INDUSTRIAL INNOVATION BY USERS:
EVIDENCE, EXPLANATORY HYPOTHESES AND IMPLICATIONS

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Many who have seriously examined the matter are now persuaded that technological change is a major - and possibly the major contributor to the economic growth and increase in productivity of nations. As a result, interest in the process by which technological change occurs, and the "causes" of success and failure, appears to be rising. Unfortunately, those studying these issues cannot at the moment offer any simple prescription for innovation success. As is the case with many social processes, numerous factors appear to discriminate significantly between the successful and failing practice of industrial innovation. But "numerous factors" are typically not of much operational use to a policy maker or practitioner. Rather, a few strong, "operationally malleable" factors are needed which interested parties can and would find it worthwhile to respond to.

Research to this end is being pressed on several fronts, but in the present paper, we wish to focus on progress being made in one area only: Understanding the role of the user in industrial product and process innovation. It now appears that the innovation work by the user is more important than previously recognized. Further, it now appears likely that a strong, operationally malleable variable for the study and practice of innovation may be constructed on measures of such user activity. In outline, this is so because:

- Careful examination of innovation practice in several industries has shown that the level of the user involvement is often unexpectedly large: Indeed, it now appears that users, rather than first-to-market manufacturers actually are the designers of many new industrial products and processes.
- Strategies appropriate to the management of innovation are strongly impacted by the level of user involvement in the innovation work.
- The level of user involvement in the innovation work appears to
differ between industries, but appears to be quite consistent from case-to-case within a given industry - thus suggesting that it should be practical for firms to organize around the pattern which may be dominant in their industry.

At the moment, the fact of high user involvement in the innovation processes of some industries is reasonably well established, but the causes of the various levels of involvement observed are not yet clearly understood. In the sections which follow, we will begin by reviewing three categories of empirical data which bear on the fact of user involvement in the industrial innovation process: (1) The sources of designs for industrial product and process innovations; (2) the sources of "ideas" for industrial product and process innovations; and (3) the sources of problem statements for research whose results were key to the development of industrial product and process innovations. Next, we will discuss current hypotheses as to when and why the user adopts a major role in the industrial innovation process, and finally, we will consider the implications of what is currently known about the user's role in that process.
Table 1 offers a summary of the results of all studies I am aware of which provide empirical data on the "source" of successful industrial product and process innovations - and which also meet a methodological criterion which I have found key to obtaining accurate data on this matter. (This criterion is reviewed - and excluded studies identified - in a later section of this paper).

An initial glance at the data in Table 1 will show something very interesting: Users seem to often be the most frequent "sources" of new product and process innovations - designing, building and using a home-made version of a given innovation before a commercial version is available from any manufacturer.

The frequency with which the studies summarized in Table 1 credit innovations to product users rather than product manufacturers is striking, because the conventional assumption is that product manufacturers are the developers of new products. Since this is so - and since the impact on innovation research and practice would be considerable if the conventional assumption were proven often incorrect (for example, the prescriptive literature on 'how to manage the innovation process', is currently built around the conventional assumption) - I should be especially clear about key definitions and methodologies by which some of the studies in Table 1 have come to a different conclusion. To this end, I will first provide an example of a user-developed industrial product to convey the flavor of what may well be an alien concept to the reader, and then will move on to a summary of key definitions and methods.
Table 1: Empirical Data on the Source of Industrial Innovation

