OBSERVING THE EFFECTS OF RESEARCH ON BUSINESS

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Current American research about research suffers from at least two difficulties. First, everyone recognizes that the government's policy is not really to encourage research, but to make new kinds of military hardware; and business's aim is not to encourage research, but to develop new and more profitable goods, services and production processes. Since it is not now possible to obtain data on the amount of technological change (new goods, services and processes) in the economy, it is not possible to observe the consequences of research programs on the economy. Second, it is ordinarily held to be impossible to measure research output. In this case, even if technological change were quantifiable, it would be impossible to talk in concrete terms about how research is related to technology.

In what follows, an effort will be made to resolve the first problem. It will be shown that some aspects of technological change are in fact observable and quantifiable, at least at the level of an individual industry. If these findings meet the test of close scrutiny, then half of the larger problem can, in principle, be met. Having seen the possibility of direct measures of technological change, we can, with perhaps a lighter heart, proceed to study the connection between the output of new technology and the input of research.

There will be presented below the results of examining various records maintained by Bell Telephone Laboratories, Inc. These records refer to the adoption, alteration and abandonment of specifications of "apparatus" and "equipment" used by the American Telephone and Telegraph Company and its subsidiaries. I have nowhere seen similar data published, and I think that they will perhaps suggest avenues for further study.

If technological change is ever to be quantified, and associated with a supporting research operation, then the telephone industry would seem to be a perfect laboratory for starting experiments. The industry is virtually monopolized by American Telephone and Telegraph and its subsidiaries. One of these--Western Electric--makes most of the hardware used in the system, and is the buying agent for those subsidiaries which actually sell telephone service. Another--

Bell Telephone Laboratories--is one of the largest research organizations (I am tempted to say research faculties) in the country and is responsible for all research subcontracting in the system. Moreover, the system has a major (and unique) technical problem, called "compatibility." Since it must be possible to connect each telephone in the country to each other telephone, special control must be exercised to make sure that new types of hardware[1] are compatible with existing types. Bell Laboratories, therefore, must ascertain the compatibility of new hardware with existing hardware, before it can be used by any operating company,[2] or made by Western Electric. All these companies are large, all are regulated by state and federal government, and all have careful records. They represent an almost perfect environment in which to observe the introduction of new technology into an industry.[3]

Western Electric supplies thousands of individual items of hardware to operating companies. A new item in Western Electric's catalog means a technological change in the operating companies, since these can now buy an output which they could not formerly buy. However, a change in Western Electric's own manufacturing processes need not change technology of the operating companies. (In some cases, of course, a change in Western Electric technology necessitates a change in operating company technology.)

Conceptually, the introduction of a new item into the catalog represents an innovation. It represents a discrete change in the set of possibilities open to the operating companies, a change from n to n+1 in the number of inputs on which the operating companies seek to minimize the costs of a given output of telephone messages, and a change which cannot be broken down into arbitrarily small parts.[4] On the other hand the changes themselves are numerous. Taken one at a time most are not very important. In this sense, one can think of innovations as a set of changes, perhaps with "magnitudes" distributed on the basis of a probability law of some sort.

In a recent paper I presented a contribution to the "theory" of the production of innovations.[5] In order to retain some consistency in my own discussion I repeat some simple definitions:

> Research is a flow of new statements about the natural world.
>
> Invention is a flow of prototypes of articles which have never been made before, or processes which have never been used before.
>
> Development is a flow of instructions (blueprints, diagrams, etc.) which enable the construction and equipment industries to build fixed plant of kinds

never used before, and also enable the personnel of these plants to operate them when finished. It may also make it possible to use existing fixed plant to make articles unlike those they had hitherto made.

If this terminology is to be useful, it should be possible to apply it to the data on new technology which are presented here.

The distinction between research and development exists administratively within Bell Laboratories, but it is clear that there is overlap. Thus "systems development," the unit which plans the most complicated and expensive changes in technology, does draw upon research personnel as well as upon engineers. On the other hand, invention is specially recognized within the Laboratories only where it involves patenting. The patent operation, which will be discussed below, is talked of as a legal problem, and (in connection with licensing agreements) a matter of intercorporate strategy. Patenting is even handled by A. T. and T. rather than the Laboratories. Thus the economic concept of invention, given above, has no organizational recognition in the administrative structure of Bell Laboratories.

The terms apparatus and equipment are used in the Bell System for internal control purposes. Apparatus is relatively cheap and simple, equipment relatively expensive and complex. In principle equipment has several interdependent functioning parts, while apparatus does not. (A piece of apparatus is often a component of a piece of equipment.)[6] Terminology in the Bell System is in flux, and in the future "equipment" may be considered an old-fashioned term for "system" and "apparatus" an old-fashioned term for "component," corresponding to the systems and components engineering units in the Laboratories. No data are available on systems, the largest and most complex units of hardware; or on components, in the development and design of which a large body of Bell Laboratories personnel is engaged.

The administration of the Bell Laboratories generates data about the rate of technological change. Bell Laboratories assigns a code to new pieces of apparatus consisting of a name (e.g., cord, relay, coin collector, jack mounting plate) and a (sequential) number. When the new apparatus becomes available to operating companies, a descriptive index card is printed. These cards are sent to purchasing departments of the operating companies, and constitute the catalog of purchasable items. When a change in a piece of apparatus occurs, a replacement card is issued. In some cases, Western Electric may discontinue production of an item, while it still has an inventory on hand, or Bell Laboratories for technological reasons may wish to restrict use of an item. Then an entry "A and M only" on a new card restricts future use of the item to "assembly and maintenance," that is, forbids its use in new installations. Finally an entry "M. D." may be made, when manufacture is discontinued and the item is no longer available to operating companies. Here, too, a new card is issued.

Since 1931 Bell Laboratories has kept an annual record of the number of new codes assigned to apparatus, and the number of "M. D." designations issued, and the number of "active" code numbers at the end of each year. The number of codes rated "A and M only" is available since 1938. These data are given in Table I.

