried out for the gas chromatograph (GC) and the nuclear magnetic resonance spectrometer (NMR), two of the four instruments included in the von Hippel study. It is felt that GC and NMR are representative of the larger group of four instruments in that:

1. Over half of the major improvement innovations presented in the M.I.T. study were taken from GC and NMR (i.e. 25 from a total of 46 major improvement innovations -- see p. 11).

2. GC and NMR cover almost the entire range of unit instrument cost for those instruments studied. (The range for all four instruments is $2.7 - 100k, the range for GC and NMR is $3 - 100k. See von Hippel, op. cit., p.4).

3. The total percentage of user domination in the innovation process found for all four instruments, 81%, is mirrored in the 82% found for GC and the 79% found for NMR. (See p.11).
in addition, it is felt that separate analysis of GC and NMR renders a more current appraisal of materials cost in that both instruments were first commercialized more than a decade later than the ultraviolet spectrophotometer and the transmission electron microscope, the two other instruments included in the M.I.T. study.

Because data concerning the exact dollar cost of the materials is not available retrospectively, a consensus of expert opinion was relied upon for an approximation of such costs for the various innovations included in the GC, NMR sample. (Both inventive users and instrument manufacturers were consulted.) The table below illustrates these cost approximations.

Table 2

ORIGINAL MATERIALS COST
FOR BASIC, AND MAJOR IMPROVEMENT INNOVATIONS

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Approximate Materials Cost Range (Dollar amounts at time of innovation)</th>
<th>Number of Innovations</th>
</tr>
</thead>
<tbody>
<tr>
<td>GC</td>
<td>0 - $100</td>
<td>7</td>
</tr>
<tr>
<td>GC</td>
<td>100 - 400</td>
<td>4</td>
</tr>
<tr>
<td>GC</td>
<td>over 400</td>
<td>1</td>
</tr>
<tr>
<td>NMR</td>
<td>100 - 1,000</td>
<td>5</td>
</tr>
<tr>
<td>NMR</td>
<td>10,000 - 20,000</td>
<td>3</td>
</tr>
<tr>
<td>NMR</td>
<td>50,000 - 100,000</td>
<td>3</td>
</tr>
<tr>
<td>NMR</td>
<td>250,000 - 500,000</td>
<td>1</td>
</tr>
<tr>
<td>NMR</td>
<td>NA</td>
<td>3</td>
</tr>
<tr>
<td>Total Innovations</td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>
In the table, 17 of the 27 basic and major improvement innovations required materials costing $1,000 or less. The following examples describe the hardware embodiment of four GC and NMR innovations.

First Gas Chromatograph

-approximate cost $100
-copper or glass column (several feet in length)
-column support material (diatomaceous earth)
-partitioning agent (non-volitile liquid)
-carrier gas system (tank of pressurized gas and valves)
-titration detector

Electron Capture Detector for GC

-approximate cost $300
-brass chambers
-inlet for carrier gas and anode
-diffuser made of 100-mesh brass gauge
-radiation source
-gas outlet and cathode

First NMR Spectrometer

-approximate cost $20,000
-magnet (approx. cost 5 - 10k)
-rf oscillator (approx. cost $1,000)
-rf receiver (approx. cost $1,000)
-probe, of machined aluminum, copper wire, capacitors, (approx. cost $1,000)
-xy recorder (approx. cost $2,000)

(continued)
- voltage sweep unit (approx. cost $2,000)
- oscilloscope (approx. cost $5,000)
- misc. electronic components (approx. cost $1,000)

Multi-Nuclei Probe, NMR

- approximate cost $500
- shaped glass tubing
- copper wire
- teflon rod
- misc. electronic components
3.3 Materials Cost Characteristics, the Engineering Thermoplastics Industry