<table>
<thead>
<tr>
<th>Study</th>
<th>Nature of Innovations and Sample Selection Criteria</th>
<th>n</th>
<th>Innovation Source</th>
<th>User&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Mfg.&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knight (2)</td>
<td>Computer innovations 1944-62: - systems reaching new performance high</td>
<td>143</td>
<td>25%</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- systems with radical structural innovations (level I)</td>
<td>18</td>
<td>33%</td>
<td>67%</td>
<td></td>
</tr>
<tr>
<td>2. Enos (3)</td>
<td>Major petroleum processing innovations</td>
<td>7</td>
<td>43%&lt;sup&gt;b&lt;/sup&gt;</td>
<td>14%&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>3. Freeman (4)</td>
<td>Chemical processes and process equipment available for license, 1967</td>
<td>810</td>
<td>70%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>4. Berger (5)</td>
<td>All engineering polymers developed in U.S. after 1955 with &gt;10mm pounds produced in 1975</td>
<td>6</td>
<td>0%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>5. Boyden (6)</td>
<td>Chemical additives for plastics: All plasticizers and UV stabilizers developed post World War II for use with 4 major polymers</td>
<td>16</td>
<td>0%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>6. Lionetta &amp; von Hippel (7)</td>
<td>All pultrusion processing machinery innovations first introduced commercially 1940-76 which offered users a major increment in functional utility</td>
<td>13</td>
<td>85%</td>
<td>15%</td>
<td></td>
</tr>
<tr>
<td>7. von Hippel (8)</td>
<td>Scientific instrument innovations: - first of type (eg. first NMR)</td>
<td>4</td>
<td>100%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- major functional improvements</td>
<td>44</td>
<td>82%</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- minor functional improvements</td>
<td>63</td>
<td>70%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>8. von Hippel (9)</td>
<td>Semiconductor and electronic subassembly manufacturing equipment: - first of type used in commercial production</td>
<td>7</td>
<td>100%</td>
<td>0%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- major functional improvements</td>
<td>22</td>
<td>63%&lt;sup&gt;c&lt;/sup&gt;</td>
<td>21%&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- minor functional improvements</td>
<td>20</td>
<td>59%&lt;sup&gt;c&lt;/sup&gt;</td>
<td>29%&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> NA data excluded from percentage computations.

<sup>b</sup> Attribute missing percentage to independent inventors/invention development companies.

<sup>c</sup> Attribute missing percentage to joint user-manufacturer innovation projects.
Solderless Wrapped Connection:
A User-Developed Industrial
Product

The following example has been abstracted from an innovation history
developed for my study of innovation patterns in semiconductor and electronic
subassembly process equipment\(^{(9)}\), and may be comfortably seen as a typical
example of innovation by product users:

Solderless wrapped connection is a means of making a gas-tight,
reliable electrical connection by wrapping a wire tightly around a special terminal
whose sharp edges press into the wire. The system is much faster than the pre-
ceeding system used to make such connections - soldering - and allows much closer
spacing of terminals.

The entire solderless wrapped connection system, including a novel
hand tool needed to properly wrap the wire around the terminal, was invented and
developed at Bell Labs for use in the Bell System in 1947-48. After several years
of testing by the labs, it was given to Western Electric for implementation.
Western Electric decided to have the hand tool portion of the system built by an
outside supplier and Keller Tool (now part of Gardner-Denver Company) bid for and
won the job in 1952-53. Keller engineers suggested some modifications to the Bell-
designed tool which they felt would make the tool easier to manufacture and operate
and, Western agreeing, began manufacture.

Keller had other customers who did electronic assembly work and realized
that some of these would also find the system useful. It therefore requested
and obtained a license to sell the tools on the open market. Currently, solderless
wrapped connection is a major wire connection technique and Gardner-Denver (Keller)
the major supplier of equipment for that use.
Key Definitions and Study Methods Used

The definitions and methodologies used by the several studies whose results are summarized in Table 1 differ in many particulars. Nevertheless, some general statements can be made, under the headings of definitions and sample selection criteria, which the reader may find useful.

Key Definitions

- **Innovation**, as distinct from invention, is the first **utilization** of a new product or process. In the usage of the studies reviewed here, first utilization means first world use, not simply first use within a particular firm.

- An innovation "user" uses an innovation but does not manufacture it for sale. An innovation "manufacturer" manufactures an innovation for sale but does not use it. The industries studied in Table 1 were in the main structured in such a way that the distinction between the user and manufacturer could be made quite clearly via organizational boundaries: Few firms both used a given innovation and manufactured it for sale. Two exceptions are (1) computer manufacturing firms, which have many sophisticated uses for computers in-house, and (2) petroleum product and chemical manufacturing firms (process users), which often derive additional income from their process innovations by licensing these to others. In three studies of these industries I did not have access to detailed innovation histories (2,3,4). In these instances coding for Table 1 was done by taking the major role of these two classes of firms as controlling: All innovations by computer manufacturing firms were attributed to "manufacturer" and all process innovations by petroleum product and chemical manufacturing firms attributed to "users".
An innovation is attributed to the user or manufacturer which first builds and utilizes it in conformance with his economic function. Thus, attribution to a user is made if a user builds and uses an innovation before a manufacturer builds and sells a commercial version. And conversely, attribution to a manufacturer is made if a manufacturer builds and sells a commercial version of an innovation before a user builds and uses a home-made version.

