Factors Affecting Innovation Time

How multiple sources of technology, internal vs external sources, and firm size influence timing

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A recent report prepared for the National Science Foundation by Gellman Research Associates, Inc.[1] provides extensive empirical data collected on 500 innovations introduced into the marketplace during 1953-1973, and originating from six Western countries: United States, Canada, United Kingdom, France, West Germany, and Japan. The objective of their study was to determine and compare, on the basis of data collected on each of the innovations, the underlying trends and characteristics which are indicative of the relative innovativeness of the different countries. The 500 innovations selected for the study were drawn from an original field of over 1,300 innovations, and were considered by an international panel of experts as most important in terms of technological, socio-economic, and political significance.

The study provides a rich collection of data on the background and events surrounding each innovation, including the time period for the innovation, including the time period for the innovation process.

The time span for technological innovation is important in that it directly affects the rate at which innovations are produced. A higher rate of technological innovation is desired for increased competitiveness and timely response to market needs. A closer examination than afforded by the study into the innovation time and how it might relate to other factors influencing the innovation process would be helpful in attempting to identify those conditions tending to shorten the innovation process.

The Innovation Period

The innovation period is the time elapsed between the conception of an innovation and its introduction into the commercial market. The period covers the point of first invention or basic discovery through various phases of research and development, test, design engineering, manufacturing, market analysis, marketing, and commercial introduction.[2] A host of nontechnical factors affect to a large extent the length of the innovation period, such as the availability of capital, the nature and structure of the market, management policies, government regulatory practices, energy and material resource availability, and human behavior. Obviously, many innovations are aborted before ever reaching the point of commercial realization. Thus, the innovation period is defined only for those innovations which have succeeded in reaching commercial realization.

Several studies have been made in the past concerning the innovation period for selected industry areas.[3] The average innovation period associated with various industries was found to be significantly different. Shorter innovation periods were found to prevail for consumer products as opposed to industrial products, and for products developed with government funds as opposed to private funds. Furthermore, there appeared to be a progressive shortening of the innovation period with time. However, variances in definitions and concepts employed in the studies, plus difficulties in establishing accurate dates for conception and realization of innovations, provided only an estimate of the actual innovation period in many of the cases studied. Consequently, only gross interpretation of the data was warranted.

The innovation period nevertheless provides a convenient indicator for comparing the innovative performance of organizations, industries, or countries when averaged over the appropriate field of innovations. All the confluent factors which act to stimulate or impede the innovation process will be reflected in the innovation period. Those exhibiting a comparatively shorter innovation period on average are generally more proficient in the art than those requiring a longer time. In addition, it is reasonable to expect a close correlation between profitability or economic performance and innovativeness as measured by the average innovation period. A shorter average innovation rate, which constitutes the fundamental basis for improved productivity and competitiveness in commercial markets.

Dependence on Multiple Sources

Information on the sources of technology underlying the innovations included in the Gellman Research Associates (GRA) study was obtained by requesting people associated with the innovations to check the series

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of questions and statements listed in Table 3. In addition, the year in which the basic invention was made and the year of first market introduction for each innovation provides a rough indication of the innovation time.

Looking first at innovations derived from a single technology source, a comparison of how the United States stacks up with other countries is given by Table 1. The number of innovations for each country relying on a single technology source as well as the total number of years for these innovations are shown. Innovations were removed from consideration in those cases where respondents indicated that the source of technology was unknown. Nevertheless, fully 25% of the total number of cases are included.

	U.S.	U.K.	Japan	W.Germany
Number of innovations	65	36	11	11
Total innovation time (years)	481	278	35	57
Average innovation period (years)	7.4	7.7	3.4	5.2

*France and Canada are not included because of insufficient number of cases involving a single technology source.

Comparison by Country of Average Innovation Time from a Single Technology Source.

TABLE 1

The average innovation period for the United States at 7.4 years remains unchanged from that of the total U.S. sample, and continues to compare unfavorably with the corresponding figures for Japan and West Germany. The U.K. average innovation period for this single-source data subject, however, has increased appreciably from 6.6 years for all U.K. innovations to the 7.7 years shown in the table. Although the amount of data on innovations stemming from more than multiple sources was insufficient to carry out meaningful country-by-country comparisons, the appreciable change in the U.K. figure does demonstrate that the average innovation period in the United Kingdom should become significantly shorter from multiple-source innovations than in the other countries.

