TRANSFERRING PROCESS EQUIPMENT INNOVATIONS FROM USER-INNOVATORS TO EQUIPMENT MANUFACTURING FIRMS

Eric von Hippel

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User-Innovators to Equipment Manufacturing Firms

1.0 INTRODUCTION

In previous publications,[1,2] we have presented evidence that, in some industries, industrial good innovations judged by users to offer them a significant increment in functional utility are usually invented, prototyped and first applied by users themselves, and not by the firms which make a business of manufacturing such goods for commercial sale. The typical innovation process role played by industrial good manufacturers in such industries is "simply" to become aware - somehow - of the user innovation and its value, and then to manufacture a commercial version of the device for sale to the user community as a whole. Schematically, the process may be envisioned as in Figure 1, below.

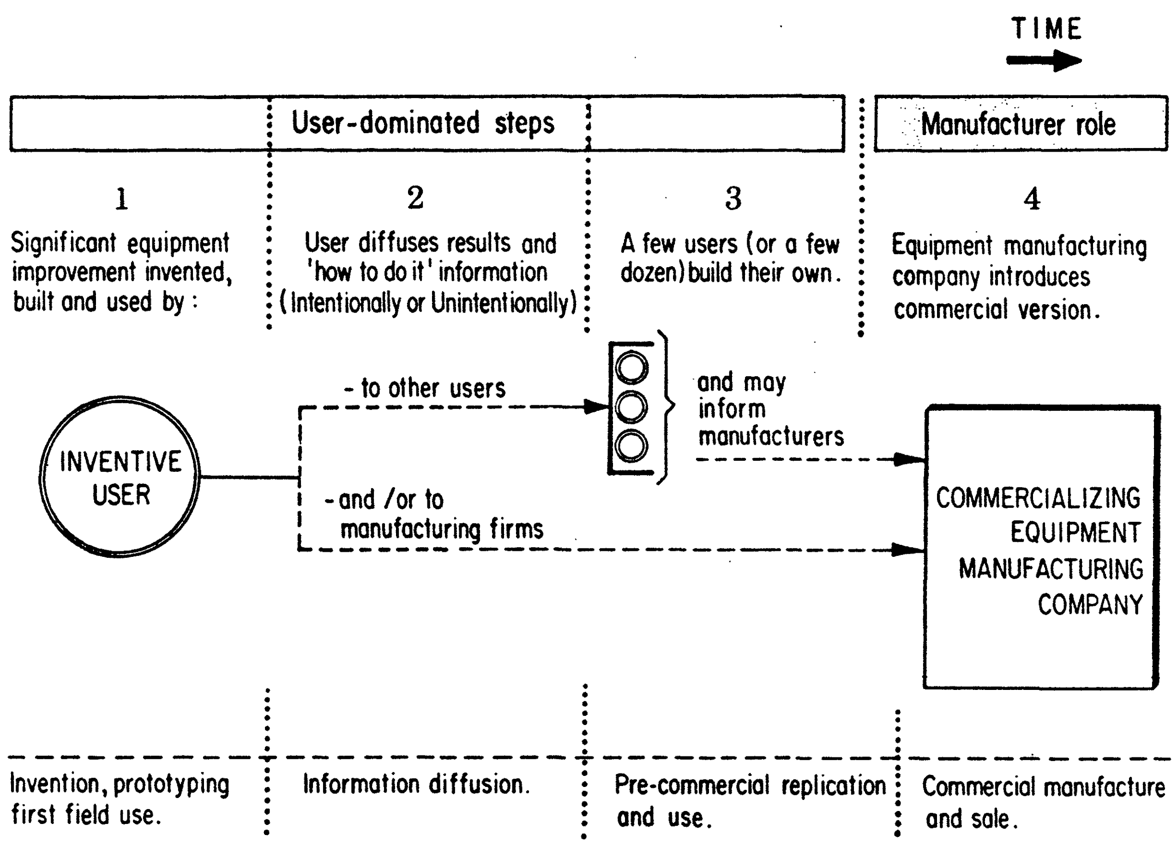

Figure 1: Typical Steps in the Invention and Diffusion of a Process Equipment Innovation

As an example of such a "user dominated" innovation process, consider the innovation history of "wire wrapping". Wire wrapping is a means of making a gas-tight, reliable electrical connection between a wire and a terminal without the use of solder. It has great advantages over soldering in speed, and also allows one to design very dense arrays of terminals without fear that workers, in the process of making a solder connection to one terminal, will inadvertently damage adjacent connections with the heat from their soldering equipment.