The engineering thermoplastics user (fabricator) desirous of developing an improved resin for internal use, unlike his counterpart in the scientific instrument industry, must be concerned not only with a workable prototype (a test-tube quantity of a new resin) but also with producing usable quantities of the new plastic for product fabrication. The need for quantities of the resin requires the construction of a production facility. Although the materials cost required in laboratory formulation of prototype resins can be inconsequential, anecdotal information from manufacturers and users in the plastics industry reveals that the cost required in constructing even the smallest resin production facilities runs into the many hundreds of thousands of dollars. Specific examples of the kind of costs that can be involved here are General Electric's pilot-plant for polyphenylene oxide production which required an investment of approximately $7 million and the first relatively small scale commercial facility for polycarbonate resin which required an $11 million investment.
3.4 Speculation: Influence of Materials Cost Characteristics on the Locus of Innovation Activity

It is clear that the cost of materials required of users to innovate for internal need satisfaction is very different in the two industries. It is felt that the low materials cost involved in scientific instrument innovation permits the user to engage in a good deal of experimental activity whereas the extremely high cost faced by the plastics user limits his incentive and ability to innovate. The economic ability of many users to pursue research activity in the scientific instrument industry may well be a factor influencing the locus of innovation activity toward the user. Conversely, the high cost involved in engineering thermoplastic resin development may be a factor shifting the locus away from the user.

Although no cases have been found in which users have synthesized new engineering thermoplastic resins, it is interesting to note that a few cases have been found in other families of plastics. In each case the user required small quantities of very specialized material. Polaroid Corp., for example, has developed and patented several resins for internal use. The resins required special photographic properties and only a few thousand pounds were needed annually. At least one new resin has been developed by IBM for use in their own products. Again, only small quantities of specialized material were required. If very small quantity requirements imply production facility costs much lower than those described above, then the user involvement here further supports the influence of the materials cost factor on the locus of innovation activity.
3.5 Pitfalls Involved in Comparative Analysis

In an effort to isolate factors influencing the locus of innovation activity through a comparison of differing industry characteristics, care must be taken in a determination of whether or not the factors can be viewed independently. For example, the impact of materials cost required in internal user innovation upon the locus of innovation activity is very much dependent upon the payback users expect from innovating and other factors such as payback expected by manufacturers from innovating. The innovations of Polaroid and IBM attest to this dependence. Here, low expected payback to manufacturers (because of the small amounts required) and the worthwhile expected payback to users may have combined to determine this user-dominated locus. Although it is felt that the treatment of this particular factor as independent of others in the preceding speculative section does not really jeopardize the conclusions, it is not difficult to construct hypothetical treatments of a similar nature which lead to naive results.

If, for example, one compared manufacturers in terms of sales volume, one would discover that the plastics manufacturers dwarf the instrument makers. From this one could naively conclude that the size of manufacturers is a factor important in determining the locus of innovation activity. Moreover, one could propose, on the basis of this, that a direct correlation exists between the size of manufacturers and the degree of manufacturer dominance in the process of innovation. Here, in order to draw more worthwhile conclusions, one would want to know, for instance, how the size of user firms, in relation to the size of manufacturing firms, impact the locus of innovation activity.
Although, as shown, efforts to determine the influence of various factors upon the locus through comparative analysis are rife with potential hazards it is felt that the technique can be applied successfully. Before conclusions can be drawn from an industry comparison of a factor, the potential impact of the interdependence of that factor, with others, upon the locus must be carefully appraised.
Chapter IV
Some Further Speculation
Regarding the Impact of Materials Cost Upon the Locus
in the Scientific Instrument Industry

4.1 The Speculation

Chapter III, through a comparison of industries with differing loci, proposed that the level of materials cost required of users to satisfy internal needs may be an important factor in influencing the locus of innovation activity. The pitfalls of comparative analysis were pointed out and the fact that materials cost to users, as a determinant of the locus, is dependent upon other factors was mentioned. This chapter will speculate as to exactly how a low materials cost interacted with other factors to help determine a user-dominated locus in the scientific instrument industry.

The speculation is based upon the propositions that:

- A large population of users, many working in highly specialized areas, were able to pursue research activity due to the low cost of materials;

- The instrument manufacturers were unable because of the high costs of technical manpower, to duplicate the specialized work of the user community.

In order to give the reader an understanding of some of the important factors and relationships that existed in the scientific instrument industry and which support the speculation, the following sections will:

- Briefly describe the users and manufacturers;
- Outline the user contribution to inventive activity;
- Consider the limitations of the manufacturer contribution to inventive activity;
- Describe the nature of innovations developed by both users and manufacturers.