**Sample Selection Criteria**

- Most of the studies reviewed in Table 1 focus on innovations of "major significance" (cf. Table 1 for criteria of significance used by each). Such innovations are comparatively rare and, while there is some evidence that minor innovations follow a pattern similar to major ones (8,9) this cannot be taken as a given at present.

- The innovation samples of the studies reviewed in Table 1 consist of successful innovations only. The high level of user-designed products and processes observed cannot therefore be used as a predictor of success: a sample of failing innovations might show an equal - or higher or lower - incidence of user involvement.

- The bulk of the studies reviewed in Table 1 (studies 1, 2, and 6-9) judge innovation success in terms of benefit derived by the user ("... offers a major increment in functional utility when judged relative to previous best practice ... ") Innovations selected on this basis may be major commercial successes for product manufacturers as well - but not necessarily (functionally important innovations are not necessarily of commercial importance to their manufacturer(s)).
Two Excluded Studies

The portfolio of studies on "the locus of innovation" is currently so slim that it would seem folly to exclude any from the present review. I have, however, excluded two studies from my Table 1 list of "all extant studies" because their methodologies do not correct for a source of bias I have found to be very important. These two studies gathered data on the locus of innovation from only one class of potential innovator. The bias introduced by this data collection strategy will be evident to those familiar with the aphorism, "Success has many fathers ... " Asking only one class of potential innovators, in effect, "Who developed this marvelous thing?" (recall Table 1 studies examined only successful innovations) "You or someone else?" will obviously result in under reporting of the contributions of other classes of potential innovators. One of the two studies excluded for this reason was the Gellman Study\(^{(11)}\), a study commissioned by NSF's Science Indicators Unit as an input to their periodic assessment of trends in US science and technological innovation, Science Indicators\(^{(12)}\). The Gellman study polled only manufacturers - "innovating organizations" in their terminology - for data regarding the contributions by manufacturers and others to the innovations being examined. The second study excluded for this reason was, unhappily, Peck's pioneering study of "The Sources of Invention in the Postwar American Aluminum Industry"\(^{(13)}\). Peck relied largely on new product information in Modern Metals, a trade journal well regarded in the field being studied, for his data as to the 'source of invention'. This material, I have found\(^{(13)}\) was in the main supplied to the journal editor by product manufacturers.

The studies reviewed in Table 1 considerably reduced this source of bias by using direct channels to multiple classes of potential innovators.
Studies 4-8 in Table 1, for example, involved searches of journals and patents, plus interviews with expert users and manufacturers and "others" in the fields at issue, to identify potential innovators in addition to conducting interviews with personnel at firms first to manufacture an innovation for commercial sale. (Channels appropriate for access to the various classes of potential innovators are very much a function of the field being examined. Tom Duchesneau, for example, exploring the diffusion of process machinery innovations in the shoe industry - a field not noted for a high rate of journal publications by process machinery users (shoe companies) - recently found that a survey of all users asking in effect "Do you know of any innovation work by users in the following machine categories?" provided a useful means of access to information regarding possible user-innovators (14).)

Evidence Regarding Requests for Innovations from Users (Customers)

To this point, we have reviewed only studies which attribute an innovation to the party which builds the first functional version. It should be noted that this is a very conservative measure of user involvement in the innovation process in that it ignores user inputs such as requests for innovations from customers containing vague or precise specifications which, while falling short of that criterion, may none the less be significant contributions.

I have focused on studies which use this measure, despite its conservative bias, for a simple but very important reason: Data on the source of the first functioning version of a given innovation can often be collected retrospectively with far greater reliability than can data on such measures as the presence (absence) of "Innovation Requests" by customers and any associated specifications. The latter are evanescent and seldom documented contemporaneously. In contrast, a first-functioning version of an innovation tends to leave substantial contemporaneously-generated traces such as the physical device
itself, records of prototype construction and results, patents, publications noting the accomplishment and its date.

Despite the difficulty of the work, however, several empirical studies have explored the frequency with which innovation requests from customers are associated with the decision to: Develop new industrial products (Table 2A); engage in research which ultimately led to new industrial and military products (Table 2B) (in the latter studies the "customer" for the research results solicited was an engineering group). The relevant finding of all studies of these two types which I am aware of are summarized in Table 2.

Insert Table 2 Here

(The interested reader will find a more detailed review of the studies in (22)).

