Transferring process equipment innovations from userinnovators to equipment manufacturing firms

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Abstract. Product users are not usually thought of as product innovators. We have found, however, that 67% of the significant process equipment innovations in the two fields of semiconductor manufacture and electronic subassembly manufacture were in fact developed by equipment users rather than equipment manufacturers. Our analysis of the process by which these user innovations are transferred to the first firm to manufacture them commercially shows three major patterns: 46% transferred by multiple user-manufacturer interactions; 21% transferred via a direct purchase order from the inventive user; 8% manufactured by a user firm for commercial sale. A final 25%, we found, were apparently *not* transferred, but were reinvented by the equipment manufacturing firm.

Inventive user firms and adopting equipment manufacturing firms are characterized, and the implications of our findings discussed.

1.0 INTRODUCTION

In previous publications (von Hippel, 1976a and 1976b), we have presented evidence that, in some industries, industrial products 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 product 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.

This pattern of innovation by product users is contrary to the usual assumption that product manufacturers are responsible for the innovation process from 'finding the need to filling it' via development of a responsive new product. Yet we have found that innovation by users is strongly present in the industries we have studied: The percentage of innovative products developed by users ranges from 67% to 77% of all innovative products sampled.

An innovation pattern so strongly present in some industries is of research interest and may also be of potential operational utility to firms: it may well be managerially practical to reorganize a firm's innovation activities in a manner responsive to a pattern accounting for more than two-thirds of all innovation cases. Accordingly, we have felt it appropriate to press our studies of innovation by users beyond a simple demonstration that the phenomenon exists and is pervasive in some industries.

In this paper, we will report on further research into innovation by product users built upon our previously characterized (von Hippel, 1976b) sample of innovations in process equipment used in the manufacture of (a) silicon-based semiconductors and (b) electronic subassemblies fabricated on printed circuit boards. We will proceed by first briefly reviewing our evidence that users are indeed the source of most innovations in some industries (Section 2). We will next describe our research methods (Section 3) and then focus in turn on each of the three major elements involved in the transfer of user innovations from innovating user to adopting manufacturer, viz: Characteristics of the *innovative* user firm (Section 4); characteristics of the process machinery manufacturing firms which are the first to commercialize user innovations (Section 5); and, thirdly, the nature of the process by which user innovations are transferred from innovative users to the adopting manufacturers (Section 6). Finally (Section 7), we will discuss some implications of our findings regarding product innovation by users and its transfer, for firm and governmental policymakers.

2.0 INDUSTRIAL PRODUCT INNOVATION BY USERS-AN OVERVIEW

We have termed a pattern of innovation activity 'user dominated' if it is the initial *user* of an industrial product who:

-perceives the need for the product innovation;

- -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.

Schematically, the process may be envisioned as in Figure 1.

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

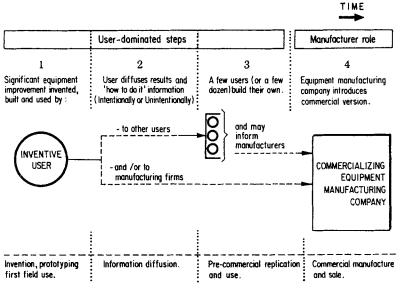


Figure 1. Typical steps in the invention and diffusion of a process equipment innovation.

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 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 inplementation. 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. The wire wrap technique is now widely used in the electronics industry, and Keller (now a division of Gardner-Denver) is a major supplier of wire wrap equipment ranging from simple hand tools to complex automated machinery.

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 innovative industrial product to an interested manufacturer. The *manufacturer* then undertakes to conceive of a responsive solution, and then to build, test, manufacture and sell the product with no further input from the user required.

3.0 METHODOLOGY

3.1 Sample selection

In brief, our samples of process machinery innovations were 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. Eleven of the 16 major process steps identified for semiconductor manufacture and 2 of the 4 steps identified for electronic subassembly manufacture were so selected. (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 Table 1 [von Hippel, 1976b].)