Wire wrapping was developed at Bell Labs to provide a means of making electrical connections to a new relay (also being designed at the Lab at that time for use in the Bell Telephone system). The basic wire wrapping process requires a hand tool which winds the exposed end of a wire to be connected tightly onto a terminal of novel design. This hand tool was also designed at Bell Labs, and the entire wire wrap system then passed over to Western Electric for implementation. The Make/Buy Committee of Western Electric decided to have the hand tool portion of the system made by an outside supplier and put it out for bid. Keller Tool of Grand Haven, Michigan - a company which had an excellent reputation as a manufacturer of rotary hand tools such as powered screwdrivers, and which was a supplier of such tools to Western Electric - won the bid. Western Electric gave Keller a complete set of drawings for the tool. Keller suggested design changes which, while preserving the tool's basic design and operating principles, would, in Keller's opinion, make the tool easier to manufacture and use. Western Electric agreed to the changes and, in 1953, a purchase order was negotiated.

Keller realized that some of its other customers for electronic assembly tools would have a use for wire wrap and so requested and obtained a license from Western Electric which would allow sale of the tools on the open market.

In this paper, after a brief review of our evidence that users are indeed the source of most innovations in some industries (Section 2), we will describe our research methods (Section 3) and then focus on findings from our sample of process machinery innovations. We will attempt to characterize: the innovative user (Section 4); the process machinery manufacturer which is first to commercialize user innovations (Section 5); and the means by which information regarding user innovations is transferred to these manufacturers (Section 6). Finally (Section 7), we will discuss some implications of our findings regarding user dominated innovation and its transfer for firm and governmental policymakers.

2.0 INDUSTRIAL GOOD INNOVATION BY USERS - AN OVERVIEW

We have termed a pattern of innovation activity "user dominated" if it is the initial user of an industrial good innovation who:

- perceives the need for the innovative industrial good;
- conceives of a solution;
- builds a prototype device;
- proves the value of the prototype by using it;
- diffuses (intentionally or unintentionally) detailed information on the value of his "homemade" device and on how it may be replicated to other potential users and to firms which might be interested in manufacturing the device on a commercial basis.

Only when all of the above has transpired does the first commercial manufacturer become active in the innovation process. Typically, the manufacturer's contribution is then to:

- Perform product engineering work on the user's device to improve its reliability, convenience of operation, etc. (While this work may be extensive, it typically affects only the engineering embodiment of the user's invention, not its operating principles);

- Manufacture, market and sell the innovative product.

The second pattern of innovation activity which we have observed and reported on - which we term "manufacturer dominated" - displays a more conventional distribution of innovation process activity between user and manufacturer. In this pattern, the maximum user role is a simple expression of need for an industrial good innovation to an interested manufacturer. The manufacturer then undertakes to conceive of a responsive solution, and then to build, test, manufacture and sell the good with no further input from the user required.

To date we have studied two industries which display a high level of user dominated innovation, as is shown in Table 1, below.

Table 1: Pattern of Innovation Activity Observed for Innovations in Two Industries

"Industry" Studied	% user dominated	# user dominated	# other user/ manufacturer[c]	# manufacturer dominated	# NA	sample size
Process Equipment[a]	67%	29	5	9	6	49
Scientific Instruments[b]	77%	72	2[d]	20	17	111

[a]Source: von Hippel[2], Table 2.

[b]Source: von Hippel[1], Table 4.

[c]"Other" patterns of innovation activity sharing between user and manufacturer include any such not subsumed by the definitions of user dominated and manufacturer dominated patterns. Joint ventures between users and manufacturers where both share in all aspects of the innovation work would be an example of such.

[d]In the Scientific Instruments paper[1] both manufacturer dominated and "other" patterns of innovation activity were conservatively (since we were trying to establish the existence of the user dominated pattern) categorized as manufacturer dominated. Summing of the other and manufacturer dominated categories in Table 1, therefore will give the total attributed to manufacturer dominated innovations in that previous paper.

3.0 METHODOLOGY

As we have laid out our research methodology in great detail in two preceding publications[1,2], we will restrict ourselves here to a brief survey of the essentials of our sample selection and data collection methodologies. Readers who would find a more detailed discussion interesting and/or useful are warmly applauded for their excellent taste and earnestly referred to the two sources noted.

3.1 Sample Selection

In brief, our sample of process machinery innovations[1] was drawn from the universe of machinery used to manufacture 1) Silicon based semiconductors and 2) Electronic subassemblies mounted on so-called "printed circuit cards". The processes by which each of these two types of product are manufactured involve a series of steps. To make electronic assemblies mounted on printed circuit cards, for example, one must first fabricate the boards themselves, then mount electronic components on the board, then make a good electrical connection between the board and the components by soldering, etc. Our sample selection procedure involved selecting a subset of all process steps involved in each type of manufacture for study.[2] For each process step selected, the process

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[1] Although we focus on our research regarding process machinery here, the research methods used in our study of scientific instruments were identical.