Note that with one exception, these studies do not indicate the content of the customer request. The data they provide is compatible with a request as vague as: "Please think up a new product for me", or as precise as: "Please make me 10,000 units of X according to my design." (The exception is the study by von Hippel (17). In the sample examined there, it was determined that customer requests, when present, contained complete design data for the desired product). Even given this caveat, however, it is useful to find that the data provided by these two types of studies are clearly congruent with the central finding of the studies reviewed in Table 1, viz: product users play a significant role in the innovation process in some industries - and a minimal role in others. Some of the authors of the studies reviewed in Table 2 find the evidence for significant user involvement in the innovation process quite striking, as do I. For example, the Materials Advisory Board, in its discussion of the findings of
**Table 2: Frequency with which Manufacturers Initiated Work on an Industrial Innovation in Response to a Customer Request.**

<table>
<thead>
<tr>
<th>Study</th>
<th>Nature of Innovations and Sample Selection Criteria</th>
<th>Data Available Regarding Presence of Customer Requests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. STUDIES OF INDUSTRIAL PRODUCTS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meadows (15)</td>
<td>All project initiated during a two year period in &quot;Chem Lab B&quot;, a lab of a chemical company with $100-300mm annual sales in &quot;industrial intermediates&quot;</td>
<td>9 of 17 (53%) commercially successful product ideas were from customers.</td>
</tr>
<tr>
<td>Peplow (16)</td>
<td>All &quot;creative&quot; projects carried out during a 6 year period by an R&amp;D group concerned with plant process, equipment and technique innovations.</td>
<td>30 of 48 (62%) successfully implemented projects were initiated in response to direct customer request.</td>
</tr>
<tr>
<td>von Hippel (17)</td>
<td>Semiconductor and electronic subassembly manufacturing equipment: First of type used in commercial production (n = 7); major improvements (n = 22); minor improvements (n = 21).</td>
<td>Source of initiative for manufacture of equipment developed by users (n = 29) examined. Source clearly customer request in 21% of cases. In 46% of cases frequent customer-manufacturer interaction made source of initiative unclear.</td>
</tr>
<tr>
<td>Berger (5)</td>
<td>All engineering polymers developed in U.S. after 1955 with &gt;10mm pounds produced in 1975</td>
<td>No project-initiating request from customers found.</td>
</tr>
<tr>
<td>Boyden (6)</td>
<td>Chemical additives for plastics: All plasticizers and UV stabilizers developed post World War II for use with 4 major polymers.</td>
<td>No project-initiating request from customers found.</td>
</tr>
<tr>
<td>Utterback (18)</td>
<td>All scientific instrument innovations mfd. by Mass. firms which won &quot;IR-100 Awards&quot; 1963-68 (n = 15); Sample of other instruments mfd. by same firms (n = 17).</td>
<td>75% initiated in response to &quot;need input&quot;. When need input originated outside product manufacturer (57%) source was &quot;most often&quot; customer.</td>
</tr>
<tr>
<td>Robinson et al. (19)</td>
<td>Standard and non-standard industrial products purchased by three firms</td>
<td>Customers recognize need, define functional requirements and specific goods and services needed before contacting suppliers.</td>
</tr>
</tbody>
</table>
Table 2: continued

<table>
<thead>
<tr>
<th>Study</th>
<th>Nature of Innovations and Sample Selection Criteria</th>
<th>n</th>
<th>Data Available Regarding Presence of Customer Requests</th>
</tr>
</thead>
<tbody>
<tr>
<td>B. STUDIES OF RESEARCH - ENGINEERING INTERACTION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isenson</td>
<td>R&amp;D accomplishments judged key to successful development of 20 weapons systems</td>
<td>710</td>
<td>85% initiated in response to description of problem by application-engineering group.</td>
</tr>
<tr>
<td>(Project Hindsight) (20)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials Advisory Board (21)</td>
<td>Materials innovations &quot;believed to be the result of research-engineering interaction&quot;.</td>
<td>10</td>
<td>in &quot;almost all&quot; cases the individual with a well-defined need initiated the communications with the basic researchers.</td>
</tr>
</tbody>
</table>
its study of innovation histories of ten important materials innovations, such as silicones, observes (emphasis theirs):

In all but one of the cases studied, the recognition of an important need was identified in a majority of the events as an important factor in bringing about the research-engineering interaction.

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In almost all of the cases under consideration, it was an individual with a well-defined need who was the initiator of the communications. It was most frequently he who began the dialogue with the basic researchers and determined its continuation until the need was satisfied.
DETERMINANTS OF THE USER’S ROLE IN THE INNOVATION PROCESS

To this point, I have presented and discussed evidence for the fact that product and process users often play a major role in the industrial innovation process. Next, I wish to explore current hypotheses as to "causes" of a high - or low - level of user participation in the innovation process of a given industry.

