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ABSTRACT

The main problem considered in this project is whether it will be possible for civilization to cope with the increasing quantities of archival information that must be stored in libraries, and if so, whether traditional methods of identification and access will prove adequate to the task. It is concluded that unless the storage, transmission, and retrieval of information in library archives is automated, there is no hope of keeping pace with the exponential growth of libraries. Part I explores the problem of determining the relationship of library growth to the growth of those components of civilization that support and use libraries. Part II analyzes cost factors in maintaining and updating card catalogs. It was found that simple situations do not require automation, but that complex ones, which appear unavoidable for most large libraries, demand automation on economic as well as on access grounds. (Author/JB)

FINAL REPORT

PROJECT NO. 8-0292

CONTRACT NO. OEC-9-8-00292-0107

THE COST OF MAINTAINING AND UPDATING LIBRARY CARD CATALOGS

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Los Altos, California and Houston, Texas

27 May 1969

U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

Office of Education
Bureau of Research

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We wish to thank the publishers who have kindly given their permission for the reproduction of figures which first appeared in the indicated publications: Figure 3—reproduced from Energy in the Future by P. Putnam, by permission of Van Nostrand-Reinhold Company, a division of Litton Educational Publishing, Inc., Litton Industries, Princeton, New Jersey, 1953; Figures 6 and 7—reproduced from The Biology of Population Growth by Raymond Pearl, by permission of Alfred A. Knopf, Inc., New York, 1925; and Figure 12—reproduced from Science Since Babylon by Derek J. de Solla Price, by permission of Yale University Press, New Haven, Connecticut, 1961. The above figures are found in Chapter 1.

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INTRODUCTION AND SUMMARY

This is the final report prepared under Contract Number OEC-9-8-00292-0107 for the U. S. Office of Education, Bureau of Research. Its principal concerns are broader than the title indicates, for although a great amount of detailed information concerning comparative estimates of the cost of maintaining and updating library card catalogs will indeed by found in Chapter 2, the authors view their contribution as directed toward wider concerns. The main problem considered in this work is whether it will be possible for civilization to cope with the increasing quantities of archival information that must be stored in libraries, and if so, whether traditional methods of identification and access will prove adequate to this task.

The answer is clear, and was already presented in our earlier book, Computerized Library Catalogs: Their Growth, Cost, and Utility (by J. L. Dolby, V. J. Forsyth, H. L. Resnikoff) July 1969, M.I.T. Press. The original report, without revisions, was prepared for the Office of Education in July 1968 (OE Proposal 7-1182 and OE Contract OEC-1-7-071182-5013) under the title of An Evaluation of the Utility and Cost of Computerized Library Catalogs: unless the storage, transmission, and retrieval of information in library archives is automated, there is no hope of keeping pace with the exponential growth of libraries. In the first chapter of the present work this thesis is elaborated upon, and the critical problem of determining the relationship of library growth to the growth of those components of civilization that support and use libraries is explored.

Although we believe that all major libraries will ultimately be highly automated, the problem of when and how a particular library ought to convert from traditional processing techniques to automated techniques is one that deserves serious attention. The catalog operation is certainly an early and obvious candidate for conversion. In Reference 1 we studied the cost and problems associated with automated library catalogs.

To place the information presented there in the proper background, Chapter 2 of this report provides a comparable study of the cost of traditional non-automated catalog techniques. The question of the utility of the traditional techniques has by and large been ignored as lying outside the compass of this study.

The major conclusions of this study can be summarized as follows:

1. Exponential growth of library holdings will persist for the foreseeable future. To maintain current growth rates, automation of the production of portions of the intellectual content, as well as the production of the physical books and equivalent forms of stored information, will increase.

2. There is a connection between the growth of library archives and the growth of various estimators of the degree, level, or state of civilization. The role of the preservation and transmission of information in the development of civilization ought to be investigated to provide a working tool for those responsible for the allocation of national resources. Our studies indicate that this can be done in an objective way, and that clarification of the details of this relationship will possibly lead to techniques for controlling the rate of development of civilization in a rational manner. We use the term "civilization" in a limited way, principally referring to the technological component of society.

3. Growth curves of importance to library management consist in general of piecewise exponential segments connected by transitional fluctuations. Determination of the nature of the current and short-term future portions of the curves is necessary for realistic and practical planning purposes.

Turning now to questions concerned with the maintenance and updating of card catalogs, our conclusions are of a piece with the above: in general, we find that simple situations do not require automation, but that complex ones, which appear unavoidable for most large libraries, demand automation on economic as well as on access grounds.

4. Libraries using the short form of a catalog and having no immediate need for multiple copies of the catalog may find it desirable to wait a while before converting to an automated system.

5. Libraries using the full form of catalog, or those requiring multiple copies of the catalog will almost certainly find that there is a substantial economic advantage to computerization at the present time.