For each process step selected, the process 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 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.

Innovations which offered a major increment in functional

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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.

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 sub-assembly manufacture), and these made up a sample of *minor improvement* innovations.

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

- -Only the *first* commercial introduction of an innovation was included in the sample. Second and subsequent 'me-too' commercializations of the same innovation by other manufacturing firms were *excluded* from the sample, as were second and subsequent innovations in which the same functional result was attained by a technical means different from that employed by the initially commercialized version.
- -All process equipment innovations in the sample were successful in the sense of receiving widespread use in their respective 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; and 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 evidence of relevant user activities. When such were 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).

		% User ^a dom.	No. user dom.	No. mfr. dom.	No. other user-mfr pattern ^b	No. NA	No. total
Semiconductor	Initial comm'l practice	100%	5	0	0	0	5
processing	Major	100/0	Ũ	-	-		-
innovation	improvement Minor	71%	10	2	2	2	16
	improvement	56%	5	3	1	2	11
	Initial comm'l practice	100%	2	0	0	0	2
Electronic							
subassembly processing	Major improvement	40%	2	2	1	1	6
innovation	Minor improvement	62%	5	2	1	1	9
	Total	67%	29	9	5	6	49

Table 1, Innovation pattern observed for process machinery innovations

^a Conventional wisdom suggests that user-dominated innovation is rare, but even if we allow H_0 to be that user-dominated innovation will be present in 50% of all cases, H_0 would be rejected (p < 0.02) due to the still higher overall level of user-dominated innovation found (67% for two-industry sample).

^b '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.

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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' is displayed in Table 1. 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 innovation 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

The equipment-using firm which innovates is the information generating and transmitting component, as it were, in the system via which user-developed innovations are transferred to equipment manufacturing firms. To the extent that we can identify parameters which distinguish *innovating* user firms from the total set of user firms, we will ease the search task of manufacturing firms wishing to find user developed innovations to commercialize, allow the policymaker wishing to impact the innovation process to focus on an appropriate subset of user firms, and contribute to the innovation researcher's armory of data bearing on the issue of characteristics of firms which innovate.

The data we were able to obtain regarding innovative user firms is displayed in Table 2. This data falls into the categories of innovation counts, firm size (dollar annual sales), dollar sales of product impacted by the process innovations in our sample (this obtained for our semiconductor sample only) and patent counts (semiconductor sample only). The latter two data categories were available as a result of Tilton's work (1971). We did *not* compile data on organizational variables which studies of relatively recent innovations (Achilladelis, 1971) were able to obtain and found to be of interest (e.g. size of R & D team) because the bulk of the innovations in our sample were ten to twenty years old (cf. Table 2, Column 3), and we found the information currently obtainable on such variables to be unreliable.

Note from Table 2, Column 1 that in only 19 out of the 29 instances of user-dominated innovation in our sample were we able to determine which user firm was the *first* to develop the innovative process equipment involved and use it in commercial production. (In the remaining cases of user-dominated innovation in our sample [listed as NA in Table 2] *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, but we were unable to determine which innovating user had been *first* to do so.) These firms are identified on the left side of Table 2 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).

The measure in Table 2 which proved to discriminate best between innovative and non-innovative users of semiconductor process equipment was share-of-market rank in semiconductor shipments (Column 4b). As the reader will note from a com-

parison of Columns 1, 4b and 5, four out of the five innovating user firms identified are ranked among the largest eight firms in terms of share of market in the year of first commercial use of their innovation(s). (The probability that four out of five innovating firms would be found in the top eight of 26 [minimum] extant firms is p < 0.05 if H_0 is that the likelihood of user firm innovativeness is independent of share of market ranking.) Unfortunately, we do not have similar market share data for users of electronic subassembly process equipment. 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. (Computers [IBM], TV sets [Admiral, RCA], and telephone switching systems [Western Electric and Automated Electric] are major consumers of electronic subassemblies.) This would be in line with our finding regarding the large share of market of innovative users of semiconductor processing equipment.