At this point, two hypotheses regarding the cause of a high or low level of user participation in the industrial good innovation process are under active consideration. (see (23) for a brief review of a third hypothesis which seems to naturally spring to the minds of scientists.)

The first of the hypotheses, offered in somewhat different formulations by Utterback and Abernathy (24) and Knight (25), is that performance requirements are poorly understood by manufacturers in the early stages of a new product area, and that new product innovations in these early stages are therefore carried out by those closest to the need, eg. users. This hypothesis also predicts a shift from a user to manufacturer "locus of innovation" as, over time, the needs become more generally known and well-defined. This shift occurs, Utterback and Abernathy go on to propose, because when needs are well-defined, the key to successful innovation becomes new technological insights - and product manufacturers, it is suggested, have an advantage over product users in the latter arena.

The shift in locus of innovation predicted by this first hypothesis has been observed in three of the industries studied to date. A statistically significant shift in the predicted direction is shown in two of the studies summarized in Table 1 during the time spans examined as follows: Knight(4) showed a shift from user to manufacturer innovation as a function of time.
p < .001 for systems reaching new performance highs and p < .01 for systems containing radical structural innovations (Mann-Whitney U Test); von Hippel (9) found process machinery innovation which were the first of a "type" (eg: the first to be used to carry out a new "process step" in the industries studied) to be significantly more likely to be developed by users (p < .05, $\chi^2 = 4.1$) than the major and minor improvement innovations which followed. Some indication of the predicted shift is visible in the Scientific Instruments (8) data (basic innovations vs. major plus minor improvements to these p = .34 (Fisher exact test), but not in the studies of petroleum processing innovation or pultrusion process equipment innovation. (These five studies are the only studies summarized in Table 1 which could possibly have shown the effect because their samples included both innovations from when the product area "was new" and later innovations.)

Given the partial success of the first hypothesis in at least one prediction regarding the locus of innovation activity in user vs. manufacturer, why is there interest in other hypotheses? There are two reasons. First, Many variables in addition to clarity of desired performance specifications, such as market size, also tend to covary with the newness of a product area, and it may be any one or a combination of these others which actually causes the shift in locus of innovation observed. Second, "accurate understanding of need" for a new product or process would clearly be a difficult measure to work with experimentally or operationally (whose "understanding" counts: The project engineers? The market researchers? At what point(s) in the innovation process is accurate
understanding important? How can the "accuracy" of the understanding be determined \textit{ex ante}? etc.). Such difficulties lead one to rather hope that the answer lies elsewhere.

At present, the second hypothesis as to the cause of innovation has a rather global formulation, e.g.: The locus of innovation activity (and cost) is a function of the locus of benefit from such innovation. This hypothesis, of course, quickly reduces to that basic premise of market economics: Investment is a function of expected return. For a long time, however, it was not clear that innovation had any relationship to such a premise. In fact, as Schmookler\footnote{26} notes, economic theory tended to treat technological progress as an exogenous factor - a factor not determined by economic forces - to be introduced into economic analysis \textit{ad hoc} "like war or an earthquake". Painstaking work by economists such as Schmookler, Mansfield\footnote{27} and others, however, have now empirically established that economic measures such as the level of investment in certain categories of capital equipment, and proxy measures for innovation, such as rates of patent application bearing on those types of capital equipment, are strongly correlated. Further, by showing that rises in rates of invention follow rises in rates of investment, they have been able to provide support to the hypothesis that increases in investment cause increases in the frequency of invention (and, presumably, related innovation) - by raising the expected value of such.

Once it is established that invention and innovation are a function of expected value, it is a short logical step to the hypothesis that the locus of invention and innovation expenditure - user/or manufacturer and/or "other" - is a function of the locus of expected benefit. Peck, in his study\footnote{13} of the sources of invention in the aluminum industry, made a pioneering attempt to empirically test the correlation between the amount and time-distribution of
profits logically derivable by potential "sources" of aluminum-related-invention - producers of aluminum, producers of fabricating equipment for aluminum, producers of products using aluminum, etc. - with the actual invention record compiled by these sources. (While for methodological reasons mentioned previously, I don't find the study's empirical results convincing, the conceptual contribution of the work has been very useful to succeeding workers).