CHAPTER 1

ANALYSIS OF LIBRARY GROWTH

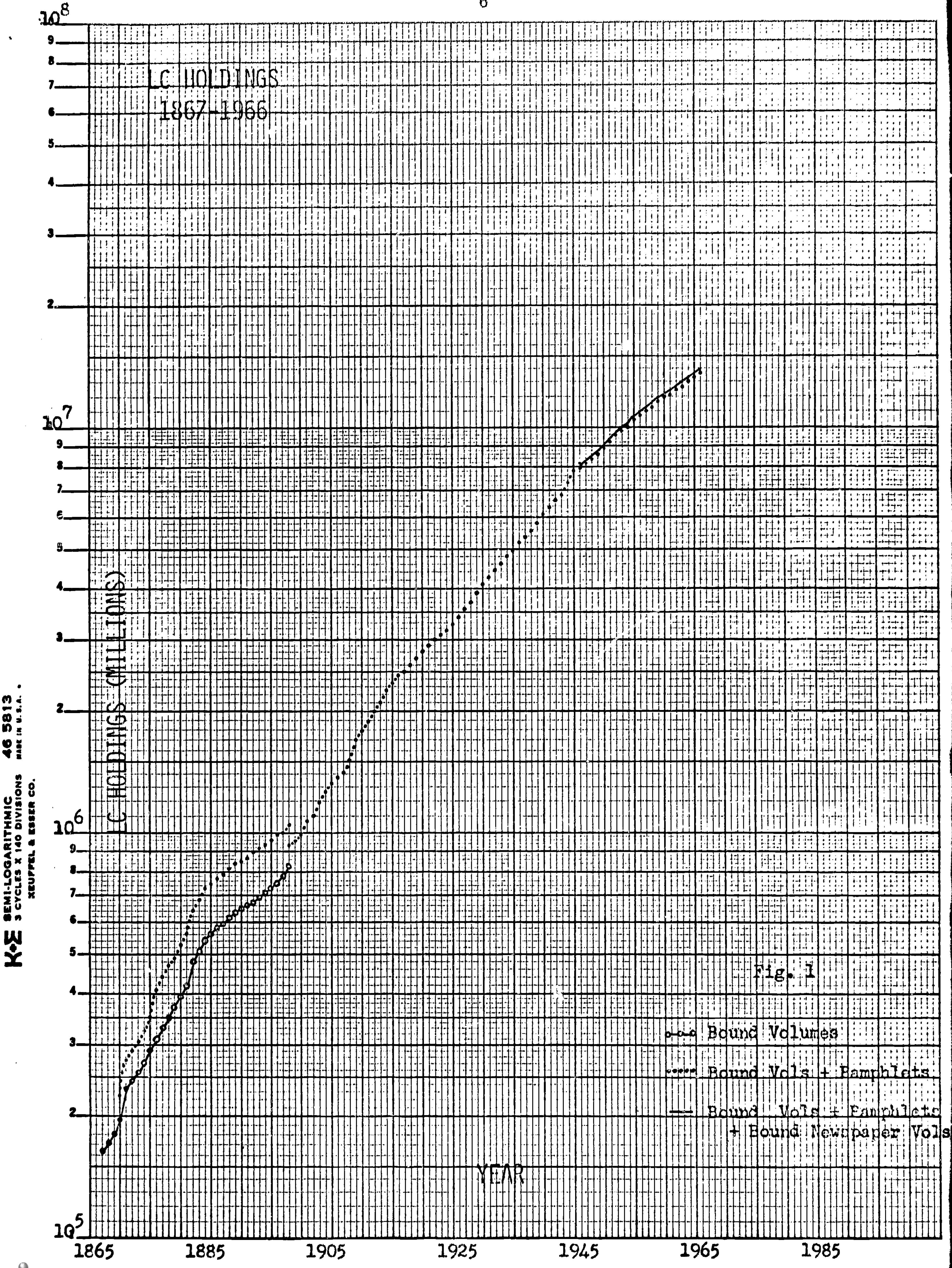
H. L. Resnikoff and J. L. Dolby

ANALYSIS OF LIBRARY GROWTH

INTRODUCTION

The single most striking statistical fact about library holdings is their rapid rate of growth. Whereas population growth in the United States proceeds at rates less than 1.5 percent, all major university libraries add at least 3 percent annually to their holdings (which consequently double every 23 years), and the Universities of Connecticut, Maryland, and Toronto are adding to their holdingsat a 10 percent annual rate (doubling in less than 8 years) (Ref. 3). Such rapid growth to an ever-increasing extent determines the reaction to the collection of both library users and library management. It creates and sustains an ever-present and ever-increasing pressure against the human, financial, and physical resources of the library, and limits opportunities for increasing access to the information buried in the growing archive.

In a previous study (Ref. 3) the nature and most obvious implications of library growth were examined. There it was concluded that for long periods, in some cases nearly 500 years, the current exponential pattern of holdings growth has sustained itself, subject only to local fluctuations representing the effect of major historical phenomena, but always returning to the steady certainty of exponential growth. This important observation referred to the number of holdings arranged by date of <u>imprint</u>; it did not refer to growth in holdings arranged by date of <u>accession</u>. Although these two types of growth are related, they behave in significantly different ways. Even libraries that are much younger than the invention of printing show the exponential behavior of their collections as a function of imprint date, but they also usually show a much more complex behavior of holdings as a function of accession date. For example, the holdings of the Library of Congress as a function of accession year are displayed in Figure 1 on semi-logarithmic graph paper--see also Table 1 on the following page. It is evident from Figure 1 that there are several distinct periods of growth, each of which is approximately exponential, but with varying growth rates. In effect, the Library's growth rate was greatest when it was small and inadequate; as it developed, a smaller rate of growth appeared. This pattern is easy to interpret, and occurs in many situations



Source - Annual Rpt of the Librarian of Congress 1867-1966

TABLE 1

LC HOLDINGS

YEAR	PAMPHLETS	BOUND VOLUMES	TOTAL BOUND VOLUMES & PAMPHLETS	BOUND NEWSPAPER VOLUMES	TOTAL BOUND VOLS & PAMPHLETS & BOUND NEWSPAPER VOLUMES
1866	~ 40,000	99,650			
1867		165,467			
1868		173,965			
1869		183,227			
1870	30,000	197,668	227,668		
1871	40,000	236,846	276,846		
1872	45,000	246,345	291,345		
1873	48,000	258,752	306,752		
1874	53,000	274,157	327,157		
1875	60,000	293,507	353,507		
1876	100,000	311,097	411,097		
1877	110,000	331,118	441,118		
1878	120,000	352,655	472,655		
1879	120,000	374,022	494,022		
1880	133,000	396,788	529,788		
1881	145,800	420,092	565,892		
1882	160,000	480,076	640,076		
1883	170,000	513,441	683,441		
1884	185,000	544,687	729,687		
1885	191,000	565,134	756,134		
1886	193,000	581,678	774,678		
1887	194,000	596,957	790,957		
1888	200,000	615,781	815,781		
1889	206,000	633,717	839,717		
1890	207,000	648,928	855,928		
1891	210,000	659,843	869,843		
1892	220,000	677,286	897,286		
1893	223,000	695,880	918,880		
1894	225,000	710,470	935,470		
1895	230,000	731,441	961,441		
1896	245,000	748,113	993,113		
1897	218,340	787,715	1,006,055		
1898	226,972	832,107	1,059,079 (932,094) Sic		
1899			957,056		
1900			995,166		
1901			1,071,647		
1902			1,114,111		
1903			1,195,531		
1904			1,275,667		

Table 1 (cont'd)

YEAR	PAMPHLETS	BOUND VOLUMES	TOTAL BOUND VOLUMES & PAMPHLETS	BOUND NEWSPAPER VOLUMES	TOTAL BOUND VOLS & PAMPHLETS & BOUND NEWSPAPER VOLUMES
1905			1,344,618		
1906			1,379,244		
1907			1,433,848		
1908			1,535,008		
1909			1,702,685		
1910			1,793,158		
1911			1,891,729		
1912			2,012,393		
1913			2,128,245		
1914			2,253,309		
1915			2,363,873		
1916			2,451,974		
1917			2,537,922		
1918			2,614,523		
1919			2,710,556		
1920			2,831,333		
1921			2,918,256		
1922			3,000,408		
1923			3,089,341		
1924			3,179,114		
1925			3,285,765		
1926			3,420,345		
1927			3,566,767		
1928			3,726,502		
1929			3,907,304		
1930			4,103,936		
1931			4,292,288		
1932			4,477,431		
1933			4,633,576		
1934			4,805,646		
1935			4,992,510		
1936			5,220,794		
1937			5,395,044		
1938			5,591,710		
1939			5,828,126		
1940			6,102,259		
1941			6,349,157		
			6,353,516		
1942			6,609,387		
1943			6,822,448		
1944			7,304,181		
1945			7,877,002		

Table 1 (con't)

YEAR	PAMPHLETS	BOUND VOLUMES	TOTAL BOUND VOLUMES & PAMPHLETS	BOUND NEWSPAPER VOLUMES	TOTAL BOUND VOLS & PAMPHLETS & BOUND NEWSPAPER VOLUMES
1946			7,946,460	118,159	8,064,619
			8,193,200		
1947			8,187,064	121,251	8,308,315
1948			8,387,385	124,619	8,512,004
1949			8,689,639	128,055	8,817,694
1950			8,936,993	131,425	9,068,418
1951			9,241,765	136,717	9,378,482
1952			9,578,701	140,573	9,719,274
1953			N/A		
1954			10,155,307	147,090	10,302,397
1955			10,513,048	151,623	10,664,671
1956			10,776,013	155,921	10,931,934
1957			11,037,773	159,015	11,196,788
1958			11,411,475	161,389	11,572,864
1959			11,779,894	165,741	11,945,635
1960			12,075,447	167,654	12,243,101
1961			12,329,678	169,993	12,449,671
1962			12,534,331	160,466	12,694,797
1963			12,752,792	156,766	12,909,558
1964			13,139,494	150,530	13,290,024
1965			13,453,168	149,509	13,602,677
1966			13,767,403	145,721	13,913,124

NOTE - The decline in Bound Newspaper Volumes 1961-1966 is undoubtedly due to the weeding out of old newspapers and replacing by microfilm unrelated to library problems. Of more significance is that this growth is essentially piecewise exponential, that is, it consists of consecutive growth periods, each of which is exponential (see Section 3).