[2] 11 of 16 major process steps identified for semiconductor manufacture and 2 of 4 steps identified for electronic subassembly manufacture were selected for study. Because we originally intended to study all process steps but ran out of time before all were completed, the subset studied was not chosen randomly - it was, however, chosen by no conscious system. Process steps and innovations studied are explicitly identified in von Hippel[2], Table 1.

machinery (if any) used in the initial commercial practice of that step was identified and its innovation history included in our sample. Next, all subsequent improvements to process machinery for each step which offered a major improvement in functional utility[3] to the user of such machinery when judged relative to previous best practice used in commercial manufacture were identified, and the innovation histories of these added to the sample. Finally, an exhaustive list of process machinery innovations which offered any increment in functional utility to the user was collected for two randomly selected process steps (one used in semiconductor manufacture and one used in electronic subassembly manufacture), and these made up a sample of minor improvement innovations.

Additional selection criteria common to all innovations included in our process machinery samples are:

- Only the first commercial introduction of an innovation is included in the sample. Second and subsequent "me-too" commercializations of the same innovation by other manufacturing firms are excluded from the sample, as are second and subsequent innovations in which the same functional result is attained by a technical means different from that employed by the initially commercialized version.

- All process equipment innovations in the sample are successful in the sense of receiving widespread use in their respective

[3] Those innovations which offered a major increment in functional utility to users relative to previous best practice were identified independently for each process step studied (e.g., major improvements in component insertion equipment were identified by comparison with the universe of component insertion equipment innovations only). Improvements in equipment typically had an impact on several dimensions (precision, speed, reliability, etc.) not easily made commensurable. Judgments as to which of these represented "major" increments in utility were made by the researchers after a polling of the opinions of several expert users of such equipment - manufacturing engineers in semiconductor and electronic subassembly manufacturing companies - in the Boston area.

industries and becoming a commercially viable industrial good - manufactured for commercial sale by at least one (and usually several) process equipment firms.

3.2 Data Collection Methodology

Once we had identified the sample of innovations for study, we sought out essentially every potential source of information regarding: the first user, if any, to invent the equipment innovation and reduce it to commercial practice; the first process equipment firm to manufacture the equipment for commercial sale; the method(s) of information transfer between these. As a first step, equipment manufacturers and users were queried, and trade journal ads were searched to determine the first firm to commercialize the innovation. Then all at the commercializing firm who claimed to have been directly involved in the innovation work or to have knowledge of it were interviewed, usually by telephone. Other persons identified by interviewees as having knowledge of the innovation were traced to their present addresses and also interviewed.

In parallel with our interviews of persons associated with the first commercializing firm, we searched for possible user innovators via interviews at likely user firms and via examination of the appropriate technical literature in the period prior to commercial manufacture of the innovation for evidences of relevant user activities. When such was found, authors of the articles were contacted and the user innovators identified, traced and interviewed.

Information from these various sources was assembled, discrepancies noted, and interviewees with information bearing on the discrepancies contacted again for further discussion. Some areas of confusion were cleared up by this process, others were not. We always attempted to accurately preserve differing versions of events where they existed, and did not attempt to determine "who was right". If proper coding of an item would require us to make such a judgment, we coded it NA (Not Available).

3.3 The Sample

The total sample of process machinery innovations studied, and the distribution of these into the categories of user dominated innovation, manufacturer dominated innovation and "other user/manufacturer" (cf. Table 1, note c) is displayed in Table 2, below.

Table 2: Innovation Pattern Observed for Process Machinery Innovations

		% User Dom.	# User Dom.	# Mfr Dom.	# Other User-Mfr Pattern	# NA	# Total
Semiconductor Processing Innovation	Initial Comm'l Practice	100%	5	0	0	0	5
	Major Improvement	71%	10	2	2	2	16
	Minor Improvement	56%	5	3	1	2	11
Electronic Subassembly Processing Innovation	Initial Comm'l Practice	100%	2	0	0	0	2
	Major Improvement	40%	2	2	1	1	6
	Minor Improvement	62%	5	2	1	1	9
	TOTAL	67%	29	9	5	6	49

For our present purposes - an exploration of how user dominated innovations are transferred to the first equipment firm to manufacture them for commercial sale - we will focus on that subset of our innovations sample which we found to be user dominated, with only occasional reference to our sample of manufacturer dominated innovations for purposes of comparison.

4.0 CHARACTERIZING THE INNOVATIVE USER

In 19 our of the 29 instances of user dominated innovation in our samples we were able to determine which user firm was the first to develop the innovative process equipment involved and use it in commercial production.[4] These firms are identified in Table 3 below along with the number and "type" (i.e., initial commercial practice, major improvement or minor improvement) of innovations in our sample for which they had priority (Column 1).

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[4] In the remaining cases of user dominated innovation in our sample (listed as NA in Table 3) many user firms had built and used "homemade" versions of the innovative equipment prior to introduction of a commercial version by an equipment manufacturing firm, and we were unable to determine which innovating user had been first to do so. Note that in such instances and in general, we are unable to say that the first user to invent a process machinery improvement and reduce it to practice and use in commercial production was the only "inventing" as opposed to invention-adopting user. Independent invention of the same device by two or more users is a clear possibility and, had we investigated it, we could probably have increased our sample of inventive users thereby. Maximum return for our investigative resources in terms of "inventing users identified per user case examined", however, is clearly attained by focusing on cases of first users, and we therefore made the decision to adopt such a focus for this study.