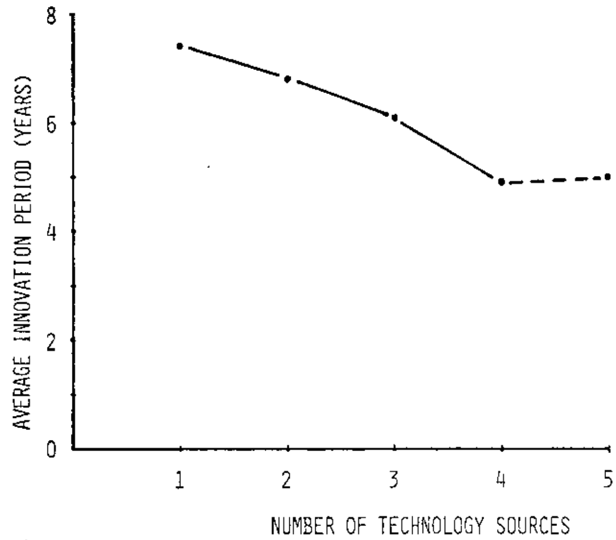
Let us confine our attention now to the record of U.S. innovations. The data can be grouped according to the number of technology sources as shown in Table 2. Innovations involving up to five different sources are included although it is important to note that the preponderence of cases involve one to four distinct sources. The average innovation period appears to be longest for innovations involving two and three sources, and shortest for cases involving four and five sources.

	Number of Technology Sources				
	1	2	3	4	5
Number of innovations	65	67	68	52	6
Total innovation time (years)	481	534	530	257	30
Average innovation period (years)	7.4	8.0	7.8	4.9	5

Average Innovation Period for U.S. Innovations According to Number of Technology Sources.

TABLE 2

However, the two-source grouping includes an innovation which required the unusually long time of 82 years to complete, whereas the three-source grouping includes two innovations each of which took 63 years. These time periods are many times longer than the average for their respective groupings. Furthermore, the dispersion of the rest of the U.S. data about the mean does not approach the magnitude of these particular cases. If these cases were removed from consideration for being non-representative the average innovation period for the two and three-source groupings would become 6.8 and 6.1 years, respectively. These adjusted data are illustrated in Figure 1.



Average innovation period in the United States as a function of the number of technology sources.

Figure 1

Questionnaire Statement	Firm Internal	Firm External
A. Basic research – internally generated	Y	N
B. Applied research – internally generated?	Y	N
C. License – from abroad?		Y, N
D. Merger or acquisition of a going concern.		X
E. Transfer of technology from an existing product of the innovating enterprise.	X	
F. Corporate R&D activity – located in same country?	Y, N	
G. Outright purchase of patent or know-how		X
H. Other	Intermediate	
I. Not known.	Intermediate	

Internal or External Source Determination from Responses to GRA Questionnaire.

TABLE 3

The figure suggests a general inverse relationship between average innovation period and number of technology sources. Because of the limited number of innovation cases available utilizing five different sources, the last data point, and consequently the plateau effect depicted at the end of the curve, must be held to be highly tentative until more date becomes available. Nevertheless, the apparent inverse relationship presents a strong case for technology transfer. By acquiring technology from independent sources, the overall innovation process would be appreciably shortened.

Internal and External Sources

Whether the technology sources originated from within or external to the innovating firm was determined from the responses to the questions and statements in the manner shown in Table 3. A yes answer to questions A and B places the source within the firm. Similarly, a source is determined to be internal if statements E and F were checked. Conversely, a source is determined to come from outside the innovating firm if: either questions A or B were answered negatively, either statements D or G were checked, or if question C was answered either affirmatively or negatively. Question C asks whether the license for the technology came from abroad or not. The fact that a license was negotiated means that the firm did not previously hold title to the technology, regardless of whether the license came from abroad or not.