In Figure 2 the growth of the Widener Library subcollection represented in Volume 7 (bibliography) of the Widener Shelf List (Ref. 15) is shown as a function of date of imprint. This distribution, which covers a period of more than 400 years, is exponential for almost 300 with but minor deviations. It should be contrasted with Figure 1.

The significant conclusion which is suggested by these two figures, and confirmed by further studies, is that there are two kinds of library growth. Some care must be taken to distinguish them from each other. What we have called the imprint growth rate is related to the total amount and nature of all published materials; the other kind of growth is particular to the life cycle of each library; it can reasonably be called accession growth. It is obvious that accession growth must be influenced by the more fundamental growth of imprints, but, except possibly in special situations that do not currently exist, the converse is not true. Accession growth does not influence imprint growth.

The management problems of a specific library will be composed of a complex combination of sub-problems stemming from both types of growth (as well as from other variables). It is necessary to be able to separate these two kinds of sub-problems to be able to analyze their relative importance and to be able to provide reliable projections of future requirements.

It should not be thought that the observed long-term exponential growth of imprints will continue indefinitely. Physical resources, as well as author resources, cannot maintain the pace of exponential growth. It follows that the current phase of imprint growth must ultimately terminate, yielding to a type of growth, or perhaps decline, that will have an upper bound. It is important to know whether this time is come, or whether it still is far in the future, for in the first case we may breathe a sigh of relief, assured that our resources will come into compass with library requirements and perhaps even permit the luxury of elaborating access to library collections in a studied and leisurely manner not subjected to the current continual strain to catch up with the flood of accessions. In the second case, which the authors believe is the more likely of the two, exponential growth

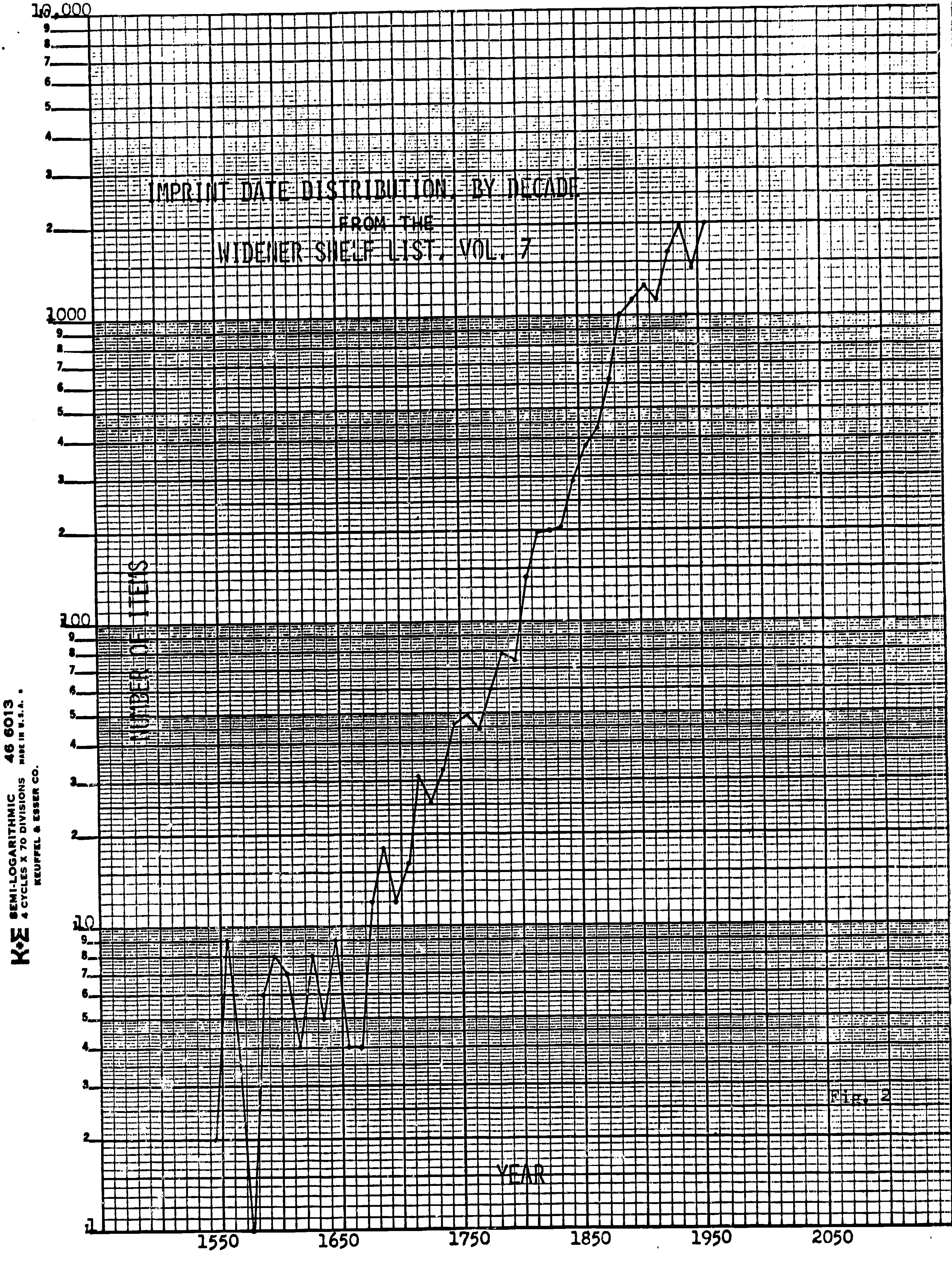

IMPRINT DATE DISTRIBUTION, BY DECADE
FROM THE
WIDENER SHELF LIST, VOL. 7
NUMBER OF ITEMS
YEAR
10,000
1000
100
10
1
1550
1650
1750
1850
1950
2050
K+E SEMI-LOGARITHMIC 46 6013
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. 2

at least current (and historic) rates will continue for a long period, and a relaxation of current accession pressures cannot be hoped for. In this case, every effort must be bent to command resources in the most efficient and rapid manner possible to cope with the information glut. It is in this case that the computer inevitably enters, for the growth with time of the number of computer operations per second, and the number of operations per dollar, are both exponential also, and therefore provide the possibility of containing and assimilating the growing flow of information.