These new codes always represent development.[7] They may also involve invention, where codes are issued to apparatus of a kind not previously made. It is not clear what proportion of the new codes issued involve invention (of some degree of importance).

To gain some clues as to the relation between invention and development, a special set of data was devised. Bell Laboratories maintains a historical file of all apparatus cards issued since about 1910.[8] These are arranged chronologically by code number. There is a card issued whenever a new code number is assigned; and a card is issued to record minor design changes, and discontinuation of individual items.

Some changes in apparatus take place on the initiative of Western Electric. These ordinarily do not affect the user, but are attempts to reduce manufacturing costs. (Such changes might include changes in the diameter or length of pins on which small parts move or in the composition of the alloys of which the parts are made. The user would ordinarily be unaware of and uninterested in the fact that they occur.)

Other changes, however, take place on the initiative of Bell Laboratories. In the main these changes do matter to the user, and frequently change the operating characteristics of the apparatus. When these changes take place, cards are issued telling the new specifications of the apparatus. Both old and new revised cards are kept in the historical file.

The cards issued annually by Bell Laboratories thus record some new apparatus--apparatus given new code numbers--and some alterations in old types of apparatus. Both kinds of cards represent development, but only a part of the former would involve invention of apparatus. These cards would not note either development or invention in manufacturing processes.[9] But though Bell Laboratories records how many <u>code</u> numbers it issues per year, it does not record how many new <u>cards</u> it prints per year.

In order to estimate the annual issue of apparatus cards I took a sample of the historical index. This index consisted of 68 drawers of cards, not all of them full. The sample consisted of 2,741 cards, drawn at a rate of one per centimeter of drawer. Of this total, 644 were issued in 1920 or before. The dates of issue of the remaining 2,097 are given in Table II, Column 2. It was not practical to determine how many cards were in the index, so that the sample is only an index of the relative numbers issued.

The records on equipment are somewhat different from those on apparatus. When a new type of equipment is approved, a document called a Specification ("Spec") is issued. This consists of a description and a set of circuit diagrams. The specification may contain several "codes"[10] if the equipment has sub-assemblies, or if some parts are optional or alternatives.[11] Bell Laboratories maintains a library and distribution service, so that the engineers in the operating companies can obtain sets of specifications and diagrams. The card index to these specifications contains a record of all equipment, and the dates of changes made in the individual items. The following discussion of equipment is based on analysis of this catalog. The Spec series devoted to equipment have, since 1929, been the "J-Spec series." Before then, two series, X-61000 and X-63000, were used, the former being used for manual and the latter for dial switching systems. Every piece of equipment has a Spec number--X or J followed by a five-digit number, the first two digits designating the general use of the equipment and the last three a sequential listing. A "small" change involves a new appendix to the Spec; a "larger" change requires a new issue (with retention of number). The designations "A and M only" and "M. D.," which are used as with apparatus, are the subject of special appendices (or occasionally issues) in the case of equipment. The card index records the dates of all issues and appendices for Specs issued since about 1921. Thus the statistics of changes in specifications can be studied much more readily for equipment than for apparatus.

Table III presents three series: the number of new specification numbers (J-Spec) issued annually since 1927, a complete enumeration by the Laboratories; an estimate of the number of Specs issued (new plus alterations) annually since 1921,[12] based on a sample in which I counted every fourth card in the index, including the J, X-61000 and X-63000 series;[13] and estimates of the number of revisions of specification, as the difference between the foregoing series.[14]

These tables suggest that technological change in a large firm involves numerous changes in the list of hardware it uses. The central notion of "changes in a list" bears some relation to the familiar notion of changes in an inventory. Since, however, the change in nomenclature is to be distinguished from changes in the inventory of hardware itself, care is necessary in adapting familiar concepts to the unfamiliar data given here.

The question, "How long does technology of a given type remain in use?" is not the same as the question, "How long does a physical piece of equipment last?" although the two are related. Imagine the following sequence of events:

(1) an article is accepted by the Laboratories;
(2) some operating companies use it;
(3) it may become widely used;
(4) an alternative device is developed;
(5) the alternative gradually displaces the original article;
(6) the article is purchased only for replacement and repair purposes;
(7) it eventually is taken out of production.[15]

Consider a piece of apparatus or equipment given a code number in year T. What is the probability that it will "survive" (i.e., not be listed "manufacture discontinued") until the end of years T+1, T+2, etc.?[16] Can one, in short, prepare a survivor table for technology?