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 2 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.

Calculation of Kendall and Pearson correlation coefficients for total process innovation activity of the firms in our sample vs. accumulated market share of those firms shows that the relationships, while significant, do not offer great predictive power. Interestingly, however, accumulated market share is a better predictor of semiconductor process equipment innovation in our sample of users of such equipment than either of the more traditionally used variables-patent counts and 'size of firm'. (See C. Freeman [1974], Chapter 6, for an excellent review and discussion of research findings regarding the correlation of measures of innovation with measures of R & D expenditure, size of firm, etc.) This relatively good performance may hold in the instance of user process innovation only. On the face of it, market share is a measure of the amount of processing going on in a user firm, and this may be related to process innovation but not, perhaps, to product innovation.

5.0 CHARACTERIZING THE MANUFACTURER OF USER INNOVATIONS AND THE INNOVATIVE MANU-FACTURER

Table 4 data shows that equipment manufacturers which independently develop innovative process equipment have sales volumes similar to those which are first to adopt user innovations—while both look very different from innovative user firms on this measure.

From Columns 2 and 3 of Table 4, we see that almost all companies which are first to commercialize user innovations are

					2			In year c	In year of first commercial use of process equipment innovation	ise of process er	quipment innovat	ion
	Ζ	No. of process equipment innovations	ess t is	Mé pro innov	Major process innovations ^a	ю	4a 4b Innovative firm's semiconductor	4b /e firm's /ductor	a	9	4	ω
					60	Date of first	shipments ^c	entsc	No of U.S.	No. of U.S.	Patent rank relevent to	Sales of
First-innovating user firm	leitinl	noisM	топіМ	notliT	ibloÐ	of process equip- ment innovation	÷	Industry rank	semiconductor firms extant ^d	awarded year + 3 ^e	other extant U.S. firms ^f	firm ⁹ (total)
Semiconductor process equipment												
Fairchild	-		ы	*	۲	1959 1960	20 mm 27 mm	ю u	34	54 6	19	43 mm 68 mm
						1966 (3)	146 mm	9 M	50	A Z	19*	207 mm
IBM		7	-			1965 1965		້ດ	20 20	41 41	ოო	3-7 B 3-7 B
						1967		50	53	۸A		5·3 B
Western Electric	-	-		S	4	1956 1960	4 : 5 mm 27 mm	99	26 47	72 54		7-9 B
Hughes	-					1970		AN	NA	٨N	*8	٩N
Motorola		-				1961	28 mm	9	53	80	8	298 mm
NA	2	ى ك										
Electronic subassembly process equipment												
IBM		2				1959						1·3 B
						1964						3.2 B
Western Electric	-					1952						4 B
Admiral Radio			-			1952						191 mm
Saunders Associates			-			1956						4-2 mm
Automatic Electric			-			1967-8						498 mm
RCA			-			1957						1,171 mm
NA	-	0	-									
Sources for Table 2: Data from our own research except as	from ou	ir own rese	arch excep	ot as indica	indicated below.	are are	used. Conv	ersion of S	are used. Conversion of SOM rankings into \$ shinments was effected via use of Tilton's data	shinments was	effected via use 0	f Tilton's data

^a Ref.: Tilton (1971) p. 60, Table 6.3, and Golding (1971) p. 68, Fig. 3-2. Firms not listed in Table 2 and found by Tilton and Golding to be responsible for major process innovations are General Electric and Philco-Ford. The process innovations were: (11) 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 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 2 would not have been weakened had we included the three additional process innovations in our sample. ^b Share of market rankings are derived by conversion of Tilton data (p. 66, Table 4-5) and 2 were innovations primarily applicable to germanium rather than silicon substrates and excluded from consideration in our sample because of our sample selection criteria; e.g.,