Because the current phase of exponential growth must ultimately change to some type of growth occurring at a lower rate, and ultimately to a growth or decline which has an absolute upper bound, it is of some interest to study the likely forms that future growth curves will take, as well as the way in which one growth stage will pass into the next. The remaining sections of this chapter are devoted to determining the forms of natural growth curves that appear pertinent to the problem of library growth so that three main problems can be investigated. These are:

1. Is the current phase of exponential growth likely to persist for long?

2. What is the utility of approximating library and related growth curves by piecewise exponential functions in place of more complex curves?

3. What is the nature and interpretation of fluctuations about the exponential trend?

The answer to the first problem has the greatest immediate significance, for it determines whether future decades have in store for us exponential struggle, or the peaceful and perhaps dull coexistence with a steady state of information production and decay.

FOUR FUNDAMENTAL COMMUNICATION INVENTIONS

The purpose of the library is to store and provide access to the information accumulated by man throughout history. Thus it is reasonable to expect a relationship between library growth and growth or change in other components of civilization. This fundamental relationship does not seem to have been sufficiently emphasized in the literature, but it is important for a balanced understanding of the current growth situation. Therefore, it seems appropriate to make a brief historical digression.

Four fundamental inventions can be recognized in the history of civilization. Each of them produced changes of unprecedented magnitude and extent; all of them have a common aspect. The first was the invention of complex writing systems, capable of expressing abstract concepts as well as names and actions, in the Near East not much earlier than 3000 B.C. (cp. Ref. 4). It was immediately followed by the rise of the oldest of the high civilizations known today --- the Egyptian and Mesopotamian --- and was, perhaps, the cause of their rise. These elaborate and inefficient writing systems made possible the accumulation of archival information stores containing records of complex processes and observations relating to mathematics, astronomy, law, political administration, and commercial accounts. There is no indication of the existence of complex political organizations or scientific effort in societies not having a writing system.

Nearly 2000 years later the alphabetic system of writing was introduced by the Greeks (Ref. 4)[1], and their remarkable civilization rose to its great heights shortly after. The significance of an alphabetic writing system cannot be overestimated: it is markedly more efficient for communication, requires less time to learn, and is therefore accessible to greater numbers of people. It provides a startling comparative advantage in communication for the maintenance of commercial and administrative records, for the recording of mathematical and scientific information, and even for those communications necessary for the extended prosecution of military efforts ranging over great distances. The mental effort and time required to read a given amount of information recorded in one of the ancient Egyptian writing forms or in cuneiform Akkadian is enormous compared with an alphabetic language representation; scientific information presents special difficulties.

The third invention that we consider fundamental is that of movable type, and its application to printing, probably by Gutenberg and Johann Fust, in the mid-fifteenth century; the earliest known book printed in Europe is dated 1456. Although movable type was known in China and Korea before its independent invention in Europe, its influence in China was negligible, no doubt because of the non-alphabetic nature of the chinese language, while its development in Korea antedated the European invention by about 50 years, and was probably connected with the Korean adoption of a phonetic alphabet about that time.

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[1]Gelb (Ref. 4) writes: "If the alphabet is defined as a system of signs expressing single sounds of speech, then the first alphabet which can justifiably be so called is the Greek alphabet."

Each of these three inventions provided a remarkable advantage over previous methods for storing, transmitting, and retrieving information, with a corresponding decrease in the unit costs involved. The principle consequence of increased efficiency and effectiveness was the opportunity to build on past knowledge and experience; this greatly accelerated the growth and progress of civilization in each of the periods of invention.

The modern general-purpose digital computing machine epitomizes the common properties of these three earlier inventions; no one other instrument or technique in the history of civilization has created such a change in the ability to store, transmit, and retrieve information as has the computer. It is difficult not to view it as the fourth fundamental invention in the field of communication of information, and to speculate that its effect will be no less than the effects of each of its predecessor inventions. From this standpoint, a new "information explosion" must be anticipated, that is, a new period of exponential growth having a growth rate (i.e., an exponent) greater than that characteristic of the post-printing press growth period. One consequence of this new explosion will be an increased rate of library accession of information and quite likely a new role for libraries as archives of information in machine-readable form. If this argument is accepted, the answer to the first of the questions posed in Section 1 is clear: the current exponential growth rate is not likely to persist; it will be replaced by an information growth rate greater than the current rate.

If the role of the computer in civilization is in fact similar to the roles previously played by the invention of writing systems, alphabet, and printing, then there will probably be changes in the essential fabric of civilization as we know it that cannot now be foreseen. The role of the library is central to this point of view, for libraries represent the archive wherein the knowledge and experience accumulated by previous generations is maintained and organized (albeit superficially); they are the information repositories on which all future developments are founded. If it is true that the growth of civilization, and indeed its growth rate, depends on the capabilities for storage, transmission, and retrieval of information, then it inevitably follows that the role of libraries as storage banks for information in printed as well as machine-readable form--and of computers to transmit and retrieve, as well as to analyze, modify, and re-store that information--must become more central and important as time passes. Governmental support for library systems, and library support for and experiments with, computers is, if our argument is essentially correct, imperative for the continued growth of civilization. Examples of the interaction between efficient information-processing and the growth of civilization that may help to place the previous remarks in perspective are discussed below.

World Population Growth

The "population explosion" is a consequence of decreased death rates since there is relatively little that can be done to increase the per capita annual birth rate. As Figure 3 shows, the rate of growth of world population--that is, the decrease in the death rate--increased markedly after 1500, and has been increasing ever since in an historically unprecedented manner. This must be attributed primarily to the rapid communication of medical knowledge, sanitation techniques, advances in agriculture, and so forth, made possible by the invention of printing a few decades earlier. A similar population explosion probably occurred in the Greek world between 1000 B.C. and 500 B.C., and even earlier in historical Egypt and Mesopotamia, although accurate population estimates are lacking. The vast construction programs of the Egyptians, and Akkadians, and the similar later ones of the Chinese, provide evidence of a massive long-term employment of labor and consequently of a relative surplus of population. It is of no importance to this argument what proportion of these populations might have been "immigrants" of one type or another.

Mathematical Research

Mathematical research depends in a direct way on the availability of an archive and the efficient transmission of information. Even in ancient times there was relatively rapid communication of new important results. For instance, Archimedes was well-informed about the astronomical theories of Aristarchus although the latter was only 25 years older than Archimedes and they were separated by most of the "known" world of the times (circa 200 B.C.), Archimedes residing in Sicily, and Aristarchus on the island of Samos near modern Turkey. Because of the critical role that communication plays in mathematical progress, one would expect that mathematics would experience a renaissance following an invention which decisively improves communication. In fact, there is no real mathematics known prior to the Egyptian and Mesopotamian civilizations, although

