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Shifting the Functional Source of Innovation

We have now found that differences in the functional source of innovation may be caused by potential innovators' differing expectations of innovation-related rents. If this is so, we may be able to *shift* the likely source of innovation by changing the distribution of these expectations of rent. Further, by understanding how expected innovation rent is distributed, we may be able to *predict* the likely source of innovation. And if we can do these two fundamental things, we are well on the way to learning how to manage an innovation process that is actually or potentially distributed across different functional loci.

In this chapter, I report on a natural test of the possibility of shifting the functional source of innovation. In chapter 8, I report on a test of the possibility of predicting the sources of innovation.

Nature of the Test

The test I present here deals with a variable that is under the control of firm managers: product design. It starts with the observation that product manufacturers can design products that are easy (inexpensive) or difficult (expensive) for users to modify. An easily modified product will lower a user's expected costs for innovations that require such modification. In contrast, of course, a product that is expensive for users to modify should raise users' expected costs. Such differences in expected costs should in turn affect users' expectations of innovation-related rents and cause differences in the amount of innovation activity involving product modification.

We should be able to observe this hypothesized shift in the functional source of innovation if we can contrast two products—one difficult for users to modify and one easy for users to modify—that are otherwise identical in

function and market. Stan Finkelstein and I explored such a situation in the clinical chemistry-analyzer market.[1]

Automated clinical chemistry analyzers are used in clinical laboratories to determine the level of a chemical such as glucose in blood. These automated machines execute a clinical chemistry test method by first combining a sample of blood serum with one or more reagents and then allowing the chemical reaction(s) thus initiated to take place under prescribed conditions of time and temperature. Substances that would interfere with the test measurement are removed (by precipitation, dialysis, or other means), the test measurement is made (through techniques such as colorimetry, fluorometry, etc.), and, finally, the test result is recorded. Automated clinical chemistry analysis has been widely adopted in the United States.[2]

This study focuses on the three brands of automated clinical chemistry analyzer equipment that were most frequently present in hospital clinical chemistry laboratories at the time of our study: Technicon, Du Pont, and Abbott.[3] Each of these analyzers was designed by its manufacturer to perform a number of common tests. Users who wish to use them to develop and perform other tests must use different chemicals and/or modify the analyzers themselves to achieve their goals.

According to clinical chemistry autoanalyzer users and manufacturers, Technicon and Abbott analyzers were much easier to adapt to new test development than were Du Pont analyzers. The cause of this difference lay in the design of each product's reagent handling system. Let me briefly describe that aspect of each brand's design to make the matter clear.[4]

Technicon automated clinical chemistry analyzer models are based on a principle called continuous flow analysis, and they function much like miniature, continuous-process chemical plants. They consist of functional modules—for example, pump modules, dialyzer modules, and so on—interconnected by plastic tubing. Reagent is placed in bulk reservoirs and metered into the system as needed.

Abbott Laboratories automated clinical chemistry analyzers meter the amount of reagent(s) needed for a particular test from bulk reservoirs into transparent, disposable, open-topped plastic cups called cuvettes. Samples of patient serum are also metered into these cuvettes and the desired test reaction proceeds.

Finally, the Du Pont aca clinical chemistry analyzer uses reagents supplied in single-use, disposable, factory-sealed test packs. These are quite complex. Each contains a plastic pouch divided internally into several sealed compartments that contain reagent quantities needed for a single execution of a particular test. The pouch itself is sealed to a plastic header that contains a serum inlet valve and, for tests that require it, a built-in chromatographic column. All chemical reactions required for a test occur inside the disposable test pack; the pack itself is never opened during its transit through the analyzer equipment.

On the basis of the above capsule descriptions, the reader may find it

reasonable that users could experiment with novel test methods and equipment configurations by using Technicon or Abbott Laboratories equipment at a lower cost than could be done by using Du Pont equipment. Technicon modules may be purchased and connected up in a novel configuration. In both Technicon and Abbott equipment, desired novel reagents can be mixed up in bulk, placed in the machine's reservoirs, and the *machine* will meter out the proper amount of reagent(s) and serum needed for each test.