Further work on the hypothesis Peck attempted to test has shown that a successful empirical test involves formidable methodological difficulties in addition to those he encountered, notably:

- Simply obtaining needed economic data on the costs and benefits of innovation is very hard. (Corporations are understandably loath to provide data on profits, etc. related to particular products.)
- Proper attribution of costs and benefits is often difficult. (For example, what is the proper benefit to be attributed to an innovation which is sold as part of a larger system? It may contribute to system sales - but how large is that contribution?)
- Making various important types of costs and benefits commensurable is sometimes a problem. (For example, user-innovators of scientific instruments are largely university-based scientists who are rewarded primarily in terms of increases in understanding, reputation among peers etc. How does one make such benefits commensurable with those with the benefit which might induce an instrument company to innovate - an increase in annual sales?)

Given this rather grim list of methodological difficulties, one might well wonder how hypothesis 2 could be considered interesting. The answer is:

The benefit to a potential innovator is the benefit he can capture. Easily
observable features of market structure and institutional factors such as patent policy serve to put an upper bound on what an innovator can capture which may be easily computable and be so low for some classes of potential innovators as to allow us to predict where the locus of innovation will not be. Let me elaborate. A user who innovates has two potential ways to capture benefit from his innovation to compensate for innovation-related costs incurred. He may benefit from in-house use of the innovation and/or he may benefit from the diffusion of the innovation to others who wish to use and/or manufacture the innovation. In the instance of the first method of capture - in-house use - the upper bound on the percentage of total benefit available from an innovation which a user-innovator may capture is simply determined. It is the same percentage as his share of the market to which the innovation benefit applies. (eg, if the innovation is a processing machine which reduces the cost of manufacturing product A only, and the user-innovator manufactures 20% of all product A, he could capture a maximum of 20% of the total benefit potentially derivable from the innovation via in-house use. (I emphasize that share-of-relevant-market is an upper bound to the user's benefit from in-house use because, depending on market circumstance and company strategy, the user may choose or be forced to pass along some of the benefits to customers or others.) The second source of benefit potentially available to the user-innovator involves the "capture" of some of the benefit obtained by others when they use and/or manufacture the innovation. Mechanisms available for such capture are royalties, license fees, sale of "know-how", etc.

Similar reasoning applies in the instance of capture of benefits by a manufacturer-innovator: Capture via in-house manufacture and sale has an upper bound equal to the manufacturer's market share. A share in the remaining available benefit must be sought via royalties or other fees from other manufacturers.
and/or users. (In the instance of the independent inventor - who neither uses his innovation nor manufactures it for sale - all benefit captured must be via fees from manufacturers and/or users.)

Clearly, many different strategies for capture are available as a function of market structure, patentability of a given innovation, etc. (29) In principle, this plethora of options could lead to difficulty in predicting - as opposed to explaining post hoc - the locus of innovation in any particular industry. In practice, however, I speculate that, in many industries, capture of benefits resulting from non in-house activity by user or manufacturer is either restricted to a few clear mechanisms (eg. licensing in chemicals) or absent. (In my studies of scientific instrument (8) and process equipment innovations (9,16) I have seldom found any capture of benefit by innovators other than via in-house use. Patents were either seldom applied for (scientific instruments) or the innovations were of such a nature that patents could easily be skirted by imitators (process machinery). Other possible mechanisms for capture (eg. effective brand-name "franchise") were also largely ineffective in these industries.)(30)

Without an ability to prevent imitation or share in the benefits derived from imitation, the potential benefit to some classes of innovators can, as I mentioned above, have an exceedingly low upper bound. In the pultrusion industry, for example, total sales of pultruded product distributed among approximately 30 users of pultrusion machinery were found by Lionetta and von Hippel (7) to be approximately $60 million in 1976. Sales of pultrusion machinery by the single commercial builder of such were found to have climbed to a plateau of only $300 thousand annually. (Many users in this industry build their own process equipment). Machine manufacturers and users alike were seen unable to protect their innovations by patent or other means in this industry. This observation plus the relative sales volume of users and manufacturer
observed seems to me to be a reasonable, hypothesis 2-based, explanation for our finding that 85% of the innovations sampled had a user source. (It is also a reason to suggest that, in this industry, the shift in the locus of innovation predicted by hypothesis 1 would not occur unless and until the ability of the manufacturer to capture benefit from innovation costs incurred improves. Currently, total before-tax pultrusion-related profits - a potential source of additional R and D funding - is on the order of $7 million annually for the total user community versus only $30-40 thousand annually for the single commercial manufacturer of pultrusion equipment.)