RATE OF GROWTH OF WORLD POPULATION

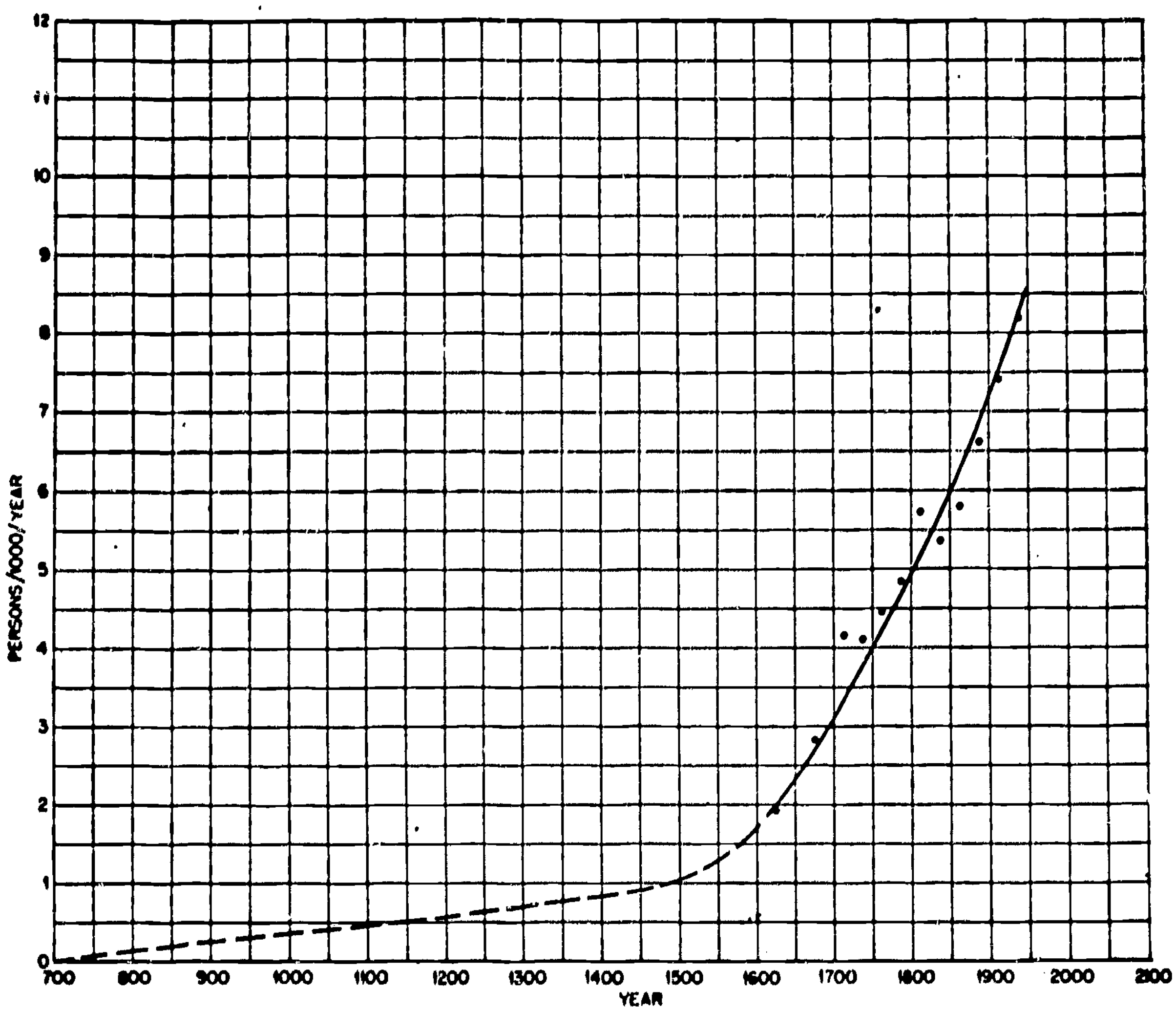

Fig. 3 Estimated trend in the rate of growth of World population, A.D. 700 to 1950. *The point for 1951 was estimated by the U.N., 1952.*

Data from Palmer Cosslett Putnam, Energy in the Future, D. Van Nostrand Co., Inc., New York (1953)22 serious mathematics of high caliber is attested in the earliest phases of these civilizations. Much more information is available about what has happened since Greek times, and it supports our view. Indeed, if the number of memorable mathematicians is graphed as a function of the birthdate of the mathematician, then the curve displayed in Figure 4 results. Here a mathematician is "memorable" if he is named in the index to a standard history of mathematics; the book by Struik (Ref. 13) has been used for the illustration. Other choices would not change the shape of the curve. Estimates of world population are shown in Figure 4 for comparison purposes. Observe that the number of memorable mathematicians rose rapidly after 700 B.C.--that is, not long after the invention of the alphabet by the Greeks--and grew exponentially from 300 B.C. until about 1450 A.D. after which time the growth rate increased dramatically. If the exponential portion of the memorable mathematician curve is extended back in time, it suggests that the "first" memorable mathematician lived about 3700 B.C., not long before the first writing systems are attested, and probably simultaneous with their development.

European Universities

The growth curve illustrating the currently extant European universities as a function of their date of founding (Figure 5) is interesting. The data came from the Random House Dictionary, and is given in Table 2. Figure 5 shows four distinct phases of growth, three of which are clearly exponential, with a fourth that is approximately so. The earliest period, from 1100 to 1210, corresponds to such small numbers of universities that statistical arguments cannot be reliable, and we thus ignore it. The second period, from about 1210 to 1500, indicates a uniformly exponential growth doubling approximately every 110 years. After 1500, there is a 300-year period of roughly exponential growth, which may mark a transitional phase from the previous period to the next one, beginning in 1800 and continuing to the present, which shows exponential growth proceeding at the same rate as the 1210 to 1500 growth.[2] Thus, shortly after the invention of printing, a major change in the growth rate of

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[2]The data given in Table 2 appears to agree with that used by De Solla Price for his figure on page 115 of Reference 2, but his description of the growth there given seems to be in error.