Table 3: Characteristics of Equipment User Firms Identified as Equipment Innovators

	First-Innovating User Firm:	1 # of Process Equipment Innovations: initial	major	minor	2 Major Process Innovations[a]: Tilton	Golding	3 Date of First Commercial Use of Process Equipment Innovation	In Year of First Commercial Use of Process Equipment Innovation: 4a Innovative Firm's Shipments $	4b industry rank[b]	5 # of U.S. Semiconductor Firms Extant[d]	6 # of U.S. Patents Awarded Year + 3[e]	7 Patent Rank Relevant to Other Extant U.S. Firms[f]	8 Sales of Parent Firm[g]
SEMICONDUCTOR PROCESS EQUIPMENT	—						1959	20mm	6	34	2	19	43mm
	Fairchild	1	1	3	1	1	1960	27mm	6	47	3	20	
	—						1966(3)	146mm	2	50	NA	19*	
	—						1965			50	41	3	3.7B
	IBM		2	1			1965		NA[c]	50	41	3	3.7B
	—						1967			53	NA		5.3B
	Western Electric	1	1		5	4	1956	4.5mm	6	26	72	1	
							1960	27mm	6	47	54	1	7.9B
	Hughes	1					1970		NA	NA	NA	8*	NA
	Motorola		1				1961	28mm	6	53	8	8	298mm
	NA	2	5	1									
ELECTRONIC SUBASSEMBLY PROCESS EQUIPMENT	IBM		2				1959						1.3B
							1964						3.2B
	Western Electric	1					1952						4B
	Admiral Radio			1			1952						191mm
	Saunders Associates			1			1956						4.2mm
	Automatic Electric			1			1967-8						498mm
	RCA			1			1957						
	NA	1	0	1									

Sources: Data from our own research except as indicated below.

[a]Ref.: Tilton[3], p. 60, Table 6-3, and Golding[4], p. 68, Fig. 3-2. Firms not listed in Table 3 and found by Tilton and Golding to be responsible for major process innovations are General Electric and Philco-Ford. The process innovations were: (1) jet etching by Philco-Ford in 1953; (2) alloy process of junction formation by GE in 1952; and (3) plastic encapsulation of semiconductors by GE in 1963 (Tilton only). These were excluded from consideration in our sample because of our sample selection criteria; e.g., 1 and 2 were innovations primarily applicable to germanium rather than silicon substrates and 3 applied to protective encapsulation of completed semiconductors, a process step we did not study. Tilton (p. 66, Table 4-5) shows that both GE and Philco-Ford had a major market share in the 1957-66 period examined by him, so the correlation between high market share and process innovation which we observe in Table 3 would not have been weakened had we included the three additional process innovations in our sample.

[b]Rankings derived by conversion of Tilton data (p. 66, Table 4-5) on percent of semiconductor shipments attributable to major firms into rankings (shipments data includes in-house and government sales). Firms with the same shipment % in a given year are all given the same rank. Tilton's data only cover the years 1957, 1960, 1963 and 1966. For innovations whose date of first commercial use (Col. 3) falls between these years, data on the <u>nearest</u> of the years examined by Tilton are used.

[c]IBM has, since 1962, been a major producer of silicon semiconductors for in-house use only, and thus "shipments" data are not available to determine IBM's market share rankings. Industry "guesstimates" of IBM's ranking in 1965 and 1967 place that firm conservatively among the top ten - and probably among the top five producers for those years.

[d]Tilton, p. 52, Table 4-1.

[e]Patents issued reflect innovative activity at the time the patents were filed. Average lag between patent filing and issuance in the period at issue was 3-4 years. We therefore use patent data from Tilton, p. 57, Table 4-2, three years later than the Column 3 date for an innovation's first commercial use.

[f]Patent counts from Tilton, p. 57, Table 6-2, are converted into rankings. Where the year required (e.g., three years <u>after</u> the date in Col. 3 - cf. Footnote e) is not covered in the span of Table 4-2, the rank has an asterisk appended and represents an average rank for the company for all years covered by the Table (1957-1968).

[g]Data from annual reports of parent companies.

A key finding which emerges from Table 3 is that semiconductor firms which are responsible for equipment innovations are among the largest firms in the industry in terms of semiconductor shipments. In fact, a comparison of Columns 1, 4b and 5 will show that the top 15-25% of firms in terms of shipments are responsible for 100% of the process equipment innovations in our sample.

Other measures indicate that the five firms which we have identified as innovative users of semiconductor process equipment are unusually innovative in other aspects of semiconductor technology as well. From Column 2, we see that these same firms are responsible for 6 of the 9 process (as opposed to process equipment) innovations judged by Tilton to be the most important in the history of semiconductor manufacture. And, as is indicated by Columns 6 and 7, semiconductor-related patent activity[5] is relatively high in these firms - with the notable exception of Fairchild.