The grouping of the data-set of U.S. innovations according to this criterion, and according to numbers of technology sources is shown in Table 4. Numbers of innovation cases are shown, with the total length of time for these cases in years given in parentheses. In cases where respondents checked questionnaire statements H and I it was not possible to ascertain whether the source of technology came from within the innovating firm or not. These cases were consequently disregarded, reducing the total number of cases included in this data-set to 231 from the 258 of Table 2.

It is readily evident from Table 4 that U.S. firms tend to rely heavily on internal sources of technology. Only 6 cases, or 2.6% of the sample, relied solely on external sources of technology. Even if the cases requiring both internal and external sources of technology were considered, the total of 56 cases relying on external sources of techology constitutes only 24% of the sample. This may reflect an understandable reluctance on the part of innovating firms to acquire technology from outside sources if something comparable or substitutable is available within the firm. But this reluctance may develop too heavy an inward orientation to the extent that applicable technology available outside the firm may be overlooked even if no satisfactory solution exists within the firm.

The table also shows that external technology is seldom applicable directly to the particular innovation without additional internal technology to complement it. Of the 56 cases utilizing external technology, 50 cases, or 89%, required additional internal technology.

The average innovation period for those cases relying solely on external technology is considerably longer than the time required when internal sources of technology were employed either solely or in conjunction with external technology. This may be due to a variety of reasons. Aside from statistical dispersion arising from a limited data-set, it could stem from an overly optimistic and perhaps naive appraisal of the outside technology on the part of the acquiring organization, unfamiliarity with the "nuts-and-bolts" applications aspects of the technology, unforeseen difficulties in adapting the outside technology to the particular innovation, or simply a lack of in-house technical capability to handle the problems of application.

Number of Sources	Number of Innovations (Total Years) Internal	Internal & External	External
1	52 (370)	0	4 (61)
2	52 (359)	7 (63)	1 (6)
3	44 (228)	16 (87)	1 (5)
4	27 (112)	23 (140)	0
5	0	4 (23)	0
Total	175 (1069)	50 (313)	6 (72)
Average Innovation Period (Years)	6.1	6.3	12

Average Innovation Period from Technology Sources Internal and External to the Innovating Firm.

TABLE 4

Finally, it appears that cases requiring external as well as internal sources of technology tend to develop where greater numbers of sources are involved. Cases involving internal technology alone tend to cluster around 1—3 sources, whereas those requiring both external and internal technology appear to concentrate around 3—4 sources. This is probably indicative of the natural inclination of firms to rely on local technical resources to the greatest extent possible. As the need to acquire technology from more and more sources increases, the likelihood that this need can be met entirely from internal resources rapidly diminshes. As a result, access to external sources of technology is more characteristic of innovations requiring a higher number of technology sources.

Size of Firm

The size of the innovating firm determines to some extent the innovative character of the organizations. Smaller firms tend to be more innovative for the sake of improved competitiveness, but are constrained by limited human and capital resources. Larger firms generally have more resources to draw upon for innovative activity. However, despite their larger resource base, large firms are more intent on minimizing risk exposure and increasing their return on invested capital.[4] These goals are rarely compatible or conducive to a productive environment for innovation, a principal reason being the disparity in time scales associated with the typical innovation period and the realization of corporate performance objectives.[5] By shortening the average innovation period to be more consistent with the time span of corporate performances measures, the innovativeness of large firms could be dramatically revitalized.

The relationship of firm size to the average innovation period, based on GRA data, is shown in Table 5. Size of firm is in terms of number of employees.

The case distribution shows that nearly half of the total sample of U.S. innovations came from firms having no more than 1,000 employees. Furthermore, innovations from these smaller firms tend more to involve a single technology source, whereas the larger

Number of Sources	1-100	101-1000	1001-5000	5001-10000	> 10000
	Number of Innovations (Total Years)				
1	23 (245)	23 (101)	5 (37)	13 (90)	1 (8)
2	17 (88)	13 (90)	12 (108)	18 (128)	6 (38)
3	25 (57)	14 (79)	6 (38)	20 (118)	11 (112)
4	7 (31)	9 (56)	12 (78)	15 (64)	9 (28)
5	1 (3)	0	0	4 (24)	1 (3)
Total	63 (424)	59 (326)	35 (261)	70 (424)	28 (189)
Average Innovation Period (Years)	6.7	5.5	7.5	6.1	6.8

Average Innovation Period for Firms of Different Sizes.