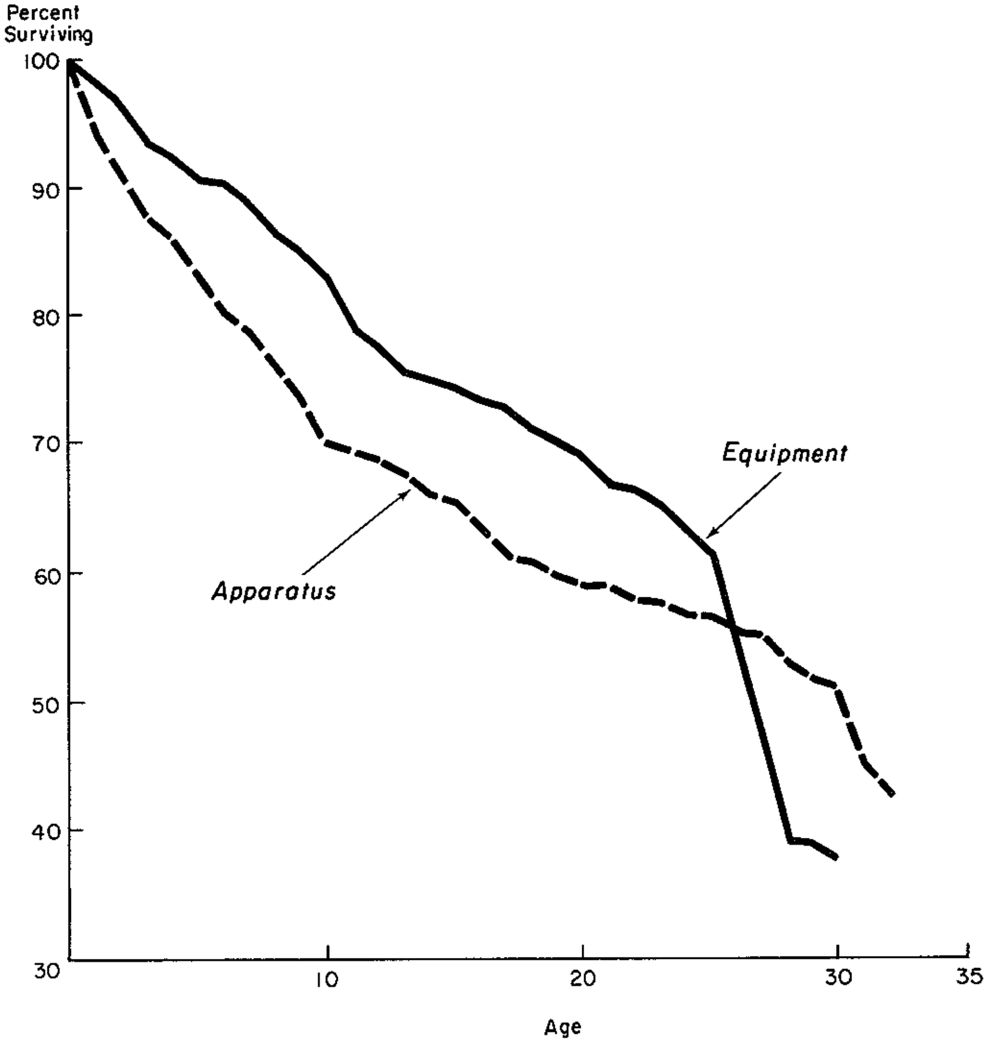
For a random sample of 204 apparatus codes, Dr. Carlson obtained the date of issue of the specification number and the date of discontinuation of manufacture. Using ordinary actuarial principles, it was then easy to compute survivor tables (Table IV and Graph 1), and the proportion of apparatus and equipment types surviving after one, two, three, etc. years.

Apparatus shows a relatively high "infant mortality." One-fifth of the new apparatus codes are designated "manufacture discontinued" within six years. It takes another fourteen years for a second fifth, and fourteen more years for the third fifth to drop out. Thus if a new type of apparatus survives the relatively sharp mortality during the first few years, it is apt to continue in use with relatively fewer chances of being taken out of use--at least until about age 35, where we begin to lose confidence in our data because of the smallness of the sample.

For the largest equipment changes, the adoption and abandonment of specification numbers, Dr. Carlson took a sample of 474 equipment specifications and prepared Table V. Equipment specifications are subject to lower "infant mortality" rates than apparatus, but by age 26, about 45 percent of both have been eliminated. Thereafter, equipment goes out of use more rapidly than apparatus.

Two conjectures about this state of affairs are possible. The first is that the simpler and cheaper apparatus is changed more easily, or perhaps tested less thoroughly than the more expensive equipment.

Graph 1. Percentage of Equipment Specifications and Apparatus Codes Surviving to Given Age



The costs of failure of equipment being greater, equipment is not apt to be adopted (given a code) unless it is relatively foolproof. Therefore, its infant mortality rate is relatively low. Second, since equipment is complicated, it is made up of many components. But many electrical components are relatively standard, so that individual jacks, switches, relays, etc., may serve several technological generations of equipment. Therefore, apparatus has greater technological longevity than equipment, once it has survived infancy. No direct test of these possibilities has been found possible.

The Bell Laboratories data give some clues as to the age of distribution of the technology in use in the telephone system. Once again, tests must be made separately for apparatus and equipment. The following data, of course, do not represent the age-distribution of the physical assets of the telephone system. Some hardware actually in use has a code number now designated "manufacture discontinued." Other newly-installed hardware may have a code number issued many years ago and use the original design. Thus the age of physical hardware may be either greater than or less than the age of the technology represented by the data given here, and no attempt is made to compare the two.

Western Electric publishes a periodical check list of apparatus cards in force.[17] This list identifies a card by the apparatus name (e.g., switches), by the card number or apparatus code number, and by date of issue. It thus is possible to determine how many cards of various ages were in use on December 31, 1959 (Table VI). There were about 7,500 cards in use on December 31, 1959, and 34,300 code numbers of apparatus being manufactured. Thus there were, on the average, 4.7 code numbers on each card. (Many items, such as relays, are listed in series.) A change in any one item on a card would necessitate a new card. Thus cards would tend to be changed more often than the apparatus designated by the cards. The numbers of cards of various ages in use at the end of 1959 reflect in part the numbers of new codes issued during these years, and the numbers of changes made in old codes during these years (where these changes needed to be brought to the users' attention).

More distinctions in degrees of technological change are available for equipment than for apparatus. The largest additions to technology occur when new J-Spec numbers are issued. The age-distribution of technology at the end of 1959, as measured by the date of issue of the Spec number of equipment, is given in Table VII.

Smaller changes in equipment occur when a new issue of a specification is made; and still smaller ones when an appendix to a specification is issued. Such an appendix may affect several "codes" (sub-assemblies) or only one. Such smaller changes occur over the "life" of a Spec. The age-distribution of technology in May 1960, as measured by the most recent change in a specification, is given in Table VIII. (In some cases, the most recent change was the original issue of the specification.)

The tabulations already presented indicate that half the apparatus cards in force at the end of 1959 had been published later than the beginning of 1954; half the equipment codes in use at the same date had been issued later than the beginning of 1946; and half of the equipment specifications in force in May 1960 had either been newly issued, or been altered in some way since the beginning of 1957.