In Column 8 we note that all firms found to be innovating users of process equipment had - or belonged to parent firms[6] which had - sales above $40 million at the time of the process machinery innovations we are considering. (We will use this rough measure of financial capability later when we compare user firms to process equipment manufacturing firms.)

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[5] Tilton, who developed this data from U.S. Patent Office records, notes that:

> "These patents cover new semiconductor devices, new methods of semiconductor fabrication, new equipment for manufacturing and testing semiconductors, and new applications of semiconductors in final electronic products where their use is important enough to have merited explicit notation in the title of the patent." (p. 56)

[6] Fairchild was acquired by Fairchild Camera and Instrument in 1954, and therefore, sales figures of the parent company are shown.

The universe of major fabricators of electronic subassemblies is large and diverse, ranging from consumer goods manufacturers to military electronics manufacturers, and, unfortunately, statistics analogous to those collected by Tilton on users of semiconductor manufacturing equipment are not available. The data in Table 3 characterizing innovative users of electronic subassembly equipment is therefore sparse. One can reasonably suspect, however, that 5 of the 6 firms identified as user innovators in our sample are among the larger U.S. fabricators of electronic subassemblies - and this would be in line with our findings regarding innovative users of semiconductor processing equipment.

In sum, Table 3 shows that the first users to develop and apply innovative process machinery which offers significant incremental functional utility to user firms (and which is eventually manufactured for commercial sale by process equipment firms) are among the top 25% of semiconductor firms and among the "larger" fabricators of electronic subassemblies in terms of product shipments. Further, the first user-innovators of semiconductor process machinery all rank in the top 40% of extant semiconductor firms in terms of patent activity in the semiconductor field.[7]

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[7] Recall that we have been able to identify the first users to innovate in only 19 of the 29 cases in our sample - is it possible that the cases coded "NA" are the very ones in which smaller users were first? It _is_ possible, we judge, if contributions by small firms were not recalled at all by user and manufacturer interviewees. Barring this collective lapse of memory, however, we judge that the Table 3 characterization of the innovative user firm as among the larger of extant user firms would remain undisturbed if NA's were identified and added to our sample. The problem of identification in these instances lay in general with _which_ of the larger firms was the first user rather than in a choice between members of a mixed group of large and small firms.

5.0 CHARACTERIZING THE MANUFACTURER OF USER INNOVATIONS AND THE INNOVATIVE MANUFACTURER

As we shall show, equipment manufacturers which independently develop innovative process equipment are similar to those which are first to adopt user innovations - and both look very different from innovative user firms.

From Columns 2 and 3 of Table 4, we see that almost all companies which are first to commercialize user innovations are very small, but seldom (Column 3) newly founded to commercialize that product. (All company names have been coded to honor the request of some manufacturing firm interviewees.)

From Columns 5 and 6 of Table 4, we see that semiconductor equipment manufacturing firms which independently developed and commercialized a process equipment innovation in our sample were also small firms in terms of annual sales. Equipment firms which independently developed and commercialized innovative process equipment for electronic subassembly manufacture were somewhat larger. (A comparison of company codes in Sections A and B of Table 4 will show manufacturing firms first to commercialize user innovations sometimes innovate independently as well.)

Note that only two user firms in our sample manufactured process equipment for commercial sale as well as for in-house use (cf. note b, Table 4). Why didn't these firms (or other large firms) choose to participate in equipment manufacture? Because, we speculate, the market for any particular item of equipment was too small to be of interest to such firms. (While equipment manufacturing firms were unwilling to release sales figures for individual equipment types, we may safely

Table 4: Characteristics of Firms First to Commercialize Innovations (A) Developed by Users and (B) Developed by the Commercializing Manufacturer

Process Equipment Innovations for:	A. Initial Manufacturers of User Innovations						B. Innovating Manufacturers					
		1 # of Innovations			2	3		4 # of Innovations			5	6
	Company Code	initial	major	minor	$ Sales at Date of First Comm'l Use of Innovation	New Company?	Company Code	initial	major	minor	$ Sales at Date of First Comm'l Use of Innovation	New Company?
Semi-conductor Manufacture	A	1	2		< 2 mm	no						
	B	1			1 mm	no	K		1	1	0	yes
	C		1		NA	no	N		1		0	yes
	D		1		2.5 mm	no	L			1	0	yes
	E		1[b]		NA	no	NA			1		
	F		1		< 16 mm	no	Total	0	2	3		
	G		1		100 k	yes						
	H		1		NA	no						
	I		1		1.2 mm	no						
	J_1	1[a]			< 2 mm	no						
	J_2		1[a]		< 10 mm	no						
	K			1[a]	0	yes						
	L			3[a]	0	yes						
	M			1	NA							
	NA	2	0	0								
	Total	5	10	5								
Electronic Subassembly Manufacture	P	1			5.8 mm	no						
	Q_1		1		1.5 mm	no						
	Q_2		1		5.7 mm	no	V		1		68 mm	no
	R	1		1	< 1 mm		T			2	< 20 mm	no
	S			1[b]	1,171mm		X		1		NA	no
	T			1	< 20 mm		NA	0	0	0		
	U			2	< 100 k	yes	Total	0	2	2		
	NA	0	0	0								
	Total	2	2	5								

[a]Even though a user(s) had invented, prototyped and applied these innovations to commercial production prior to the introduction of a commercial version and information on their activities had been diffused (thus fulfilling our criteria for user dominated innovation) in these instances the manufacturer had apparently not heard of the user activity and made an independent and parallel invention.