Finally, the effects of an increase in materials cost upon the locus of innovation activity in this industry will be considered.
4.2 Users and Manufacturers

Gas chromatographs and nuclear magnetic resonance spectrometers are widely used in medical, government, industrial, and university laboratories. The users range in size from the largest petroleum and chemical processing companies to small college and medical laboratories. The table below shows the organizational affiliations of the inventive users (those whose inventions led to successful commercialization) in the fields of GC and NMR.

Table 3

<table>
<thead>
<tr>
<th>Major Improvement Innovation</th>
<th>University or Institute</th>
<th>Private Manufacturing Firm</th>
<th>Self-Employed</th>
<th>NA</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Chromatography</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>11</td>
</tr>
</tbody>
</table>

Clearly the academic community's contribution to successful innovation is remarkably high in this area of instrumentation.

During the period of major development activity there were approximately thirty manufacturers of GC in the U. S. At this time there existed only one U.S. manufacturer of NMR spectrometers, Varian Associates. The following table lists the sales volume and research and development budgets of the three largest manufacturers. Many of the small manufacturers of GC had sales of less than $1 million.

It is interesting to note that the users greatly out-numbered the manufacturers and that the smaller users, the academics, contributed significantly to the number of successful major improvement innovations.
<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Instrument</th>
<th>Sales volume (millions $)</th>
<th>R &amp; D Budget (millions $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varian</td>
<td>NMR</td>
<td>70.9</td>
<td>N.A.</td>
</tr>
<tr>
<td>Beckman</td>
<td>GC</td>
<td>44.8</td>
<td>3.4</td>
</tr>
<tr>
<td>Perkin Elmer</td>
<td>GC</td>
<td>17.5</td>
<td>1.7</td>
</tr>
</tbody>
</table>
4.3 User Contribution to Inventive Research

In an effort to determine the user contribution to inventive research, data was gathered regarding affiliation of authors of published articles pertaining to instrument apparatus. It was felt that such information, although by no means an exact indicator of research effort, offers at least some quantifiable measure of relative contribution. It can be argued that not all users seek to publish their findings and thus some portion of their contribution will go unnoticed in an analysis of only published work. Further, the argument can be made that instrument makers will refrain from publishing at least until some patent protection is obtained. In defense of the use of such data, one can only rely upon the tradition in the sciences of publishing as a means of communicating new ideas. For the instrument-maker one would think that publication would quickly follow patent protection. Time lags in manufacturer publication may be a natural occurrence but this in no way should influence the ultimate number of manufacturer papers.

The tables following indicate the number of published articles submitted, by affiliation of author, in GC and NMR for the years given.
### Table 5
**AFFILIATION OF AUTHOR, GC PUBLICATIONS**

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Papers submitted by Users</th>
<th>Number of Papers (pertaining to apparatus) submitted by Inst. Makers</th>
<th>Total Papers</th>
<th>% User Contribution to Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1958-9</td>
<td>82</td>
<td>18</td>
<td>100</td>
<td>82.0%</td>
</tr>
<tr>
<td>1960</td>
<td>116</td>
<td>31</td>
<td>147</td>
<td>78.9%</td>
</tr>
<tr>
<td>1961</td>
<td>295</td>
<td>56</td>
<td>351</td>
<td>84.0%</td>
</tr>
<tr>
<td>1962</td>
<td>206</td>
<td>26</td>
<td>232</td>
<td>88.8%</td>
</tr>
<tr>
<td>1963</td>
<td>232</td>
<td>59</td>
<td>291</td>
<td>79.7%</td>
</tr>
<tr>
<td>1964</td>
<td>266</td>
<td>33</td>
<td>299</td>
<td>88.9%</td>
</tr>
<tr>
<td>1965</td>
<td>233</td>
<td>42</td>
<td>275</td>
<td>84.7%</td>
</tr>
<tr>
<td>Totals</td>
<td>1430</td>
<td>265</td>
<td>1695</td>
<td>84.3%</td>
</tr>
</tbody>
</table>