Let us define technological change as the introduction of new types of apparatus and equipment, and the discarding of old. At any time, the research and development operation in Bell Laboratories may be said to reach into the catalog, and select some items, for revision or discard. It is natural to inquire which items are actually selected.

Various conjectures might be advanced as to the nature of the selective process. Suppose hardware becomes technologically obsolete with the mere passage of time. Then the longer the interval which has elapsed since something received a code number, the more probable its alteration or demise in the course of the year. This policy will be called a FIFO research policy, to bring terminology into line with inventory practice, and viewing Bell Laboratories as controlling an inventory of technology.

Suppose, second, research and development work concentrates upon the least satisfactory articles. If a piece of hardware is badly designed, its defects will appear soon after its introduction. If it is well designed, it will have a long, useful life. On this hypothesis, the longer a code number has survived, the less likely it is that it will be replaced in a given year. This policy will be termed a LIFO research policy, on the grounds that the latest items in the technological inventory are the first to leave.

Finally, suppose that alteration or abandonment of a type of hardware is related only to new research and development, and thus is mainly concerned with application of new ideas rather than the displacement of old ideas. On this hypothesis, the probability that a given item will be replaced or altered is independent of the technological age of the item. The third possibility will be called a random access research policy, on the grounds that all technology, regardless of acquisition date, is equally likely to be removed in a given period.[18]

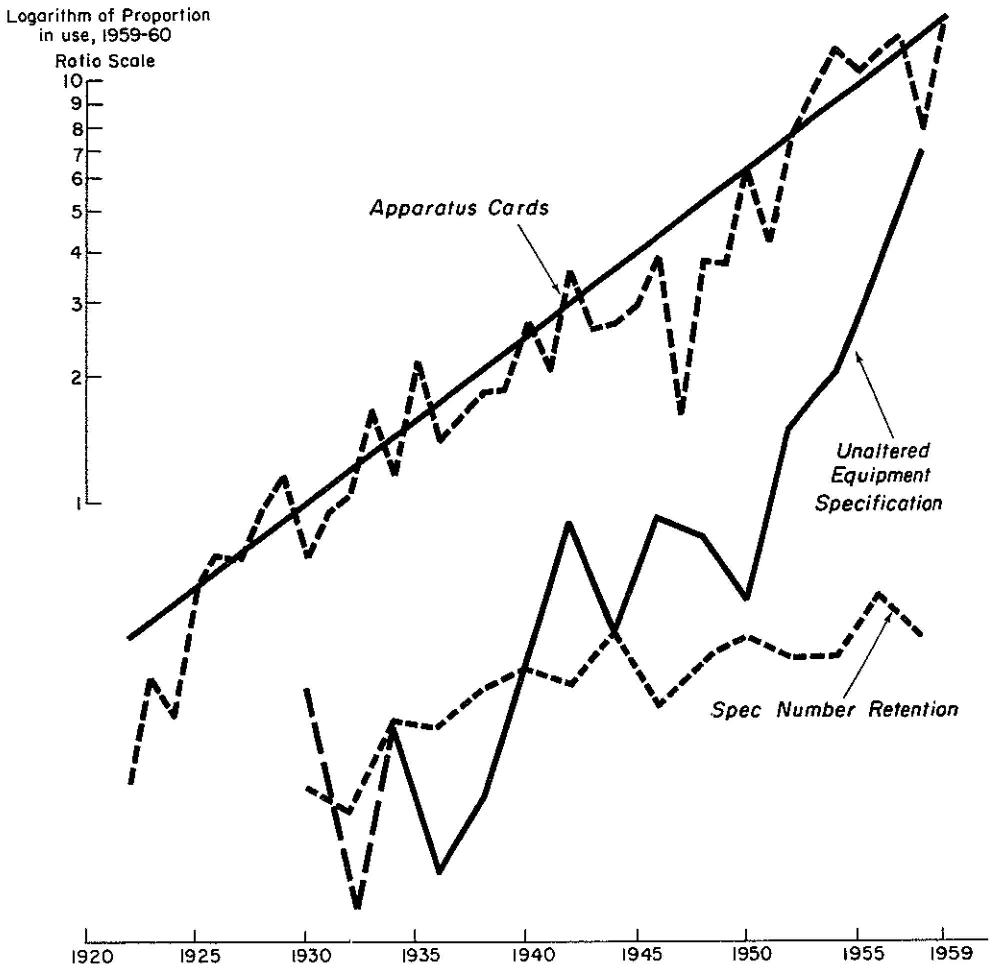
The "survivor tables" (Tables IV and V) do not answer the question of research policy satisfactorily. They relate only to the largest changes, in which manufacture of a particular item is discontinued, and ignore smaller changes, in which new apparatus cards, or changes in a Spec, are made. It proved impractical to make survivor tables for the smaller changes, because of the way the data were kept by Bell Laboratories. Instead, a different experiment was designed.

The data on apparatus include (1) the cards in use December 31, 1959, by date of issue (Table VI), and (2) the distribution, by date of issue, of a sample of cards (Table II). If (2) were a complete enumeration, the ratio (1) ÷ (2) for any year would indicate the proportion of cards still in use to the cards originally issued in that year. If these ratios are considered "survival rates," and plotted on semilogarithmic scale, all research policies would yield a curve which declined as the age of the card increased. A FIFO research policy would approximate a curve convex upward; a LIFO policy a curve convex downward, and a random access curve a straight line. Since even a "systematic" research policy could not be expected to operate with complete uniformity, an empirical curve would only approximate a smooth line, with deviations due to lack of uniformity in the workings of research policy.