Setting up the same novel method on Du Pont equipment, on the other hand, requires buying empty test packs from Du Pont (empty packs without chromatographic columns are for sale—these have a standard use in machine calibration). The experimenter would then inject precisely measured amounts of reagent into selected compartments of each pack and reseal each compartment. If 1000 tests were required for an experiment, experimenters would have to perform these operations on 1000 packs. This would clearly be a great effort, and the end result would be the accomplishment of a reagent proportioning task Technicon and Abbott Laboratories equipment does automatically.

The Test

Users employ automated clinical chemistry analyzers in research that (1) do and (2) do not utilize tests available commercially from the analyzer manufacturer. In the latter case, the needed test is developed by an equipment user. Since (as we saw) Du Pont equipment is relatively difficult for innovating users to modify, we hypothesize that research projects using Du Pont analyzers will involve a lower proportion of user-developed tests than will research using either Technicon or Abbott analyzers. That is, we hypothesize that one particular type of user innovation activity only, that involving modifications to equipment or test reagents, will be shifted away from Du Pont analyzers owing to their design.

Stan Finkelstein and I tested this hypothesis through a search of the medical research literature. If the hypothesis was correct, we would expect that the ratio of research reports involving commercial versus user-developed test methods should be significantly higher when Du Pont analyzers are used in the research than when Technicon or Abbott Laboratories analyzers are used.

First, we searched the medical literature through MEDLINE, a computerized index of approximately 3000 biomedical journals, to identify all research articles that reported using a Technicon, Abbott Laboratories, or Du Pont clinical chemistry autoanalyzer.[5] Next, we read the identified articles and coded those that did in fact use one of these analyzer brands shown in Table 7–1.

As can be seen in Table 7–1, the results of our test support the hypothesis. Thus, it does appear that product manufacturers can influence the amount of user-innovation activity related to their products by raising or lowering the cost of such activity, in this instance, through product design.

TABLE 7–1. Frequency of User Research Articles Involving Commercially Supplied Versus User-Developed Chemical Methods as a Function of Manufacturer of Analyzer Used

Number of articles found reporting research by user personnel only that involved:[a]		
(A) Manufacturer-commercialized chemistries[b]	*(B)Researcher-developed chemistries*	*Performed on automated clinical chemistry analyzers manufactured by*
20	22	Technicon
6	0	Du Pont
5	6	Abbott Laboratories
	Null hypothesis that (B)-type research as likely on Du Pont analyzers as others is rejected: Du Pont vs. Technicon $p = .02$; Du Pont vs. Abbott Labs $p = .04$ (Fisher exact)	

[a]Since our goal is to determine *user* ability to, and interest in, modifying manufacturer-supplied chemistries for the analyzer brands listed, papers written by manufacturer personnel only or written jointly by manufacturer and user personnel are excluded. One paper thus excluded was written jointly by a Du Pont and a user research team and reported a researcher-developed chemistry for the aca (Gopal S. Rautela and Raymond J. Liedtke, "Automated Enzymic Measurement of Total Cholesterol in Serum," *Clinical Chemistry* 24, no. 1 [January 1978]: 108–14). Through telephone inquiry we determined that the test packs used in the research were filled to the researchers' specifications at the Du Pont plant. This would be in line with the hypothesis that users would find it hard to do this task themselves.

[b]Du Pont commercial chemistries are always sold to the user prepackaged. Technicon commercialized chemistries may be either premixed reagents sold to the user or Technicon-specified formulas the user mixes up in his laboratory as needed.

Commercial Value of User-Developed Innovations

Of course, the practical value manufacturers can expect from shifting user innovation toward, or away from, their products depends on the potential commercial value of such user innovation. Do users really develop product modifications of general commercial interest? We explored this question in the case of both user-developed test methods and user-developed hardware modifications to Technicon and Du Pont clinical chemistry autoanalyzers.