### Table 6
**AFFILIATION OF AUTHOR, NMR PUBLICATIONS**

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Papers (pertaining to apparatus) submitted by Users</th>
<th>Number of Papers (pertaining to apparatus) submitted by Inst. Makers</th>
<th>Total Papers</th>
<th>% User Contribution to Total Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>229</td>
<td>3</td>
<td>232</td>
<td>98.7%</td>
</tr>
<tr>
<td>1970</td>
<td>176</td>
<td>3</td>
<td>179</td>
<td>98.3%</td>
</tr>
<tr>
<td>1971</td>
<td>127</td>
<td>3</td>
<td>130</td>
<td>97.6%</td>
</tr>
<tr>
<td>1972</td>
<td>96</td>
<td>3</td>
<td>99</td>
<td>96.9%</td>
</tr>
<tr>
<td>1973</td>
<td>110</td>
<td>2</td>
<td>112</td>
<td>98.2%</td>
</tr>
<tr>
<td>1974</td>
<td>83</td>
<td>4</td>
<td>87</td>
<td>95.4%</td>
</tr>
<tr>
<td>Totals</td>
<td>821</td>
<td>18</td>
<td>839</td>
<td>97.8%</td>
</tr>
</tbody>
</table>

It is clear that the user contribution to the literature is overwhelming in comparison to that of the instrument-maker.
Data was also collected on patent assignments in GC. Here too, the user's contribution is high. One would expect users to be somewhat less concerned than instrument makers in obtaining patent protection. This probably accounts for the lower percentage of user activity in this area.

Here there appears to be a strong correlation between the contribution to inventive research by the actors in the innovation process and the percentage of successful innovations credited to each. In GC for example, the users contributed 84.3% to the body of research literature and 82% to the number of successful improvement innovations.

Table 7

PATENT ASSIGNMENTS BY AFFILIATION, GC

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of U.S. Patents Assigned to Users</th>
<th>Number of U.S. Patents Assigned to Inst. Makers</th>
<th>Total Patents</th>
<th>% User Contribution to Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>100%</td>
</tr>
<tr>
<td>1956</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>1957</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1958</td>
<td>6</td>
<td>1</td>
<td>7</td>
<td>85.7%</td>
</tr>
<tr>
<td>1959</td>
<td>5</td>
<td>3</td>
<td>8</td>
<td>62.5%</td>
</tr>
<tr>
<td>1960</td>
<td>5</td>
<td>7</td>
<td>12</td>
<td>41.6%</td>
</tr>
<tr>
<td>1961</td>
<td>14</td>
<td>8</td>
<td>22</td>
<td>63.6%</td>
</tr>
<tr>
<td>1962</td>
<td>38</td>
<td>13</td>
<td>51</td>
<td>74.5%</td>
</tr>
<tr>
<td>1963</td>
<td>21</td>
<td>5</td>
<td>26</td>
<td>80.8%</td>
</tr>
<tr>
<td>1964</td>
<td>27</td>
<td>11</td>
<td>38</td>
<td>71.0%</td>
</tr>
<tr>
<td>1965</td>
<td>15</td>
<td>13</td>
<td>28</td>
<td>53.6%</td>
</tr>
<tr>
<td>Totals</td>
<td>132</td>
<td>62</td>
<td>194</td>
<td>68.0%</td>
</tr>
</tbody>
</table>
4.4 Feasibility of Manufacturer Contribution to Inventive Research

The proposition here is that the instrument manufacturers were very much limited in their ability to duplicate the inventive work of the users. The reasoning follows.

Research costs money, and for instrument makers money comes from product sales. The following table outlines sales data for the GC industry, and research and development expenditures as a percentage of sales for the years listed.

If the total dollars expended by instrument makers for basic and applied research (column V) is divided by the total number of papers published by users during the nine year period (column VI), then the average cost per paper for the instrument makers would have been $1,833,000/1,430 or $1,282 per paper. National Science Foundation statistics for the years 1961 and 1962, the median years of the sample, show the cost of R&D performance per R&D scientist or engineer in scientific and measuring instruments as $21,000/year and $22,500/year respectively. These figures represent the amount spent on R&D per scientific employee and thus include both salary and overhead expense. Using the lower figure, $21,000/year, as a "rule of thumb", one can determine the approximate length of time required of a single researcher to experiment and submit a paper for publication.