Since the data on issues are taken from a sample, and not a complete enumeration, the ratio of cards printed in year Y in force at the end of 1959 to the sample number for year Y is a multiple of the percentage actually surviving, with allowance for sampling fluctuations. A chart of the ratios of the two series, on semilogarithmic scale, would provide an estimate of the theoretical relationship described in the preceding paragraph. Despite irregularities the convexity properties associated with the various research policies, in particular, would be unchanged. Table VII reproduces the ratios, and their logarithms, and Graph 2 indicates that, in fact, there seems to be a random access rather than either a LIFO or FIFO policy. It would appear that a particular unit of apparatus, regardless of its age, had a probability of about .085 of being altered enough in a given year to require issuing a new card. The number .085 is not to be taken as being very precise, since it is the slope of a visually fitted straight line to the chart. I do not know a more sophisticated test that would be appropriate to this calculation.

The sample sizes for equipment were smaller, and the sampling variation correspondingly larger, than for apparatus. For this reason, annual estimates were replaced by biennial estimates for the period 1930-31 to 1958-59. Two estimates were made. The first reflects the probability that equipment will be designated "manufacture discontinued," and is designated "Spec Number Retention" on Graph

Graph 2. Apparatus and Equipment in Use 1959-1960
in Percent of Original Issue of Given Year



2.[19] The second reflects the probability that equipment will either be designated "manufacture discontinued" or be altered (by having a new issue or appendix) and is designated "Unaltered Equipment Specifications" in Graph 2.[20]

Since two factors operate to reduce Unaltered Equipment Specifications, and only one to reduce Spec Number Retention over time, the former is naturally steeper than the latter. Spec Number Retention shows marked linearity, except perhaps at the end of the scale where equipment introduced before 1935 is in question. Thus this series, like the Apparatus Cards series on the same graph, seems to support the random access hypothesis of research.

Even using biennial data, the Unaltered Equipment Specification series shows considerable fluctuation. My eye is tempted to see a convex downward curve, corresponding to the LIFO research policy; more elaborate statistical tests would be required to prove the matter conclusively. In view of the sampling fluctuations and the probability of autocorrelation in the data, I am unable to devise a suitable test for this purpose. But in any case, the random access hypothesis is not disproved either.

In any case, the slope of the Unaltered Equipment Specifications curve is greater, on the average, than that of the Apparatus Cards curve. Therefore, there is a greater probability in any year that equipment will be altered than apparatus. This result is consistent with the discussion of the survivor tables, where it was suggested that a piece of apparatus may be used in more than one technological generation of equipment.

We have treated technology as a list of items in a Western Electric catalog. Some balance sheet notions apply to such a list. Technology itself at any moment is an inventory of things which can be used. Over time, new technology is entered into the account, and old technology is discarded. Technological change, in some treatments, is the net change in the total stock; in others, the gross additions; in still others, the turnover in the account, the sum of additions and deletions. Finally, technological change is sometimes identified with invention, and invention with patenting, so that it would be useful to see how these data compare with patent data for the telephone system.

First, consider the additions to the stock. An elaborate time-series correlation analysis is probably premature, given our present understanding of these data. Instead, I have presented indexes of five-year averages in Table IX. With the exception of the patent data, which are new, the other data are taken from the earlier tables. Relegating to footnotes certain special observations,[21] some general conclusions stand out:

(1) Since the late 1930's there have been in general greater increases in the alterations of existing apparatus and equipment than in the number of new code or specification numbers. This fact suggests that changes in production methods and in the operating performance of existing models may have been more important than the design of drastically new models of hardware. To support this view we draw attention to the increase in patenting by Western Electric in the postwar period, compared to the decline in the rest of the system.

(2) The series relating to apparatus show greater increases (smaller decreases) than those relating to equipment. This fact suggests an increased complexity of the latter (as measured by, say, the number of components) over time.

(3) The trend in patenting tends to resemble the change in new equipment specifications, but not the other measures of technological change. Taken in conjunction with the preceding paragraph, this fact may indicate that for this industry at least, the decline in numbers of patents has taken place because individual items patented have become more complex.

(4) These conclusions are based upon a relative measure of additions to new technology, and therefore, do not really provide any basis for assigning any absolute measure of importance to the data pertaining to any single year. For this reason, it would be desirable to find some yardstick to describe their meaning more accurately.

For apparatus, the data are sufficiently complete to permit the calculation of some "pure numbers" relating to technological change. It is possible to calculate four indices, each of which has some intuitive meaning. I present all four, at the risk of undue length.

(1) A contrast may be made between the addition to technology made available during a period, and the turnover in technology, represented by the sum of new methods adopted and old methods eliminated. In Table X, Columns 1 and 2 refer to the former and Columns 3 and 4 to the latter.

(2) The importance of either additions or turnover in technology in some period must be evaluated in terms of the total stock of technology at the beginning of the period. The stock of technology may be the set of all practices in use at the time the change occurs. On the other hand, the stock of technology should perhaps include, in addition, technology once used, but abandoned prior to the change in question. In Table X, Columns 1 and 3 refer to the first concept and Columns 2 and 4 to the second.

Whichever of these four definitions is used, technological change (Table X) was greater in the late 1930's than at any time since. Whichever definition is used, a sharp drop occurred during the Second

World War. Whichever definition is used, an increase took place thereafter, and the late 1950's showed greater change than the 1940's or the early 1930's. The four measures do not agree as to when this last increase began, and how great it was, compared to the peak in the late 1930's.

We can only regret that comparable data are not available for equipment, which is bigger and more glamorous.

The measures of technological change which have been given here reflect research and development work of Bell Laboratories. To use an analogy from ordinary production processes, they constitute, in fact (disregarding work on government contract), the Laboratories' output of finished goods. It is well known, however, that a plant may accumulate stocks of goods in process, without completing anything; or it may have considerable amounts of completions, which are basically obtained by a running down of goods in process. The question of the future technological development of the telephone system cannot be decided by examining these data alone. To answer that question, it is also necessary to know whether the goods-in-process (research results not yet transformed into hardware) are available to replace those results which have been used. If all types of technological change had steadily declined in the postwar period--and not merely new equipment Specs--we might still anticipate accelerated technological change in the future. Such a prediction would be justified if it could be shown that research results had been reached more rapidly than technological change had taken place. If so, a rising backlog of technology in process has been created. To investigate this question would take another paper.