(shipments data includes in-house and government sales). Firms with the same shipment per cent in a given year are all given the same rank. Tilton's share of market data only covers the years 1957, 1960, 1963 and 1966. For innovations whose date of first commercial use (Column 3) falls between these years, data on the *nearest* of the years examined by Tilton per cent of semiconductor shipments attributable to major firms into rankings ő

unon's data

are used. Conversion of SUM rankings into \$ snipments was effected via use of inton's data on total semiconductor shipments (p. 90, Table 4-7). ⁶ IBM has, since 1962, been a major producer of silicon semiconductors for in-house use only, and thus 'shipments' data are nor 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 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 *after* the date in Column 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 (1957–68). ⁹ Data from annual reports of parent companies. Fairchild was acquired by Fairchild Camera and Instrument in 1954, and therefore, sales figures of the parent company are shown.

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Table 2. Characteristics of equipment user firms identified as equipment innovators

Table 3. Correlations between process innovations and market
share, patents and parent firm sales of innovative user firms

		Variable pair		
Statistic Kendall tau Significance Pearson r	Process innovations ^a with market share ^b	Process innovations with patents ^c	Process innovations with parent firm sales ^d	
Statistic				
Kendali tau	0.426	0.283	0.059	
Significance	(0.001)	(0.021)	(0.349)	
Pearson r	0.281	0.254	0.008	
Significance	(0-082)	(0-105)	(0-486)	

^a All classes of process equipment innovation given in Table 2, Column 1 are given equal weight for purposes of Table 3 calculations. ^b Market share is the sum of market share percentages for the four years

(1957, 1960, 1963 and 1966) shown by Tilton (1971), p. 66, Table 4-5.

^c Patents are the sum of patents attributed by Tilton (1971) p. 57, Table 4-2, to each firm for the period 1959-1968. (Patent data lagged two years with respect to market share and sales data. A three-year lag-as in Table 2-would have been preferable but 1969 data was unavailable.) Tilton, who developed his 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.' Tilton (1971), p. 56.

^d Parent firm sales are the sum of those sales for the years 1957-66. Data obtained from corporate annual reports or Moody's.

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 retrospective data on motives is unreliable, we can offer anecdotal support for this speculation as follows: An overall impression derived from our many interviews with innovating user personnel is that process equipment innovations were undertaken by user firms as a necessary evil. 'We had to develop the equipment,' was the theme, 'because no one else would do it for us.' When we raised the issue of why the firm did not manufacture the equipment for sale as well as for in-house use, the issue did not seem strange to user personnel. Apparently, most innovating user firms had at least discussed the issue internally. The issue was generally resolved by a decision that that opportunity was not an attractive

one-at least not relative to the other businesses they were engaged in. Available data on annual sales of the user-developed equipment tends to support these firms' assessment. While equipment manufacturing firms were unwilling to release sales figures for individual equipment types, we may safely 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. Further estimates collected from marketing personnel in semiconductor equipment firms indicate that, even today, free world sales of the market leaders in a particular line of equipment seldom exceed \$10 million.

6.0 TRANSFER PROCESS EQUIPMENT OF USER INNOVATIONS TO EQUIPMENT MANUFACTURING FIRMS

To this point, we have characterized the user firm which develops process equipment innovations and the equipment manufacturing firm which is first to adopt such innovations and manufacture them for commercial sale. What remains is to characterize the transfer process itself-to spell out as clearly as we can both the modes of and motivations for such transfers.