The above outlines why I think further research under the rubric of hypothesis 2 holds interest and promise of allowing prediction of the role of the user in the innovation process or, more broadly, the locus of innovation activity. At the moment, however, the argument is clearly speculative.
IMPLICATIONS

As I noted at the beginning of this paper, the fact of varying user and manufacturer involvement in the industrial innovation process is currently clear but the cause of these variations is not. And, as the reader will understand from the discussion in the preceding section, a good deal more research remains to be done before the cause(s) is well understood. Fortunately, many major implications for innovation research and practice may be derived from the fact of user and manufacturer loci of innovation development (which may be empirically determined for any industry of interest), even if the cause is unknown. This is so because knowledge of where innovation occurs is an essential prerequisite to effective management of the process by those working at the firm, industry or government level. In the remaining paragraphs of this paper I will suggest a few implications of the findings regarding the locus of innovation, starting with implications for the firm and then moving to implications for government.

Implications for the Firm

Users and manufacturers share the industrial innovation process no matter which party is the "source" of an innovation - the manufacturer picking up the work where the user leaves off. As I noted at the beginning of the paper, the currently prevailing assumption among practitioners of innovations in industrial firms - and of the prescriptive, "how to develop new products" literature addressed to them (10) - is that the user's share in the innovation process is simply to have "needs" which the manufacturer can explore via marketing research. Yet, as we have seen in this paper, in some industries the user's role is typically far greater, involving the design and fabrication of a "home built" version of the innovation and proof of its value via field use.

Clearly, a manufacturing (or using) firm facing the latter situation should organize its innovation effort differently than would be appropriate in the
former situation: Both what the firm should be looking for at the user-manufacturer innovation activity interface and what the firm itself should do are significantly changed. Consider the following changes which might logically be prescribed for a manufacturing firm wishing to switch its innovation activities from manufacturer-sourced to user-sourced innovations:

- Marketing research, now chartered to seek need data, analyze it, develop responsive "product concepts" and estimate market sizes, would be reoriented to search out data on user prototypes, analyze the utility these have displayed in field use, and estimate their potential as commercial products.

- The sales force, now designed primarily to disseminate information on present products, would acquire the added function of acquiring information on promising user prototypes during visits to customer facilities.

- R and D, now motivated and staffed to develop a product from concept data supplied by marketing research, would be reoriented to perform only product engineering work on user prototypes.

Obviously, each of these changes in the established role of an organizational group requires related changes in the interests and skills of group members, and so on. For example, salesmen are now neither trained nor motivated (sales compensation systems generally reward large volume sales of existing products, not possible sales of future products) to seek user prototypes or report back what they see. And R and D groups are presently staffed by people trained and motivated to do the entire product development job, rather than by product design specialists only.

Clearly, the finding that users often undertake a major role in the innovation process in a given industry will have major implications for
innovation-related practice for firms participating in that industry.

**Implications for Government**

Government has a major and pervasive impact on the innovation process. It is a major funder of R and D, a major purchaser of innovative products, and it sets the ground rules according to which others may innovate (FDA) and be rewarded for innovation (patent policy). When it is demonstrated that, in certain industries, users rather than manufacturers undertake the bulk of the innovation work, some problems which have traditionally concerned government policy makers will disappear and others (alas) will emerge. An example in each category:

- Government, correctly cognizant that innovation in process equipment plays a major role in the economy's improvement in productivity, has often cast a worried eye at the fact that producers of many types of process equipment (eg. machine tools) tend to be small and financially unable to support sophisticated R and D programs. This fact, I suggest, will cease to be worrisome if and when it is demonstrated - as we have already seen done for some classes of process machinery - that manufacturers of many classes of such equipment seldom innovate themselves, but simply provide the manufacturing function for innovative users.

- Government has tended not to worry when firms which use innovative industrial goods and are labor intensive (eg. textiles) depart US shores. After all, it is reasoned, the comparative advantage of our economy does not lie with goods of a high labor content - and we will still sell such off-shore industries the sophisticated capital goods they need. It has been observed in two industries, however, (4,17) that innovative process plant and machinery developed by users is very likely to be transferred to machine builders
in the same country. An implication which government may find wise to test is: In the case of industries characterized by user dominated innovation patterns, does the departure of users of innovative industrial goods from the U.S. result in the decline of domestic manufacturers of such goods due to the inaccessibility of innovative users?