Commercial Value of User-Developed Test Methods

The test methods of most commercial interest to manufacturers of clinical chemistry analyzers are generally those most frequently used (purchased) by clinical chemistry laboratories. To get an indication of the commercial potential of user activity in test development, we decided to explore whether users had played a role in adapting some of these frequently purchased test methods for use on the Technicon and Du Pont brands of autoanalyzer.

Our sample of commercially successful test methods consisted of the 20 most frequently performed clinical chemistry tests.[6] Automated methods for performing 20 of these tests were offered by Technicon and 18 by Du Pont;

TABLE 7–2. Source of Automated Test Methods Offered Commercially by Equipment Manufacturers[a]

	% User	User[b]	Equipment Manufacturer	Reagent Manufacturer	NA	Total
Du Pont aca	0%	0	18	0	0	18
Technicon SMAC[c]	74	14	4	1	1	20
				Null hypothesis that test method source identical for both brands of analyzers rejected: $p < .0001$ (Fisher exact)		

[a]As explained in the text, the sources of adaptation to automation of the 20 clinical chemistry tests performed with greatest frequency in 1977 were examined. These 20 tests are: albumin; alk phos; calcium; chloride; cholesterol; CPK; creatinine; direct (conjugated) bilirubin; total bilirubin; glucose; SGOT; SGPT; inorganic phos; LDH; potassium; sodium; total protein; triglycerides; urea nitrogen; uric acid. All 20 are offered by Technicon; Du Pont offers all but potassium and sodium.

In the numerous instances in which manufacturers offered different methods for the performance of a given test on their equipment with the passage of time, the method offered for use on the most recently introduced equipment model at the time of the study was the one we selected for inclusion in the sample. At the time of the study, Technicon's latest model was trade named the SMAC High-Speed Computer-Controlled Biochemical Analyzer. Du Pont's latest model at the time of the study was trade named aca (automated clinical analyzer).

[b]The measure used: Did one or more users publish a report of adaptation and clinical use of a given test method on Du Pont or Technicon equipment with publication date prior to the date of commercial introduction of that method (as reported by equipment manufacturer personnel)? Those who performed the adaptation to automation of a test method were coded on the basis of professional affiliation. In the event, all except three innovating users were found to be professionals working in clinical laboratories of nonprofit hospitals. The three exceptions worked in an automated methods laboratory in a Veteran's Administration hospital and were affiliated with that hospital's clinical laboratory.

[c]Some of the user-developed methods offered by Technicon to SMAC users had been developed by users on earlier models of Technicon equipment.

this yielded a sample of 38 adaptations to automation for study. (Because Du Pont and Technicon analyzers have different performance characteristics, the task of developing an analyzer-compatible version of test method x for a Du Pont analyzer is independent of the task of developing an analyzer-compatible version of the same method for a Technicon analyzer.) The innovation history of each sample member was determined through literature searches and structured interviews with manufacturer and user personnel.[7]

In Table 7–2 we see that user-developed adaptations of test methods to automation clearly can be commercially important. For example, 74% of the test methods most frequently used by Technicon customers were first adapted for use on Technicon autoanalyzers by users. In sharp contrast [$p < .0001$], no user-developed adaptations to automation were commercialized by Du Pont. As we saw earlier, the Du Pont equipment was not hospitable to user innovation and attracted very little of it. Users *may* develop product modifications that the manufacturer will find commercially valuable but only if they have an incentive to modify that manufacturer's products.

TABLE 7–3. Du Pont and Technicon Autoanalysis Equipment Innovations

Du Pont autoanalyzer equipment innovations
Basic innovation: Original Du Pont aca autoanalyzer
MAJOR IMPROVEMENTS
Improved computer control
Technicon continuous flow autoanalyzer equipment innovations
Basic innovation: First commercialized model
MAJOR DETECTOR IMPROVEMENTS
Fluorometer
Flame ionization photometer
Ion selective electrodes
MAJOR FLOW CELL IMPROVEMENTS
Smaller volume/adjacent debubbler
Bubble-gated flow cell
MAJOR DIALYSIS IMPROVEMENTS
Shorter flow path/type C membrane
Type H membrane
REDUCTION IN SAMPLE CARRYOVER
Reduced tubing diameter
Air/sample/reagent pump synchronization
Multiple bubble introduction by sample probe
Computer compensation for carryover
OTHER MAJOR IMPROVEMENTS
Multiple channel equipment
Physician-readable chart output

Commercial Value of User-Developed Hardware

We have seen that user-developed test protocols have value for autoanalyzers. What about user-designed modifications to the analyzer hardware? We examined this matter in the case of Technicon and Du Pont analyzers.