[b]User manufacturing own innovation for commercial sale.

deduce that, in the year of introduction of an equipment innovation, an upper bound on sales volume achieved for it is clearly the total sales for the firm shown in Columns 2 and 5.)

We have been able to collect some estimates (Table 5) on recent overall market sizes and market shares for many of the lines of equipment examined in our study of semiconductor process equipment, and despite the growth in semiconductor sales to the present day, 1974 sales of semiconductor process equipment are still not the stuff to enliven the dreams of the managers of major corporations. As the reader can compute for himself, sales of the market leaders in a particular line of equipment usually are under $10 million even today.

Table 5: Industry Estimates of Annual Worldwide Sales of Selected Lines of Semiconductor Process Equipment*

Equipment Category	Annual Equipment Sales in Category Worldwide 1974	1975	Market Shares, % 1st co.	2nd co.	3rd co.
Czochralski Crystal Growers	6 mm	6 mm	30%	30%	10%
Wafer Saws	NA	3 mm	30%	30%	
Wafer Lappers/Polishers	3 mm	3 mm	20%	15%	10%
Epitaxial Reactors		15 mm			
Step and Repeat Microreduction					
Wafer Coaters and Developers	15 mm		50%	35%	12%
Computerized Mask Generators		8 mm	90+%		
Photomask to Wafer Aligning in Exposing Systems	28 mm	17 mm	65%	20%	20%
Diffusion Furnaces	50 mm				
Ion Implantation Equipment	12 mm		70%	30%	1%
Scribers and Dicers:					
Diamond Scribers		0.6 mm	90%		
Laser Scribers	0.7 mm	0.7 mm	60%	30%	10%
Dicing Saws		1.2 mm	95%		
Thermocompression Bonders	30 mm		70%	20%	
Ultrasonic Bonders		1.5 mm	80%	15%	
Test Equipment	70 mm				
TOTAL	397	226			

Source: Interviews with marketing personnel in equipment manufacturing firms.

*Work on this data continuing - improved data may be available in published paper.

6.0 TRANSFER OF USER PROCESS EQUIPMENT INNOVATIONS TO EQUIPMENT MANUFACTURING FIRMS

As is indicated in Table 6, Column 2, instances of transfer of user process innovations to equipment manufacturing firms which we observed in our sample fell into one of the following categories:

(a) The initial - or an adapting - user innovator, after having proven the utility of an innovation to his own satisfaction, takes the initiative (Column 3) in transferring the innovation to an equipment manufacturing firm. The user's intent in such instances is invariably to establish an outside source of supply for the equipment capable of servicing in-house demand. (Transfers of technology in these instances are accompanied by an initial purchase order from the user innovator.) The case abstract of "wire wrap", presented in Section 1 of this paper, provides an example of this type of transfer.

Note that in such instances, the lag from the initial user innovation to general marketplace availability is generally short (Column 4), and precommercial diffusion of the innovation via homebuilt copies by other users consequently is slight or non-existent.

All transfers initiated by U.S. user innovators were to U.S. equipment manufacturing firms. (On the basis of our small sample of user initiated transfer, we cannot report further on the criteria used by user-innovators to select equipment manufacturing firms to produce their innovations.)

(b) In the type of transfer most commonly observed, the first-commercializing manufacturer rather than a user takes the initiative in transfer. In such instances, the manufacturer already has members of the user firm community as customers for products or (in one instance)

Table 6: Characterization of the Transfer of Process Equipment Innovators by Users to the First Firm to Manufacture Such Equipment Commercially

Semiconductor Equipment Innovations:

	1	2			3	4	5	6
		Innovation Type						
First User-Innovator	Transfer Pattern Observed	initial	major	minor	Initiative for Commercial Mfg. by:	Lag Between First Production Use and First Commercial Sale (yrs.)	Contact with Solution via:	Contact with Need via:
Fairchild	c	1			Mfr.	2	Independent Invention	Users as Customers
Fairchild	NA		1		New Company	3	NA	Co. Founders had Fairchild Experience
Fairchild	c			3	Mfr.	2	Independent Invention	Co. Founders had Fairchild Experience
Fairchild	c			1	Mfr.	NA	Independent Invention	Co. Founders had User Experience
IBM	b		1		Mfr.	3	Publication of Concept +	Users as Customers
IBM	b		1		Mfr.	6	Publication of Concept +	Users as Customers
IBM	NA			1	User	NA	Specs. and Concept	Co. Founders had User Experience
Western Electric	a	1			User	0	User Eng. Drawings	Customer Order
Western Electric	b		1		User	≥3	On-site Observation +	Customer Suggestion
Hughes	a		1		User	0	Eng. Drawings + Consulting	Customer Order
Motorola	d		1		NA	4	Transfer of User Engineer	Mfr. also User
NA	b	1			Mfr.	≥4	On-site Observation +	Users as Customers
NA	d		1		Mfr.	≈4	Consulting by User Engineer	NA
NA	c		1		Mfr.	≥1	Independent Invention	Users as Customers
NA	b		1		Mfr.	≥4	On-site Observation +	Users as Customers
NA	b		1		Mfr.	≈2	On-site Observation +	Users as Customers
	NA	2						
	Total	5	10	5				

Table 6 (continued)

Electronic Subassembly Equipment Innovations:

First User-Innovator	1 Transfer Pattern Observed	2 Innovation Type initial	major	minor	3 Initiative for Commercial Mfg. by:	4 Lag Between First Production Use and First Commercial Sale (yrs.)	5 Contact with Solution via:	6 Contact with Need via:
IBM	a		1		User	3	User Eng. Drawings	Customer Order
IBM	b		1		Mfr.	3	On-site Observation +	Users as Customers
Western Electric	a	1			User	0	User Eng. Drawings	Customer Order
Admiral	b			1	Mfr.	6	User Eng. Drawings	Users as Customers
Sanders	d			1	NA	4	Transfer of User Engineer	Co. Founders had User Experience
RCA	d			1	NA	NA	Mfr. also User	Mfr. also User
Automatic Electric	b			1	Mfr.	2	On-site Observation	Users as Customers
NA	a	1			User	2	User Specification	Customer Order
	NA			1				
	Total	2	2	5				

services and obtains information about the existence of, utility of, and design of the user innovation from these customer contacts. In this transfer pattern, it was impossible to find one input key to conveying need or solution input to the first commercializer. Contacts with the user community are frequent and diverse and usually, as interviewees often noted, "Everyone was talking about 'X' user design at that time". Because of the multiplicity of inputs apparently contributing to commercializer knowledge in these cases, specific channels of solution input mentioned by interviewees "plus" are noted in Table 6, Column 5 where appropriate. In Column 6, the type of relationship with the user community is noted as the source of need input, with a relationship such as "user as customers" implying multiple and diverse messages and experiences contributing to an understanding of user need.

(c) In this pattern, we could find no transfer between a user-innovator and the first firm to commercialize the innovation, and thus concluded that in these cases of "user dominated" innovation the commercializing firm made an independent parallel invention. (These innovations were nonetheless coded as user dominated because the user innovation was in commercial use prior to the initial sale of the manufacturer version. In all of the cases, information on the user developments was available prior to the initial sale of the manufacturer's version in publications (2) or in industry gossip (2) - although the manufacturers apparently were not aware of it at the time.)

(d) This category consists of "other" patterns with characteristics as described in Table 6.

In overview, the information in Table 6 suggests that the means by which an innovation is transferred varies as a function of the identity of the first user-innovator. Most strikingly, it would appear that Western Electric tends to seek outside equipment suppliers to manufacture process equipment innovations developed in-house, while Fairchild tends not to help in innovation transfer even to the extent of publication. Interviewees at these companies concur in these characterizations. In the instance of Western Electric, we were told that it is company policy to freely license manufacture of any item of equipment used in the Bell System. In the instance of Fairchild we were told that company policy, especially in the "early days" was to strive to keep process innovations an in-house secret.

7.0 DISCUSSION

Is the fact that process innovation in an industry is characterized by user dominated innovation a cause for glee or dismay on the part of those concerned about effective and efficient industrial good innovation? "Potential net glee" is possibly indicated in that the most recent work which quantitatively examines factors which differentiate between commercially successful and failing industrial good innovation projects finds that "accurate understanding of user need" is the most salient factor[5] and, clearly, users who innovate are in an advantageous position to accurately perceive user needs. Conversion of potential net glee into actual net glee, however, must await the development and testing of effective strategies for managing user dominated innovation processes - an effort not yet begun, but which can begin now that the pattern we have termed user dominated innovation has been brought into focus. As a start to the work, we will note below some of the implications of our findings to date for firms and governmental policymakers interested in the management of user dominated innovation.

7.1 Implications for the Would-be Manufacturer of User Innovations

Because user dominated innovation accounts for more than two-thirds of first-to-market innovations in at least some industries (cf. Table 1), manufacturing firms interested in being first-to-market with innovations in those industries can afford to devote considerable effort to properly matching up with one innovation source - the user. Appropriate matching will involve:

- Hiring engineers skilled at product engineering rather than R&D - or even D.
- Developing market research strategies which focus on a search for user solutions with attractive market potential rather than on a search for user "needs".