If the cost of an average paper is $1,282 then the average length of time required of a single researcher to produce the paper would equal $1,282/$21,000/year or 6.1% of a year. Assuming a fifty-week year and a five-day week, the time required would be about fifteen days. The result is absurd. Fifteen days is hardly enough time for one researcher to de-
Table 8

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Sales (millions $)</td>
<td>Median R&amp;D Expenditure as a Percentage of Sales</td>
<td>Dollars Appropriated for R&amp;D</td>
<td>Dollars for Basic and Applied Research</td>
<td>Number of User Papers</td>
</tr>
<tr>
<td>1958-9</td>
<td>3.75</td>
<td>$300,000</td>
<td>$75,000</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>1960</td>
<td>5.00</td>
<td>$400,000</td>
<td>$100,000</td>
<td>116</td>
<td></td>
</tr>
<tr>
<td>1961</td>
<td>7.50</td>
<td>$600,000</td>
<td>$150,000</td>
<td>295</td>
<td></td>
</tr>
<tr>
<td>1962</td>
<td>12.50</td>
<td>8%</td>
<td>$1,000,000</td>
<td>$250,000</td>
<td>206</td>
</tr>
<tr>
<td>1963</td>
<td>16.90</td>
<td>$1,352,000</td>
<td>$338,000</td>
<td>232</td>
<td></td>
</tr>
<tr>
<td>1964</td>
<td>20.00</td>
<td>$1,600,000</td>
<td>$400,000</td>
<td>266</td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td>26.00</td>
<td>$2,080,000</td>
<td>$520,000</td>
<td>233</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>91.65</td>
<td>$7,332,000</td>
<td>$1,833,000</td>
<td>1,430</td>
<td></td>
</tr>
</tbody>
</table>

*Basic and Applied Research are defined by the National Science Foundation as follows:

"Basic Research -- Original investigations for the advancement of scientific knowledge that do not have specific commercial objectives, although such investigations may be in fields of present or potential interest to the reporting company.

"Applied Research -- Investigations that are directed to the discovery of new scientific knowledge and that have special commercial objectives with respect to products or processes. This definition of applied research differs from the definition of basic research chiefly in terms of the objectives of the reporting company."

Data Reference: "Basic Research, Applied Research, and Development in Industry, 1962", Survey of Science Resources Series, National Science Foundation, NSF 65-18, p. 157. It is felt that the Basic and Applied Research components of total R&D expenditure represent those dollars directed toward inventive activity. Basic and Applied research make up approximately one fourth of total R&D expenditure (See NSF 65-18, p. 65). Column V is therefore derived by multiplying Column IV by $\frac{1}{4}$. 
velop a prototype device, test it in application, and write a paper describing the apparatus and experimentation. Clearly, the instrument makers could not have matched the inventive activity of the user community.
4.5 Nature of Innovations

It is of interest that whereas user innovations were strongly specific in nature, the manufacturer innovations included in the GC, NMR sample were all of a general nature. Here a specific innovation is defined as an instrument improvement first developed to aid in the analysis of a single or narrow class of unknowns. A general innovation is defined as an instrument improvement which is first developed to aid in the analysis of all unknowns for which the instrument is being used. Examples of specific and general innovations are presented below:

Case 1: Specific Innovation

Silanization of Column Support Material in GC -- 'Functional Tool'. Original work was done by E. C. Horning et. al. at the National Institute for Health, Bethesda, Maryland, and Baylor University College of Medicine from 1958-1964.

Motives: "The relative slowness with which gas chromatographic methods have been applied in problems involving amines in biology and medicine is largely due to the fact that technological improvements in the preparation and use of columns, and in the preparation of suitable derivatives, have not reached the stage necessary for general scientific acceptance. The present study, based on previous experience with thin-film columns, was undertaken in order to explore the usefulness of gas chromatography in studies of tryptamines -- related indole bases, and in studies of catecholamines. Biological amines of both types are of considerable interest in many areas of biology and medicine."

Here the stimulus for the development of the innovation was the improved analysis of a narrow class of compounds.