Problems resulting from the finding that the locus of innovation activity is an innovation process variable can only be seen and addressed when data on the locus of innovation is available. A first priority for government, therefore, is to get its measures of the locus of innovation activity in order. (Currently, as I noted in the methods section, data for NSF's Science Indicators are gathered in a manner which contains an inbuilt bias toward the finding that the manufacturer is the innovator.) Next, given the high government interest in and impact on innovation processes, further research on the locus of innovation activity as a strong, operationally malleable process would seem of potential value.
1 E. Mansfield, "Contribution of R + D to Economic Growth in the United States" Science, 4 February, 1972, pp. 447-486 provides an excellent review and critique of the several studies on this topic.


10 This assumption can be clearly seen in the prescriptive literature on the new product development process addressed to manufacturers. Examples of such literature:


11 Gellman Research Associates, Inc., Indicators of International Trends in Technological Innovation, National Science Foundation, Directorate for Scientific, Technological, and International Affairs Division of Science Resource Studies, Science Indicators Unit Content No. NSF-C889, Final Report April, 1976. A consequence of the methodology of this study which may be of interest to readers of Science: Innovations in "Professional and Scientific Instruments" which we have found to be usually the product of effort by university-based scientist and engineer users of such instrumentation, are linked to R and D performed by instrument firms but not linked to the efforts and expenditures of such users.

13 M. Peck, "Inventions in the Postwar American Aluminum Industry", in *The Rate and Direction of Inventive Activity* National Bureau of Economic Research 1962, p. . In the paper Peck kindly offered to supply interested readers with citations for the data used in his study. Via the listing I was able to reassemble 44 of the 52 published invention descriptions which comprised the "Aluminum Joining" portion of Peck's sample, and determined that 27 of these descriptions (used to code the "source of the invention") were contained in new production announcements. The Editor of *Modern Metals* during the period sampled was contacted and informed me that material for such announcements was usually provided to the Journal's editorial staff by product manufacturers and that the staff had "no way of knowing" who the inventors were.

14 Observation based on unpublished data kindly supplied by T. Duchesneau, Principal Investigator on the Diffusion of Technology Project at the Social Science Research Institute, University of Maine, Orono.


21a Ibid pp. 15, 16.

I should perhaps note a hypothesis which seems to naturally spring to the minds of scientists when informed that we have determined that 80% of scientific instrument innovations are developed by users. The scientists propose that the locus of innovation is a function of the relative technological "sophistication" of users and manufacturers in an industry - and that instrument users (scientists) are probably more sophisticated than instrument manufacturers in aggregate, while chemical manufacturers are probably more sophisticated than chemical users, in aggregate. The difficulty in testing this appealing (at least to the scientist) hypothesis - apart from the non-trivial problem of finding a replicable measure for "sophisticated" - is that only a relatively small proportion of all users appear to be product innovators (in our study of semiconductor process innovators, for example, all user-developed innovations were found to have been developed by approximately 20% of all user firms\(^{(9)}\)), and every field would seem to have at least some "sophisticated" users. Thus, while one might find that "most" users of engineering plastics are unsophisticated, would one classify major electrical equipment manufacturers and aerospace firms under that heading? And on the other hand, if we took a survey of all instrument users, wouldn't we be likely to find that the largest number were "unsophisticated" users applying the instruments to routine laboratory and industrial functions such as quality control? Clearly, the hypothesis would have to be reformulated before testing - if it could be tested at all - and its intrinsic interest to the scientist-user might well suffer in the process.

25 Knight, op cit chap. 7, p. 11.


28 See R. Merton The Sociology of Science, University of Chicago Press 1973, for an extended discussion of the incentive systems operating in the scientific community.


30 The inability of innovators in some industries to capture benefit from the diffusion of their innovation to imitators has an interesting implication: Many innovations which would pay if cost and benefit were computed on an industry-wide basis will not be undertaken because an innovator who may bear the entire cost (Although in this paper I have only mentioned mechanisms for capturing innovation benefits such as licensing, mechanisms for sharing innovation costs also exist in some industries, such as user R and D associations or government funding of R and D.) cannot capture commensurate benefit. cf. E. Mansfield et al. "Social and Private Rates of Return from Industrial Innovations", Working Paper, Wharton School, University of Pennsylvania, September, 1975.
31 See, for example, Arthur D. Little, Inc., *Patterns and Problems of Technical Innovation in American Industry: Report to the National Science Foundation* Office of Technical Services, Department of Commerce, September 1963, PB 181-573.