As is indicated in Table 5, Column 2, instances of transfer of user process innovations to equipment manufacturing firms which we observed in our sample fell into one of four categories which can be characterized as follows:

(A) The initial-or an adopting-user innovator, after having proven the utility of an innovation to his own satisfaction, takes the initiative (Column 1) in transferring the innovation to an equipment manufacturing firm. The user's intent in such

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Table 4. Characteristics of firms first to commercialize innovations (A) developed by users and (B) developed by the commercializing manufacturer

					Pro	cess equipme	nt innovations	for					
		^		manufacti innovatio	urers of user ns		B. Innovating manufacturers						
		No	1 b. of innova	tions	2 \$ sales at date of first			No.	4 of innova	tions	5 \$ sales at date of first		
	Company code	Initial	Major	Minor	comm'l use of innovation	3 New company?	Company code	Initial	Major	Minor	comm'l use of innovation	6 New company?	
Semiconductor	A	1	2		<2 mm	no							
manufacture	В	1			1 mm	no	к		1	1	0	yes	
	С		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							
	н		1		NA	no							
	1		1		1·2 mm	no							
	J1	1 ^a			<2 mm	no							
	Ja		1 ^a		<10 mm	no							
	J ₂ K			1 ^a	0	yes							
	L			3ª	0	yes							
	Ň			1	NĂ	,							
	NA	2	0	Ó									
	Total	5	10	5									
Electronic	P	1			5∙8 mm	no							
subassembly	Q ₁		1		1.5 mm	no							
manufacture			1		5-7 mm	no							
	R	1		1	<1 mm		v		1		68 mm	no	
	S			1 ^b	1,171 mm		Т			2	<20 mm	no	
	т			1	<20 mm		х		1		NA	no	
	Ŭ			2	<100 k	yes	NA	0	0	0			
	NA	0	0	0		•	Total	0	2	2			
	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.

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', set forth in Section 2 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 nonexistent.

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 equipmentmanufacturing firms to produce their innovations.)

(B) Pattern B, as stated in Table 5, consists of cases in which an equipment-using firm (any equipment-using firm-not just an

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innovating one) was the first to manufacture an equipment innovation for commercial sale. As can be seen in Table 5, Pattern B is relatively rare in the industries studied. Our speculations regarding the reason for this observation may be found in Section 5, above.

(C) The third pattern of transfer of user innovations to equipment manufacturing firms was the one most commonly observed—and it was both fascinating and frustrating to study. Note that the two objectively codable items indicated on Table 5, Column 3 which were uniformly present in this category simply are *indicators* that two potential sources of need and solution data were *easily* accessible to the company first to adopt user innovations. That is, adopting manufacturers had established supplier-customer *relationships* with user firms and had people with experience at innovating user companies *on their staffs*. We are forced to use these indicators because interactions with users were so frequent in this pattern that it was not meaningful, we felt, to attempt to isolate one or a few contacts as *the* mode by

Transfer		Displ by		Transfer lag: years from first commercial use to first open-market sale			
initiated by	Transfer pattern	%	N	Mean Yrs.	S.D.	N	
User	A. Innovative user needs manufacturer to supply in-house demand—gives purchase order and detailed design	21	(5)	1ª	1.3	(5)	
User	B. User manufactures equipment for sale as well as for in-house use	8	(2)	4	0.0	(1)	
NA	C. Manufacturer is 'part of the industry': has numerous users as customers has personnel with innovating experience	46	(11)	3·7ª	1.3	(11)	
	D. Not transferred. Independent re- invention by manufacturer (occurred in semiconductor equipment sample only)	25	(6)	1-8	0.4	(5)	
	NA	-	(5)			(7)	
	Total	100	(29)			(29)	

 Table 5. Characterization of the pattern by which user process equipment innovations are transferred to the equipment

 manufacturers first to adopt them for commercial manufacture

^a Transfer lag significantly longer in Pattern C than in Pattern A (p < 0.01, Mann-Whitney U Test).

which data on a user innovation was transferred to the firstadopting manufacturer. Usually, as interviewees often noted, 'everyone was talking about X user design at the time'.