To conclude: Data have been presented on the adoption, alteration and discontinuation of individual types of apparatus and equipment in the telephone industry. These data supplement in important ways the data concerning patents. They cast some light on the research process in this industry, for they suggest that there is no higher probability that an item whose present design was finished in, say, 1940 will be replaced in 1962 than an item finished in, say, 1950. They also give information on the turnover of technology and the age-distribution of technology now in the system. These results are difficult to assign meaning to, since nothing comparable is known about other industries. If comparison should become possible, a more complete understanding of the process of technological change in individual industries would result.

Footnotes

1. I use the term <u>hardware</u> because <u>equipment</u> is used in a very special sense in the body of the paper.

2. "Operating companies" provide regional local telephone service. I use the term here to include also long distance facilities operated by A. T. and T.

3. The objection is often made that since A. T. and T. is a monopoly, its behavior is perhaps atypical. To this, it may be answered that my remarks apply to the possibility of observation. A competitive industry might indeed be different, but as yet nobody can tell.

4. See Schumpeter, <u>Theory of Economic Development</u>, Cambridge, Mass., 1934, pp. 61-65.

5. "Research, Invention, Development and Innovation," <u>American Economic Review</u>, LI, June 1961, 370.

6. The telephone instrument used in pay stations contains various such parts--a voice transmitter, a receiver, a coin-collecting mechanism, a dialing mechanism for activating central office switching equipment, bell, cord, case, etc.--yet (probably because of its size, cost, and quantity of manufacture) it is considered apparatus.

7. The qualification is introduced because some changes represent merely changes in terminology. A large number of codes issued in 1955, for instance, merely brought the nomenclature of the Bell System into line with that elsewhere (e.g., <u>condensers</u> were renamed <u>capacitors</u>).

8. Some earlier cards also exist, but an examination of these and similar cards suggests that standardization of apparatus did not actually take place until the Laboratories was created in 1924. Rather one has the impression from the cards that several administrative units in the System divided the responsibility on a functional basis, and that either the records are incomplete or part of the apparatus in fact escaped standardization.

9. The Laboratories maintains a card index of correspondence concerning changes in apparatus, arranged by code. It would be possible, although tedious, to ascertain the numbers of changes instituted by Western Electric, as compared with the Laboratories. Such data would suggest the importance of manufacturing processes themselves, as originators of technological changes of importance to the users of the product; as contrasted with changes originating in the research and development work in the Laboratories.

10. An apparatus "code" is the code number of a particular piece of apparatus. A "code" for equipment refers to a sub-assembly. The equipment as a whole is referred to as a "Spec."

11. Apparatus is here viewed roughly as a sub-assembly of a code, and a code as a sub-assembly of equipment.

12. There is some reason to suppose that the entries for 1921-1924 are not complete, for the index contains cross-references to other indices in use before the establishment of the Laboratories. These are not readily available, and may no longer exist.

13. The equipment which has been superseded by a different type bears a notation in the index of the Spec which displaces it. My count of Specs in the X series does not include a relatively small number of X-Specs which were superseded by X-Specs not in the 61000 or 63000 series. These X series do not refer to equipment, but to other things used by the System, and I concluded that I would not have homogeneous data if I included them.

14. The very large number of new specification numbers issued in 1928-1931 seems to reflect the renumbering into the J series of equipment formerly listed in the X-61000 and X-63000 series. I base this conclusion upon my examination of the index cards themselves, rather than upon any consideration of the inherent plausibility of these data.

15. Laboratories personnel suspect that there is a tendency for apparatus to remain "on the books," even if little used; so that periodically drives must be undertaken to rid the catalog of items which in fact are little used. If this view is correct,

the "manufacture discontinued" date given an item is not altogether reliable as a date when the apparatus became obsolete.

16. This data collection was done jointly by Dr. John Carlson of Cornell University and me, in May 1960. The "survivor tables" were calculated by him. We also collected certain other data of use to him, rather than to this study.

17. Checking List of Apparatus Card Catalog, Western Electric Company, New York, December 31, 1959. The purpose of this document is to enable operating companies to make sure their own card catalogs are up to date for purposes of ordering apparatus.

18. These definitions, of course, do not assert that planning in Bell Laboratories consciously follows the practice described, for there is no reason to suppose it does. They amount to a statement that however research is planned, the effect of the planning is that described above.

19. It was obtained by dividing Column 2, Table VII by Column 2, Table III for the biennial sums.

20. It was obtained by dividing Column 2, Table VIII by Column 4, Table III, for biennial totals.

21. (1) Bell Laboratories was established in 1924, and gradually took over research and development work formerly performed in part by Western Electric. The decline in patenting by Western Electric in 1930-34 as compared with 1925-29 reflects this administrative transfer. (2) During the Second World War, Bell Laboratories and Western Electric both began to do extensive work on government contract, in contrast to the earlier period. Therefore the new technology available to the telephone system dropped sharply. However, these companies were evidently able to patent some of the results of their work for the government. (3) The input of new technology into the system was thus affected adversely not only by the Depression of the 1930's but also by the Second World War. Some part of the new apparatus cards issued in the 1950's represented only changes in the names of parts. These changes were particularly important in 1955.