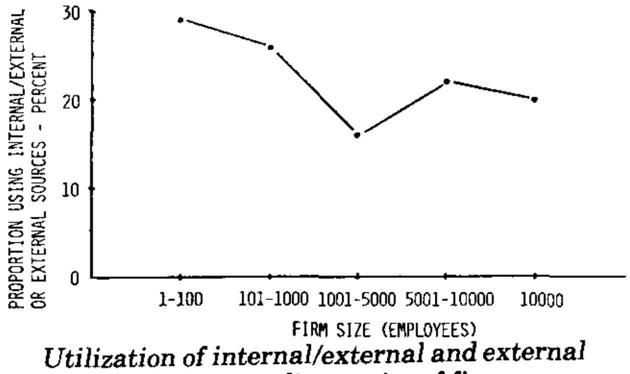
TABLE 5

firms appear to utilize multiple sources. This most likely reflects the ability of large firms to undertake projects of greater size and scope than smaller firms.

The shortest average innovation period is found to come from firms with 101—1,000 people, whereas firms with 1,001—5,000 people are found to have the longest innovation period. Small firms in the 1—100 people category exhibits a longer innovation period than the larger firms with 101—1,000 employees, conceivably because they are more resource-limited despite the higher flexibility inherent in their smaller size. On the other hand firms with 1,001—5,000 employees begin to experience the growing pains of a burgeoning organization where the flexibility of a small organization becomes less apparent and the greater resources and economies of scale associated with larger organizations have not yet been achieved. In this sense medium-sized firms share the disadvantages of both small and large organizations without fully realizing the associated advantages, as indicated by their longer average innovation period.

Table 6 shows the distribution of innovation cases and associated time periods according to firm size and whether the technology was derived from inside or outside the firm. Clearly, internally generated technology was the principal source for all firm sizes. From this table the proportion of cases relying either on internal/external or solely external technology sources for the different firm sizes can be determined as illustrated in Figure 2. In general, it appears that larger firms tend to rely less on external sources of technology than the smaller ones. This is a likely consequence of the fact that larger firms have more internal resources to draw upon than smaller firms, which is in consonance with the heavy overall dependence on internal sources of technology by all firms.

The average innovation period computed from the data in Table 6 is plotted versus firm size in Figure 3 for cases involving both internal and internal/external sources of technology. The figure shows that mixing external technology with internally generated technology helps larger firms more than smaller ones in terms of achieving a shorter average innovation period compared to where only internally-generated technology is employed. This fact coupled with the previous observation that larger firms tend to demonstrate lower reliance on external sources of technology suggests the importance of the larger technological base available in larger firms in assessing their real external technology requirements, identifying the key technological assets to be acquired from outside the firm, and in adapting the outside technology to their particular innovation. Conversely, smaller firms, despite being more outside-technology oriented, are experiencing greater difficulty in properly identifying and evaluating appropriate technology and effectively incorporating them to meet their particular needs.



Utilization of internal/external and external sources according to size of firm.

Figure 2

Figures 2 and 3 also clearly show that medium-sized firms in the 1,001—5,000 people category are distinguished by having the least reliance on external sources of technology and having the longest average innovation period of all the size categories considered. A reasonable inference that can be drawn is that a positive correlation exists between increased dependence on external technology and a lower average innovation period. In fact, by performing a rank correlation of the external technology dependence and the average

Source	1-100	101-1000	1001-5000	5001-10000	> 10000
Internal	41 (251)	39 (182)	26 (199)	49 (325)	20 (112)
Internal/External	12 (75)	13 (93)	6 (57)	14 (72)	5 (16)
External	5 (66)	1 (6)	0	0	0