Case 2: General Innovation

Capillary Column for GC

Marcel Golay was a mathematician and consultant to Perkin-Elmer Corp. He was asked by the company to look at the gas chromatograph regarding possible instrument improvement. The idea for a capillary column was based upon a theoretical principle, the telegrapher's equation. The new column, a capillary tube with coated walls, allowed for greater accuracy, sensitivity, and speed in chromatographic
Here the stimulus for development is clearly general instrument improvement. The following table illustrates the nature, whether general or specific, of the basic and major improvement innovations in GC and NMR.

Table 9

NATURE OF INSTRUMENT INNOVATIONS

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Chromatograph</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Nuclear Magnetic Resonance</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Spectrometer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>2</td>
<td>11</td>
<td>5</td>
<td>0</td>
<td>9</td>
</tr>
</tbody>
</table>

It appears from these findings that the users pursued specific instrument improvements while the manufacturers concentrated on general improvements. It is felt that, because of low materials cost, the users were able to pursue this specialized work. The manufacturers, on the other hand, because of the high costs of acquiring specialized technical manpower and the higher payback expected from appealing to a broader market base, pursued only general research.

*The criteria established in defining specific and general innovations (p.45) were applied to the innovations included in the GC, NMR sample.
4.6 The Effects of a Higher Materials Cost Upon the Locus of Innovation Activity

It has been shown that the user contribution both to successful product innovation and to the research activity leading toward innovation has been dominant in this industry. It has also been pointed out that academic users have been significant innovators.

It is felt that if for some reason the materials cost involved in instrument innovation were higher than it was, many of the smaller users, especially the very active academics, would have been prevented from engaging in inventive activity. One can imagine the difference in difficulty for a small user in obtaining, for instance, $1,000 worth of materials and equipment vs. $50,000 or $100,000. The reduction in research activity on the part of the small users would lead directly to a reduction in the number of inventions that ultimately become product improvements. The manufacturer's ability to pursue research, it is felt, would be less adversely affected by the increase in materials cost. Here the cost can be spread over the many units that stand to be sold as a result of product innovation. Thus, the locus of innovation would shift away from the user and toward the manufacturer. Innovation in this industry would suffer at the expense of the specialized work of the user.
Summary and Suggestions for Further Research

This work has focused on the locus of innovation activity as a variable in the innovation process. It has been pointed out that the variance of this locus is important to those interested in stimulating industrial good innovation through funding, and to researchers interested in describing the innovation process.

In an effort to determine factors which influence the variable, an industry exhibiting a strong pattern of user dominance in innovation activity was compared to an industry exhibiting a pattern of manufacturer dominance. The comparative analysis viewed the locus as dependent upon the characteristics of underlying factors in the environments of the innovating industries. One factor which demonstrated strong differences was the materials and equipment cost involved in user innovation. A speculative analysis sought to illustrate the manner in which this factor interacted with other factors in the scientific instrument industry to help determine the user-dominated locus.

Because so little is known about the innovation process and because the locus of innovation activity is such a new concept, much future research is needed. It is suggested that many more industries be examined in an attempt to determine loci of innovation activity. Comparative analysis among many industries exhibiting differing loci should do much to increase understanding regarding factors which influence the locus.
NOTES

Chapter I


2. Ibid., pps. 23-4.

3. Ibid., p. 20.

4. Ibid., p. 18.

5. Ibid., pps. 17-18.

6. Ibid., pps. 24-28 discussion.


Chapter II


Chapter III


Chapter IV

11. The analysis in this chapter has been carried out for the gas chromatograph and the NMR spectrometer. (See Chapter III, Sec. 3.2 for explanation).


13. Source: Annual Reports of the firms listed.

14. Gas Chromatography Abstracts, Preston Technical Abstract Service, (Niles, Ill), 1958-1965. All articles pertaining to instrument apparatus were coded as such.
Chapter IV notes continued


19. Data on R&D expenditure was gathered from annual reports of the major GC manufacturers for the years given. The 8% figure represents the median reported R&D expenditure of the major firms from 1958-1965.

20. See Table 5, p.40, Nature of Papers (pertaining to apparatus) submitted by Users.


22. Source: Interview with Leslie Ettre, Perkin-Elmer Corp.
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