Table I

Changes in Apparatus Codes in Force 1931-1959

Year	Apparatus Coded During Year (1)	Code Nos Released as Mfr Disc (2)	Col 1 Minus Col 2 (3)	End of Year Cum Total of Code Nos Mfr Disc (=4-2) (4)	End of Year Cum Total of Code Nos not Mfr Disc (=5-3) (5)	End of Year Cum Total of all Code Nos (=4-5) (6)	Codes Rated "A and M only" During Year (7)
1931	1781	550	1231	14610	23759	38369	
1932	744	358	386	14968	24145	39113	
1933	602	436	166	15404	24311	39715	
1934	754	273	481	15677	24792	40469	
1935	603	287	316	15964	25108	41072	
1936	2775	321	2454	16285	27562	43847	
1937	2081	815	1266	17100	28828	45928	
1938	2414	1147	1267	18247	30095	48342	106
1939	1781	1624	157	19871	30252	50123	147
1940	1881	2047	(-) 166	21918	30086	52004	150
1941	1473	1054	419	22972	30505	53477	183
1942	716	1057	(-) 341	24029	30164	54193	10
1943	550	259	291	24288	30455	54743	0
1944	315	199	116	24487	30571	55058	13
1945	353	308	45	24795	30616	55411	10
1946	1031	252	779	25047	31395	56442	43
1947	1388	587	801	25634	32196	57830	20
1948	1130	773	357	26407	32553	58960	4

1949	1376	985	391	27392	32944	60336	31
1950	941	1502	(-) 561	(A) 29049	32383	(A) 61432	10
1951	1194	1705	(-) 511	30754	31872	62626	26
1952	1252	2437	(-) 1185	33191	30687	63878	63
1953	1263	1518	(-) 255	34709	30432	65141	46
*1953 (ADJ)	1263	1518	(-) 255	(*) 31273	(*) 29273	(*) 61026	46
1954	1004	1322	(-) 318	33075	28955	62030	27
1955	2839	973	1866	34048	30821	64869	10
1956	1760	312	1448	34360	32269	66629	7
1957	1577	521	1056	34881	33325	68206	11
*1957 (ADJ)	1577	521	1056	(-) 26283	(-) 34450	(-) 70733	11
1958	1679	1555	124	37838	34574	72412	9
1959	1002	1284	(-) 282	39122	34292	73414	8

Notes:
(-) Based on a count of catalog cards made at the end of 1957.
(A) Includes 155 codes of old Mounting Plantes, not previously listed in catalog added to M. D. Header Cards.
(*) In Columns 4, 5, and 6, figures for 1953 and earlier years are cumulative. However, a count of catalog cards was made at the end of 1953. Based on this count the following figures were deducted from the figures given on the 1953 line in order to arrive at the figures given on the "1953 ADJUSTED" line: 4 - 2956, 5 - 1159, 6 - 4115.

Source: Bell Telephone Laboratories

Table II

A Random Sample of Apparatus Cards
by Year of Issue

Year	Original Issue Sample Numbers[a]	Year	Original Issue Sample Numbers[a]
1921	56	1941	71
1922	70	1942	62
1923	69	1943	30
1924	72	1944	24
1925	62	1945	24
1926	46	1946	23
1927	72	1947	35
1928	38	1948	50
1929	62	1949	54
1930	61	1950	56
1931	91	1951	70
1932	40	1952	73
1933	21	1953	62
1934	21	1954	57
1935	23	1955	110
1936	31	1956	46
1937	34	1957	49
1938	50	1958	73
1939	72	1959	73
1940	64		

[a] Collected by Dr. John Carlson and me from the historical card index of Bell Telephone Laboratories (see text for details).

Table III

Equipment Specifications Issued Annually, 1921-1959

Year (1)	New Specification Numbers[a] (2)	Revisions[b] (3)	Total[b] (4)
1921			12
1922			28
1923			24
1924			68
1925			184
1926			168
1927			156
1928	130	90	220
1929	154	118	272
1930	123	149	272
1931	146	162	408
1932	67	157	224
1933	17	83	100
1934	24	40	64
1935	44	88	132
1936	82	82	164
1937	58	206	264
1938	63	153	216
1939	66	150	216
1940	94	194	288
1941	85	191	276
1942	53	151	204
1943	9	31	40
1944	9	51	60
1945	8	44	52
1946	52	80	132
1947	94	98	192
1948	66	134	200
1949	68	184	252
1950	68	164	232
1951	63	113	196
1952	37	111	148
1953	39	157	196
1954	55	177	232
1955	32	156	188
1956	29	171	200
1957	59	157	216
1958	56	192	248
1959	65	131	196

[a] Full count by Bell Telephone Laboratories

[b] Based on 25 percent sample

Table IV

The Survival of Apparatus Codes

Age	Total Codes Surviving to Beginning of Year	Manufacture Discontinued During Year	Rate of Discontinuation of Manufacture	Rate of Survival to End of Year
0	204	3	.015	.985
1	199	9	.045	941
2	189	7	037	.906
3	179	6	.034	875
4	172	3	.017	860
5	167	6	036	829
6	158	5	032	.802
7	152	2	.013	.792
8	148	6	.041	.760
9	140	4	.029	.738
10	136	7	.051	700
11	125	1	.008	.694
12	123	1	.008	.688
13	121	2	.017	.676
14	119	3	.025	.659
15	116	1	.009	.653
16	115	4	.035	630
17	111	3	.027	613
18	108	1	009	.607
19	108	2	019	.595
20	100	1	.010	589
21	95	0	.000	.589
22	94	2	.021	577
23	92	0	.000	.577
24	90	2	.002	.564
25	86	0	.000	.564
26	84	2	.024	.550
27	81	0	.000	.550
28	81	3	.037	.530
29	76	2	.026	516
30	73	1	.014	509
31	71	8	.113	.451
32	62	4	.065	.422
33	56	5	089	.384
34	51	2	.039	.369
35	46	1	.022	.361
36	42	2	.049	.343
37	38	1	.026	.334
38	36	0	.000	334
39	32	0	.000	.334
40	31	0	000	334