Our sample for this test consisted of the first autoanalyzer hardware commercialized by Technicon and Du Pont and all major improvements to that hardware commercialized by each manufacturer over the succeeding years (Table 7–3). We identified these innovations by first talking to manufacturer personnel to identify all hardware changes they had commercialized. Then, expert users and manufacturer personnel helped us determine which of these had resulted in a significant increment in functional utility to the user of the analyzers.

As Table 7–3 shows, we were able to identify 13 Technicon equipment improvement innovations that met our selection criterion, but only 1 such innovation in the instance of Du Pont. (Du Pont equipment, we found, had remained almost unchanged since its commercial introduction.[8]) Data collection to determine the functional sources of innovation for this sample was done by telephone interviewing of expert user and manufacturer personnel.

Since Technicon was the only firm we examined that did commercialize a

TABLE 7–4. Sources of Clinical Chemistry Autoanalyzer Innovations

		Innovation Developed by			
Analyzer Type	*% User*	*User*	*Manufacturer*	*NA*	*Total*
Du Pont aca					
Basic innovation	0%	0	1	0	1
Major improvements	0	0	1	0	1
Technicon continuous flow					
Basic innovation	100	1	0	0	1
Major improvements	46	6	7	0	13
TOTAL		7	9	0	16

significant number of improvements to analyzer hardware, we can only really test whether user-developed hardware innovations sometimes had commercial value in the instance of the Technicon equipment. As Table 7–4 shows, user hardware innovations did in fact have significant commercial value for Technicon. The first clinical chemistry autoanalyzer they produced (in fact it was the first instrument of this type introduced by any firm) was developed by a user. Also, almost half of the hardware improvements Technicon commercialized during the succeeding years were developed by users. In contrast, the basic Du Pont aca and the single major hardware improvement to that analyzer commercialized over the years was developed by Du Pont itself.

Note that the absence of commercialized user-developed hardware modifications for the Du Pont aca is not a consequence of Du Pont policy. Instead, it is likely that users simply did not develop hardware modifications for the aca because this was more costly than modifying functionally similar Technicon equipment. As we mentioned earlier, the Technicon equipment consisted of modules interconnected by plastic tubing. In contrast, the Du Pont analyzer is of a more monolithic design.

Summary

Our data on innovation in clinical chemistry autoanalyzers suggest that the functional source of innovation related to particular products *can* be modified or shifted by actions taken by individual firms.

In the particular sample we have studied, product design appears to be the principal cause of the interbrand difference in the user innovation activity we observed. But any variable that will create shifts in the locus of innovation-related rents, however achieved, should be usable to achieve similar effects. Thus, product manufacturers who wish to increase user innovation affecting their products might offer free equipment or design help to the innovating users they want to encourage. Or, if they want to decrease user innovation,

they could refuse to service products users have modified, seal the product physically to hamper user access, or refuse user requests for technical help, circuit diagrams, software source codes, and so on.

Finally, although our study has dealt with a product manufacturer's ability to affect user innovation, the reasoning is perfectly general: Users, suppliers, and even government (for example, through tax policy and/or government purchases and/or government-sponsored research) should also be able to engage in shifting the functional source of innovation if they wish to do so.

Notes

1. Eric von Hippel and Stan N. Finkelstein, "Analysis of Innovation in Automated Clinical Chemistry Analyzers," *Science & Public Policy* 6, no. 1 (February 1979): 24–37.