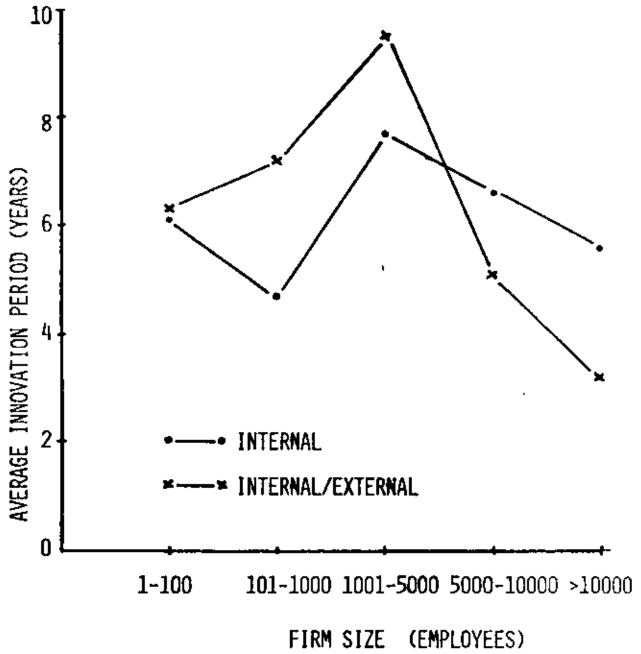
Sources of Technology for Firms of Different Sizes.

TABLE 6

Firm Size	External Source Dependence Percent	Rank	Average Innovation Period Years	Rank
1 – 100	29	1	6.7	3
101 – 1000	26	2	5.5	1
1001 – 5000	16	5	7.5	5
5001 – 10000	22	3	6.1	2
> 10000	20	4	6.8	4
Rank Correlation Coefficient = ±0.70				

Rank Correlation Coefficient Between External Source Dependence and Average Innovation Period.

TABLE 7



Average innovation period for different size firms.

Figure 3

innovation period for the different-sized firms, as indicated in Table 7, a rank correlation coefficient of +0.70 is obtained. This indicates that chances are favorable that a firm can measurably shorten the innovation process by increased utilization of external sources of technology.

Findings in Perspective

The average innovation period serves as a useful international yardstick for judging the relative innovativeness of different countries because national policies as well as human and institutional barriers and stimulants are reflected in the average innovation period for each country. Advantages in international trade and competitiveness generally reside with those countries which have managed to achieve comparably short average innovation periods. Conversely, countries with longer average innovation periods operate at a distinct disadvantage in not being able to draw upon available resources quickly and effectively to introduce competitive goods into the international market. From this standpoint the significantly longer average innovation period in the United States relative to that prevailing in West Germany and Japan spotlights the problem in this country, and at the same time constitutes the challenge to try to lower the average innovation period to be more in line with the 3—5 years period in Japan and West Germany.

The findings also showed that a lower average innovation period is generally associated with the use of more technology sources and in particular the use of external sources when complemented with internal resources. From the standpoint of the innovating firm, an increased awareness of and disposition to assess and utilize available technological resources is required, with special attention needed to maintain keen sensitivity to external technological developments alone can not be effectively utilized without adequate integration with available technological capabilities and resources within the firm. The evidence thus lends further support to the notion that technology transfer both within the firm and into the firm from without is of major importance. But it must be a highly selective process designed to utilize fully in a complementary fashion capabilities and resources already available within the firm.

Herein lies the paradox. Firms more disposed to utilizing external sources of technology are generally the smaller ones who depend primarily on their own innovativeness to remain competitive. Indeed, studies have found that the smaller firms and independent inventors produce a disproportionately larger share of innovations than the larger firms which are more concerned with maintaining a favorable return on investment.[4, 6] Yet it is these smaller firms that are at a disadvantage vis-a-vis the larger firms in their ability to exploit effectively external sources of technology because of their more limited technical capabilities and capital resources. Their smaller technical and capital base in fact could be the principal factor underlying their higher utilization of outside technology. Large firms on the other hand possess more extensive technical and financial resources for capturing the full benefits of outside technology. However, these firms tend to rely less on external sources than smaller ones. In addition, they are not prone to accept high-technical risks. As a result, innovations that are produced are generally more incremental in nature and are aimed at achieving a favorable return in the near term.

The situation for medium-sized firms would on the surface appear to be quite favorable, with greater internal resources to work with than smaller firms, and a smaller organizational and product base than larger firms from which to sustain a stronger growth

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