Table V

The Survival of Equipment Specifications

Age	Specifications Surviving to Beginning of Year	Manufacture Discontinued During Year	Survival Rate During Year	Rate of Survival to End of Year
0	474	1	.998	.998
1	460	8	.983	.981
2	438	7	984	.965
3	414	13	.969	935
4	397	6	.985	.921
5	384	6	.984	906
6	369	1	.997	.903
7	359	8	.978	.883
8	346	8	.977	.863
9	324	7	.978	.844
10	304	7	.977	.825
11	286	12	.958	790
12	262	5	.981	.775
13	245	7	974	.755
14	221	1	.995	.751
15	218	2	.991	.743
16	213	3	.986	.733
17	208	2	.990	.726
18	198	5	.975	.708
19	183	2	.989	700
20	162	3	.981	.687
21	147	4	.973	.669
22	134	1	.993	.664
23	128	2	.984	.653
24	115	3	.971	634
25	105	4	962	610
26	100	9	910	.555
27	87	15	.828	.460
28	65	10	.846	.389
29	42	0	1.000	.389
30	30	1	.967	.376
31	18	1	.944	.355
32				

Table VI

Apparatus Cards of Various Ages
in Use December 31 1959

Year	Cards of Given Year in Use Dec. 31, 1959	Year	Cards of Given Year in Use Dec. 31, 1959
1921	6	1941	123
1922	12	1942	187
1923	22	1943	65
1924	18	1944	54
1925	32	1945	60
1926	29	1946	76
1927	44	1947	48
1928	30	1948	158
1929	60	1949	168
1930	38	1950	293
1931	72	1951	240
1932	34	1952	459
1933	30	1953	488
1934	20	1954	576
1935	42	1955	1000
1936	36	1956	467
1937	46	1957	549
1938	47	1958	488
1939	113	1959	871
1940	141		

Source: Tabulation of Checking List of Apparatus Card Catalog, Western Electric Company, New York, December 31, 1959.

Table VII

Equipment in Use at the End of 1959 by Date of Introduction

Date of Introduction	Number of Equipment Specifications	Percent of Total	
		of Given Age	of Given Age or Less
(1)	(2)	(3)	(4)
before 1928	1	.37	
1928	8	2.96	99.61
1929	11	4.07	96.65
1930	10	3.70	92.58
1931	12	4.44	88.87
1932	4	1.48	84.43
1933	2	.74	82.95
1934	1	.37	82.21
1935	7	2.59	81.84
1936	11	4.07	79.24
1937	5	1.85	75.17
1938	6	2.22	73.32
1939	12	4.44	71.10
1940	17	6.30	66.65
1941	11	4.07	60.36
1942	7	2.59	56.29
1943	2	.74	53.69
1944	3	1.11	52.95
1945	2	.74	51.84
1946	7	2.59	51.10
1947	12	4.44	48.51
1948	11	4.07	44.07
1949	11	4.07	39.99
1950	13	4.81	35.92
1951	12	4.44	31.11
1952	5	1.85	26.66
1953	8	2.96	24.81
1954	9	3.33	21.85
1955	6	2.22	18.52
1956	4	1.48	16.29
1957	17	6.30	14.81
1958	14	5.18	8.52
1959	9	3.33	3.33

Table VIII

Equipment in Use, May 1960 by Date of Most Recent Alteration in Specifications (in Number of Specifications)

Year of Most Recent Alteration (1)	Number of Specifications: Sample Numbers (2)	Number of Specifications: Estimated Totals (3)	Survivals as Percent of Specifications Issued that Year (4)
1930	4	20	.073
1931	5	25	.061
1932	1	5	.022
1933	0	0	.000
1934	1	5	078
1935	1	5	.038
1936	1	5	.030
1937	1	5	.019
1938	1	5	.023
1939	2	10	.046
1940	4	20	.069
1941	4	20	.072
1942	5	25	.123
1943	3	15	.375
1944	2	10	.167
1945	0	0	.000
1946	4	20	.384
1947	7	35	.265
1948	4	20	104
1949	10	50	.250
1950	3	15	.059
1951	6	30	.129
1952	11	55	.281
1953	8	40	.270
1954	12	60	.306
1955	19	95	.409
1956	20	100	.531
1957	39	195	.975
1958	38	190	.879
1959	49	245	.987
1960	25	125	

Table IX

Some Long-term Movements of Patenting and Technological Change

	Patents Issued[a]			Apparatus		Equipment		
	Bell System Total	Western Electric	Other	New Codes	New Cards	New Specs	Revisions	Total
1925-29	126	427	54	n.a.	133	n.a.	n.a.	101
1930-34	123	202	104	50[b]	111	120	102	108
1935-39	100	100	100	100	100	100	100	100
1940-44	114	131	110	51	119	80	91	87
1945-49	81	116	73	55	89	92	80	83
1950-54	97	130	89	59	151	84	109	101
1955-59	87[c]	135[c]	75[c]	92	167	77	119	106

[a]Source: American Telephone and Telegraph Company

[b]5/4 of the 1931-34 total

[c]5/4 of the 1955-58 total

Table X

Some Alternative Measures of Technological Change in Apparatus

	Additions to Technology,[a] in Percent of		Total Technological Turnover,[b] in Percent of	
	Initial Technology[c]	Total Technology[d]	Initial Technology[c]	Total Technology[d]
1930-34	22	13	31	19
1935-39	39	23	56	34
1940-44	16	10	32	19
1945-49	17	10	27	15
1950-54	17	9	43	23
1955-59	31	14	47	22

[a]The numerators of these ratios are the numbers of new apparatus codes granted during the years in question (Table I, Column 1).

[b]The numerators of these ratios are sums of new codes plus codes rated "Manufacture Discontinued" during the years in question (Table I, Column 1 plus Column 2).

[c]The denominators of these ratios are the numbers of codes for which manufacture had not been discontinued at the beginning of the period (Table I, Column 5).

[d]The denominators of these ratios are the total numbers of codes which had been issued (including those discontinued) at the beginning of the period (Table I, Column 6)

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