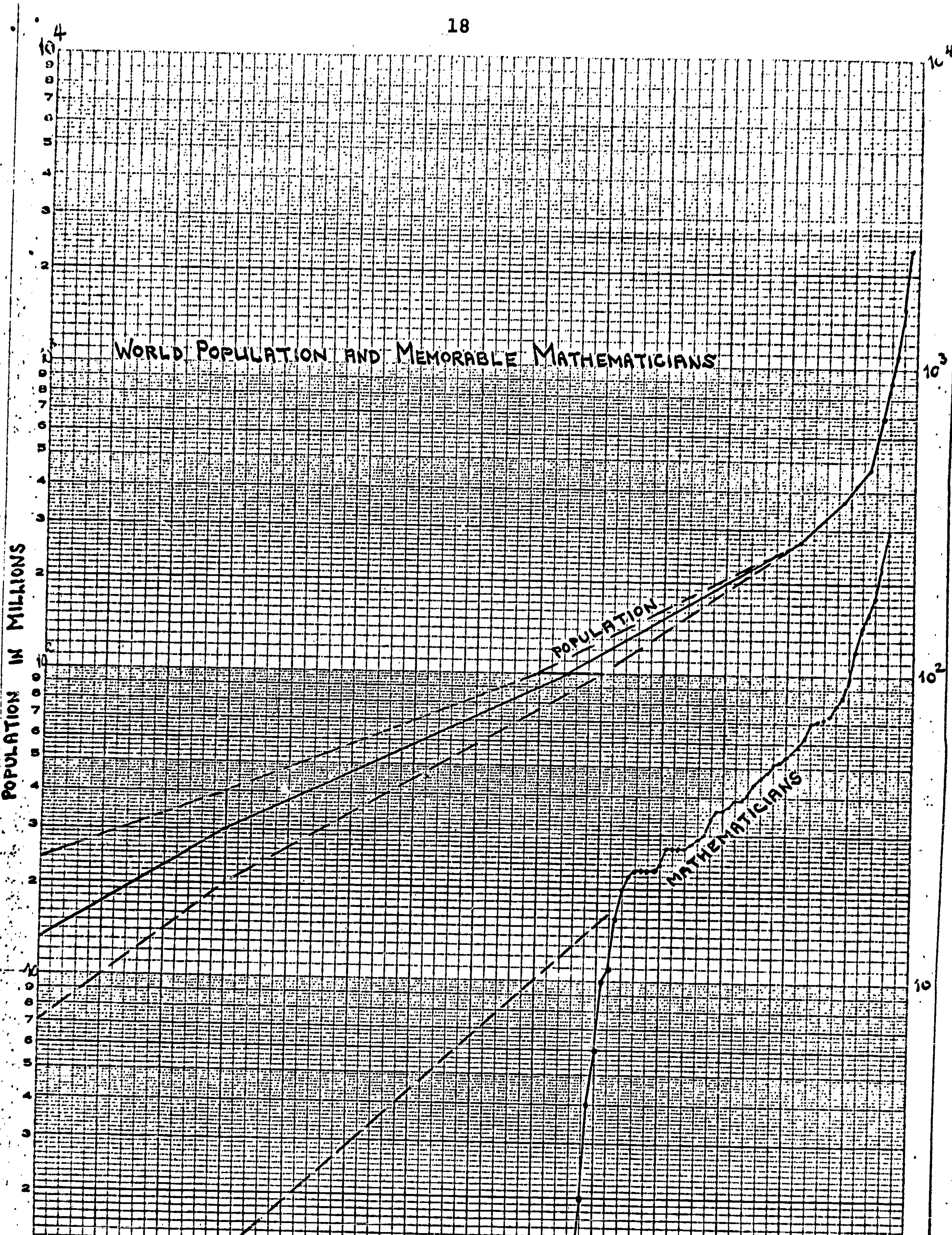
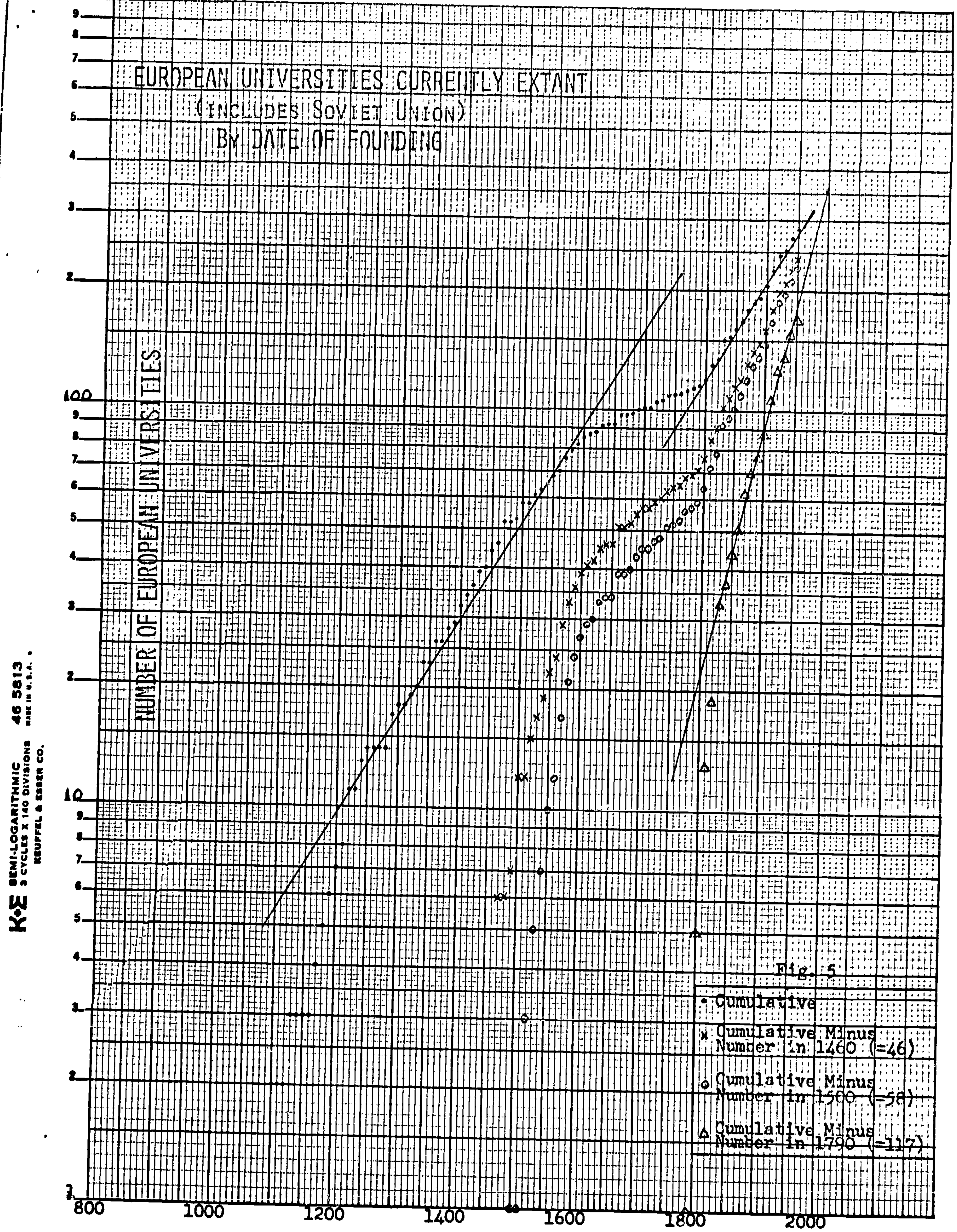

WORLD POPULATION AND MEMORABLE MATHEMATICIANS
POPULATION IN MILLIONS
POPULATION
MATHEMATICIANS
-5000
-4000
-3000
-2000
-1000
0
1000
2000
EUGENE DIETZGEN CO.
SEMI-LOGARITHMIC
4 CYCLES X 10 DIVISIONS PER INCH

Fig. 4



Source - Random House Dictionary

Table 2

European Universities Currently Extant

Year	Cumulative	Cumulative Minus Number in 1460 (=46)	Cumulative Minus Number in 1500 (=58)	Cumulative Minus Number in 1790 (=117)
1065	1			
1100	2			
10	2			
20	2			
30	3			
40	3			
50	3			
60	3			
70	4			
80	5			
90	6			
1200	7			
10	8			
20	11			
30	11			
40	13			
50	14			
60	14			
70	14			
80	14			
90	17			
1300	18			
10	18			
20	19			
30	20			
40	23			
50	23			
60	26			
70	26			
80	28			
90	29			
1400	32			
10	34			
20	36			
30	39			
40	40			
50	44			
60	46			
70	52	6		
80	52	6		
90	53	7		

Source: Random House Dictionary.