Hiring only engineers skilled in product development is easy once a firm recognizes the appropriateness of such a strategy - product design is a recognized specialty with skilled practitioners. Interestingly, however, a major implementation problem will sometimes be that manufacturing firms participating in industries characterized by user dominated innovation will resist the insight that their only innovation role is product engineering rather than "real R&D". The primary source of this resistance, we judge, is an emotional feeling on the part of some manufacturers that recognition of the dominant role of the user in the innovation process demeans the manufacturer in some way.[8]

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[8] We may bring this feeling closer to home for any fellow professional "manufacturers" of management strategies who may be reading this article. Suppose the supposition of manufacturer dominated innovation in our field is incorrect; suppose that "...the development and testing of effective strategies for managing user dominated innovation processes..." (mentioned at the start of this section) has already been done by firms using the strategies, leaving us only "product engineering" and "manufacture for commercial sale" (publishing) to do? (Do we hear a faint cry of "Impossible! Absurd! Never!"?)

Development of marketing research strategies capable of economically identifying user prototypes with commercial potential will not be easy; there are many users to be screened - and many user innovations are never commercialized.[9] Our finding that all user semiconductor process equipment innovations in our sample could be traced to only 15-25% of the firms using such equipment gives some hope, however, that efficient preliminary screening criteria can be found. Additional guidance for firms interested in being the first to commercialize user dominated innovations is provided by our finding that the most frequently observed transfer pattern in our sample (pattern b) involved initiative by manufacturers who were already "in the business" and obtained need and solution input as a result of contact with users already in their roster of customers.

7.2 Implications of User Dominated Innovation for Government Policymakers

The discovery that user dominated innovation patterns account for the bulk of innovations - other than functional "me-too's" - in industries as important to the national economy as process machinery and scientific instruments raises a host of pressing questions for government policymakers concerned with innovation. It is important to know, for example, how "efficient" user dominated innovation is relative to manufacturer dominated innovation; where the bottlenecks in the system are; what regulatory incentives available to government might impact these; etc. Answers to the vast majority of such questions must await further research. Two implications for government innovation

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[9] See John Markus[6] for a "snapshot" of the large amount of user innovation work which may go on in one industry at a moment in time.

policy, however, can be noted on the basis of research to date, and we will discuss these briefly below.

First, we note that user dominated innovation involves an extra transfer step - from user-innovator to commercial manufacturer - not required in the instance of manufacturer dominated innovation. We have seen from Table 6 that, if the user takes transfer initiative, the time lag associated with this step may virtually disappear, while if the initiative is left to manufacturers, the time lag from first commercial use by the user-innovator to first sale of a commercial version by an equipment manufacturing company averages three years. While it may be that elimination of the three year lag would not increase the speed with which an ultimately successful process equipment innovation (study might show that users who would quickly adopt a commercially manufactured version of the innovation are also quick to build homemade copies in the absence of such, while those who would "wait till it's proven" would wait three years to adopt whether a commercial device was available or not), it is quite likely that speed of adoption of process equipment innovations - and associated production economies - would be improved if the lag to commercialization were reduced.

One way to reduce lag to commercialization would be to increase the incentive of user-innovators to initiate a transfer to an equipment manufacturing firm. At the moment, the only meaningful incentive we have seen for such an initiative is the sometimes-present desire on the part of the user-innovator to have an outside source of supply for his novel equipment. Users currently have effectively no financial incentive to hasten the diffusion of the innovation to others in the user community; in fact they may have a negative financial incentive in that sole use of the innovation gives them a competitive advantage over other potential user firms. Licensing fees are the only potential positive financial pull on the user to induce diffusion currently in place, and these are seldom assessed and when they are - as the reader may suspect from the typical market sizes shown in Table 5 - they are trivial and can have little impact on the behavior of user-innovator firms of the size indicated in Table 2. Yet the benefit reaped by adopting users may well be large and could probably support a larger return to the user-innovator in exchange for quicker diffusion of his innovations.[10] Indeed, a larger return from diffusion of user innovations might even induce user-innovators to undertake innovations which would not pay out when measured against the benefit obtained by the user-innovator firm alone but which might pay out handsomely on an industry-wide basis.

A second implication of our findings for government policymakers: Those inclined to be concerned (as I am) about the state of our international balance of payments may wish to consider our finding that process innovations by users located in the U.S. are transferred to U.S. equipment manufacturing firms first. An implication which we may find it wise to test: In the case of industries characterized by user dominated innovation patterns, does the departure of <u>users</u> of innovative industrial goods from the U.S. (as in textiles) result in the decline of domestic <u>manufacturers</u> of such goods due to the inaccessibility of innovative users?

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[10] See Edwin Mansfield, et al.[7], for a presentation and discussion of the wide discrepancy found in 17 cases between returns to innovators and returns to adopting firm and society at large.

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