(D) The final 'transfer pattern' noted on Table 5 is not really a transfer pattern at all. For cases listed here, 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, as required by our definition, the user innovation was in commercial use prior to the initial sale of the manufacturer version, and information on the user developments was available outside the innovating user firm prior to the initial sale of the manufacturer's version although the reinventing manufacturers apparently had not been aware of it at the time.) As is noted in Table 5, all of these instances of independent reinvention were found in our sample of semiconductor innovations-a very fast-moving industry. (Instances of independent reinvention of user-dominated innovation by other user firms is also a clear possibility in our sample, but our data collection strategy of focusing on the first-inventing user did not allow us to observe these.)

7.0 DISCUSSION

Is the fact that process innovation in an industry is characterized by user-dominated innovation a cause for delight or dismay on the part of those concerned about effective and efficient industrial product innovation? Delight is possibly indicated, in that the most recent work which quantitatively examines factors which differentiate between commercially successful and failing industrial product innovation projects finds that 'accurate understanding of user need' is the most salient factor (Achilladelis, 1971) and, clearly, users who innovate are in an advantageous position to accurately perceive user needs. A full assessment of the relative virtues of user vs. manufacturer dominated innovation, 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 summarize what we now know about user dominated innovation and its transfer (Figure 2) and then proceed to discuss some of the implications of our findings to date for firms and governmental policy-makers 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 the industries tested to date (scientific instruments [von Hippel, 1976a] and process machinery used in semiconductor and electronic subassembly manufacture [von Hippel, 1976b]), 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:

-Employing primarily engineers skilled at product engineering rather than R & D-or even D. (Some *few* engineers who understand the sciences of the user-developed innovations may also be needed for proper interfacing between the firm and user-innovators.)

Transferring process equipment innovations

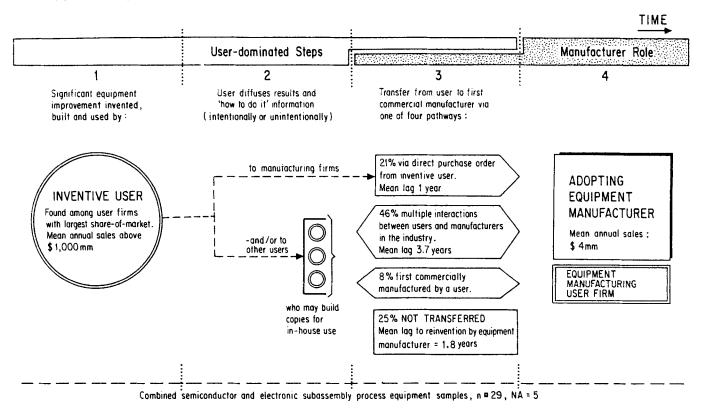


Figure 2. Summary of data regarding transfer of user process equipment innovations to equipment manufacturing firms.

-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.

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. (An article by Markus [1955] provides an interesting 'snapshot' of the large amount of user innovation work which may go on in one industry at a moment in time.) 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) was to 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 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 5 that, if the user takes transfer initiative, the time lag associated with this step will be one year, while if the initiative is left to interaction between users and manufacturers 'in the industry' (cf. Table 5, Pattern C), the time lag from first commercial use by the

user-innovator to first sale of a commercial version by an equipment manufacturing company averages 3.7 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 would diffuse (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, but these are seldom assessed, and when they are-as the reader may suspect from the typical market sizes mentioned at the end of Section 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. (Cf. Edwin Mansfield et al. [1975] 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.)

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 international balance of payments may wish to consider our finding that process innovations by users located in the U.S. were 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 *users* of innovative industrial products from a given country *cause* the decline of domestic manufacturers of such products in that country due to the inaccessibility of innovative users?

ACKNOWLEDGEMENT

The research reported on in this paper was supported by the Office of National R & D Assessment, NSF (Grant No. DA-44366) and the M.I.T. Innovation Center. The author gratefully acknow-ledges the intellectual stimulation and assistance of Walter Lehmann and Walter Yorsz, who served as Research Assistants during the project.

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