Table 2--continued

Year	Cumulative	Cumulative Minus Number in 1460 (=46)	Cumulative Minus Number in 1500 (=58)	Cumulative Minus Number in 1790 (=117)
1500	58	12	0	
10	58	12	0	
20	61	15	3	
30	63	17	5	
40	65	19	7	
50	68	22	10	
60	70	24	12	
70	75	29	17	
80	79	33	21	
90	82	36	24	
1600	85	39	27	
10	87	41	29	
20	88	42	30	
30	91	45	33	
40	92	46	34	
50	92	46	34	
60	97	51	39	
70	97	51	39	
80	98	52	40	
90	101	55	43	
1700	103	57	45	
10	103	57	45	
20	105	59	47	
30	106	60	48	
40	109	63	51	
50	110	64	52	
60	111	65	53	
70	114	68	56	
80	115	69	57	
90	117	71	59	0
1800	122	76	64	5
10	130	84	72	13
20	136	90	78	19
30	150	104	92	33
40	154	108	96	37
50	161	115	103	44
60	168	122	110	51
70	179	133	121	62
80	187	141	129	70
90	194	148	136	77
1900	205	159	147	88
10	225	179	167	108
20	245	199	187	128
30	254	208	196	137
40	272	226	214	155
50	286	240	228	169

Source: Random House Dictionary.

the number of universities occurred. One interpretation of this phenomenon is that printing made the textbook cheaper and more available and thus permitted an increased student-to-teacher ratio, decreasing the necessity for founding new institutions. After 300 years, the natural growth in the student population increased this ratio beyond levels that could be efficiently maintained even with the availability of inexpensive texts, thus encouraging the foundation of more universities, at the previously observed rate. This explanation is offered solely as a possibility; research would have to be done to see if it is consistent with the growth of student populations. An indication that this explanation may not be far-fetched is the contemporary effort to introduce television and teaching machines to permit greater student-to-teacher ratios; both of these devices are improved means for transmitting information, which of course the printed text is too.

STABLE GROWTH

The growth with time of a population (of people, or books, or any other quantity) is said to be exponential if its rate of change is proportional to the population; the constant of proportionality is the growth exponent. In the standard notations of the differential calculus, this is expressed by writing

1) $$\frac{dP(t)}{dt} = a_o P(t) \; ,$$

where $P(t)$ denotes the population at time t, and a is the growth exponent. The solution to this differential equation is

2) $$P(t) = P(t_o) e^{a_o (t-t_o)} \; ,$$

where t_o is any conveniently chosen time. If a population does grow according to this equation, then its logarithm varies linearly with the time, that is,

$$\log P(t) = \log P(t_o) + a_o (t-t_o) \; ;$$

here log denotes the natural logarithm function. This means that exponential growth is represented by straight lines on semi-logarithmic graph paper, such as is used for Figures 1 and 2, for instance.

Since two constants determine a straight line, it follows that two constants completely determine the equation of exponential growth. Complex social or natural processes will usually require more than two constants for their accurate representation, so that exponential growth laws should not be able to represent such processes for long periods except in special circumstances.

If the growth exponent is positive, then P(t) will increase indefinitely as time passes. For populations on the earth, this cannot happen, so it must be the case that a population which follows an exponential growth process must ultimately change. This change cannot be described without introducing new assumptions; it is by no means clear what these assumptions should be for human or book populations, although a number of proposals have been made.

If P(t) does grow exponentially, then it doubles every $(\frac{\log 2}{a_0})$ units of time; if time is measured in years (as will be assumed from here on), then P(t) doubles every $(0.69315/a_0)$ years. The annual rate of increase is given by $(e^{a_0}-1)$; if a_0 is small, this is approximately equal to $(a_0 + a_0^2/2)$. For instance, of $a_0=0.1$, then the annual growth rate will be 0.1052..., just more than 10 percent. For growth rates, or growth exponents, less than 0.1, the growth exponent is essentially the same as the annual growth rate.

Recognition that most growth processes could not be described by a two-parameter curve such as the exponential led many investigators to attempt generalizations having a greater number of parameters that could be adjusted so as to fit the data. This is a difficult problem. There are mathematical theorems which state that any sufficiently smooth curve--and all of the growth curves that we are considering satisfy this condition--can be represented as closely as desired if enough parameters are used. The practical problem is to provide a representation that uses as many parameters as are necessary, but no more, so that there is some hope that the representation actually corresponds to the actual underlying physical or probabilistic processes in a natural manner. The earliest well-reasoned generalization of the exponential to fit growth data was made by Verhulst (Ref. 14) in the mid-nineteenth century; his discovery of the logistic curve was independently repeated by Pearl and Reed (Ref. 11) in 1920. Verhulst's idea was to replace the differential equation (1) by the "simplest" generalization. Upon dividing both sides of eq(1) by P(t) , one finds

$$\frac{dP/dt}{P} = a_0;$$

Verhulst assumed that the right hand side should be replaced by a more general function, say f(t,P(t)), which might depend on the time t as well as on the population $P(t)$. If the population growth rate depends only on the population, and not on the time (this is realistic; for instance, had the United States been discovered 300 years earlier, its population growth is likely to have proceeded in the same manner as actually occurred), then f depends only on $P(t)$. Verhulst's next assumption was that this dependence could be expressed by means of a power series, that is, in the form

$$f(P(t)) = a_o + a_1 P(t) + a_2 P(t)^2 + \ldots\ldots \quad (a_o > o); \tag{3}$$

further, he made the approximation that all of the terms on the right except the first two in eq(3) could be neglected, and arrived at the differential equation

$$\frac{1}{P}\frac{dP}{dt} = a_o + a_1 P ; \tag{4}$$

if $a_1 = 0$, this coincides with the original differential equation, eq(1) above. The solution is the <u>logistic curve</u>,

$$P(t) = \frac{-a_o/a_1}{1+e^{-a_o t+c}} , \tag{5}$$

where c is a constant that must be determined from the value of $P(t_o)$ at some time t_o. This equation therefore involves three parameters a_o, a_1, and c instead of the two appearing in the exponential. For $P(t)$ to be positive it is necessary that a_1 be negative; then the term $a_1 P(t)$ in the differential eq(4) corresponds to an influence retarding the growth of P with time, and in fact, as t becomes indefinitely large, $P(t)$ does not, but rather approaches the value $-a_o/a_1$ as an absolute maximum. The positive number a_o represents, as before, the growth exponent. Pearl (Ref. 10) provides a useful example of a logistic curve, making use of Carlson's (Ref. 17) data on the growth of yeast cells; we have reproduced this curve in Figure 6. It illustrates both the shape of the logistic and the fact that logistic curves do sometimes provide accurate representations of growth processes. Unfortunately, the complex processes of library imprint growth, human population growth, or other growth phenomena related to society do not in general behave logistically. For instance, neither the holdings growth of the Library of Congress (Figure 1) nor the growth in the number of universities (Figure 5) are well-represented by logistic curves. Numerous attempts have been made to fit the data of civilization to logistic curves and to successions of logistics (cp. Ref. 2, 6, 7, 9, 10, 11, 16, 17).