2. Approximately 44% of the 677 million clinical chemistry tests performed in hospital laboratories in the United States in 1977 were performed on automated clinical chemistry analyzers. In 1975 there were some 14,000 clinical chemistry laboratories in the United States. Some 50% of these were affiliated with hospitals, 30% were affiliated with doctors' offices, and 20% were independent commercial entities. Their aggregate revenues were on the order of $6.2 billion in 1975 and growing at 10% annually (L. H. Smithson, *Overview of the Clinical Laboratory Market* [Menlo Park, Calif.: Stanford Research Institute, n.d.]).

3. IMS America, *Semi-Annual Audit of Laboratory Tests, Hospital Labs,* January–June 1977, July–December 1977 (Ambler, Penn.: IMS America, n.d.). IMS America generates its data by surveying and auditing laboratory records of 204 of the approximately 5800 nonfederal, short-term hospitals in the United States. The sample of hospital laboratories used is stratified by bed size, region, and hospital ownership. (IMS restricts circulation of its data; it is used here by permission of the company.)

4. Technicon offers several models of automated clinical chemistry analyzer, Abbott Laboratories offers two models, and Du Pont one. All models of a given manufacturer are fitted with the same type of reagent proportioning system; however, as a consequence, we will be able to examine the hypothesis by collecting data on analyzer *brands* rather than on specific models of analyzer.

5. To accomplish this MEDLINE was instructed to search for articles that were coded under the subject heading "autoanalysis" and that *also* contained the words "Du Pont," "Technicon," or "Abbott Laboratories" in the article's title and/or abstract. (Although this procedure flags only the subset of research publications that name the autoanalyzer equipment manufacturer in the title and/or abstract, it is reasonable that the ratio of the two types of research usage we are considering will be equal in this subset and in the total population.)

Autoanalysis is the subject heading assigned in the MEDLINE thesaurus (National Library of Medicine, *Medical Subject Headings—Annotated Alphabetical List, 1978* [Springfield, Mass.: U.S. Department of Commerce, National Technical Information Service (No. PB-270-894), 1978]) to research using clinical chemistry autoanalyzers. This thesaurus of standard subject headings is maintained for use by indexers and those wishing to retrieve citations. The MEDLINE system provides access to articles published in most biomedical journals (approximately 3000) from 1964 to 1975 to the present by title, author, subject heading, and textword. Subject headings are assigned

to articles by indexers working for the National Library of Medicine as a function of the subject matter dealt with in the article. Textwords are simply any word or combination of words. Users of the system may specify textwords and the system will flag articles containing them in the article title and/or abstract.

6. IMS America, *Semi-Annual Audit of Laboratory Tests, Hospital Labs,* Table 6–2.

7. Work on each case began with a search of the literature for papers related to the test method being examined. Authors whose papers were found germane were contacted and were told that we were interested in exploring the early history of the application of the innovation discussed in their papers to autoanalyzers. We then asked them for the names of fellow experts with user and/or manufacturer and/or other relationships to the innovation who might have a good knowledge of these matters. Finally, we asked these initial contacts for any knowledge they themselves might have on the topic of interest. Individuals identified for us by initial contactees were contacted in turn, and the process repeated until we felt we had the well-documented information we needed.

We found that FDA-required product labeling was an especially useful data source for all sampled innovations. (Product labeling is U.S. Food and Drug Administration [FDA] terminology for methods-related information suppliers of clinical test chemistry methods must make available to their customers. Among other things, product labeling contains references to research behind those methods.)

8. Several equipment changes to the Du Pont aca are listed in B. W. Perry, et al., *A Field Evaluation of the Du Pont Automatic Clinical Analyzer* (Wilmington, Del.: Du Pont, n.d.; 2nd printing, January 1978). We did not include these changes in our sample because they were made prior to the commercial introduction of that analyzer. If we had included them, they would not have changed our finding that users do not develop equipment improvement innovations for the aca. Although the monograph authors were users at the University of Alabama Medical Center in Birmingham, the equipment problems uncovered by their evaluation work were rectified by changes developed by Du Pont personnel.