THE LOGISTIC CURVE

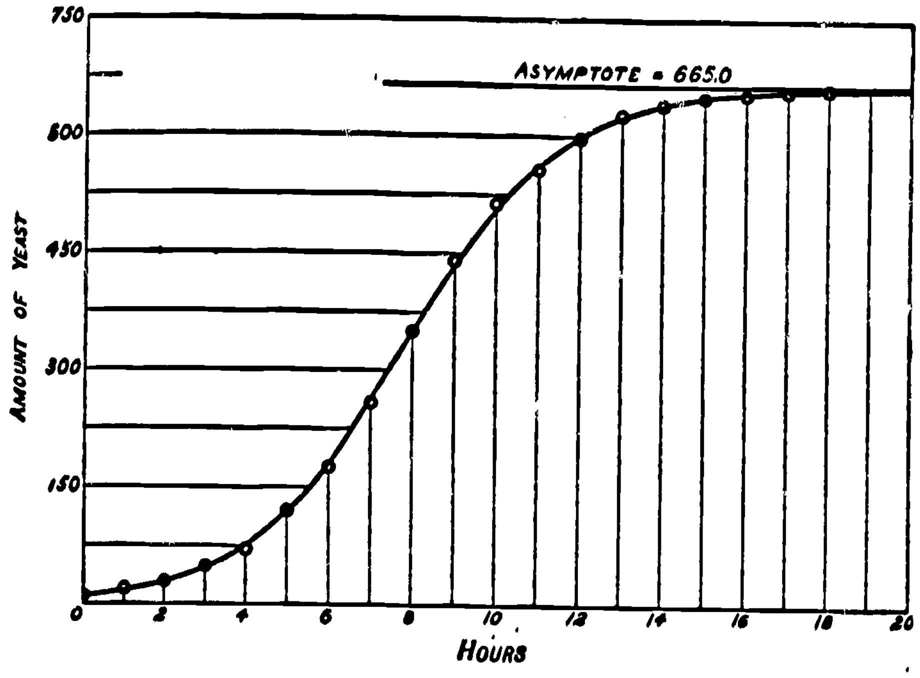


Fig. 6 The growth of a population of yeast cells. Data from Carlson (see Ref. 17) represented as small circles.

Logistic curve equation $P(t) = \dfrac{66.5}{1 + e^{-0.5355t + 4.1896}}$

Data from Raymond Pearl/JHU, The Biology of Population Growth, Alfred A. Knopf, Inc., New York (1925)9

If it is found that some data can be nicely fit by a sequence of N logistics, this means that at least 4N-1 parameters are involved (as well as some additional ones to describe where consecutive logistics are to be fit together, but this can be ignored since this problem is common to all piecewise fitting processes), since each logistic requires three parameters, giving 3N , and all but one (and sometimes that last one also!) must be shifted up or down, which requires an additional constant. For instance, if data can be fit by two logistics, as shown in Figure 7 taken from Pearl (Ref. 10), then eight parameters are required. Only 11 data points were available to Pearl, so it is no surprise that an eight parameter function could be found that would provide a good fit; it is not clear that other functions might not provide an equally good fit with the use of fewer parameters. Indeed, Pearl's data is shown on a semi-logarithmic scale in Figure 8 , from which it is readily seen that the leftmost four points are well fit by the two parameter exponential, the next three could be fairly well fit, and the remaining four are again well fit by an exponential. Therefore three exponentials, requiring a total of six parameters appear to do about as well as two logistics requiring eight parameters. One difference is that there is no evident place to transfer from one logistic to the other; Pearl arbitrarily does this at 1855. The exponential fits of Figure 8 immediately suggest that something happened between the adjacent data points for 1840 and 1855, and the fact that the lines representing the earliest and latest exponentials in the graph are nearly parallel suggests that whatever occurred to change the population growth rate between 1840 and 1855 had returned to normal by 1870. The revolutions and turmoil of 1848 and the following years could have affected the birth rate, and it might have taken a generation--about 20 years--to recover the rate loss, thus accounting for all of the features of this graph in an informative way that the logistic interpretation does not permit. Indeed, it is precisely the <u>fluctuation</u> from exponential growth that is of interest in <u>this case</u>; the logistic curves smooth that fluctuation so as to make it invisible.

The following paragraphs will argue that <u>piecewise exponential</u> approximation to growth curves provides the most convenient and informative tool for understanding the underlying processes. We will argue that the nature of civilization is such that when influences which tend to retard growth are encountered, the <u>exponent</u> of the exponential growth curve is changed to relieve that retarding pressure; in general, the <u>form</u> of the function is not changed. This is the same as saying that the growth exponent of the exponential is a

THE POPULATION GROWTH OF GERMANY

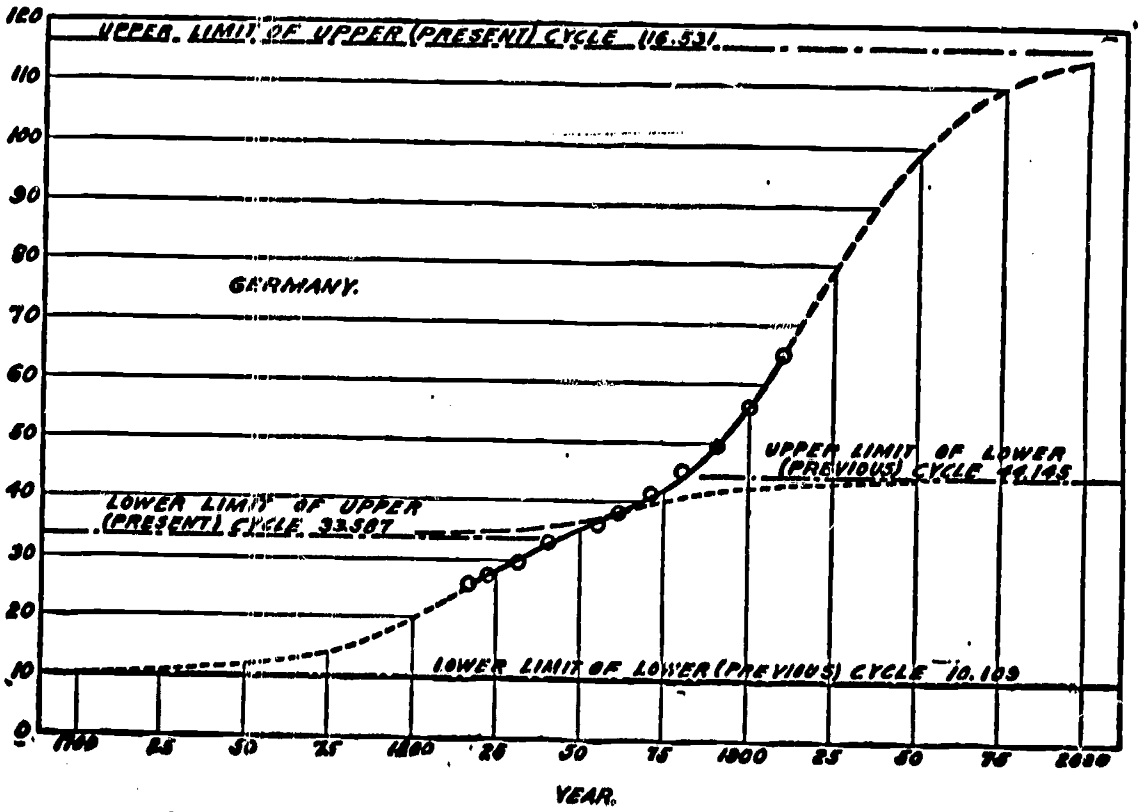
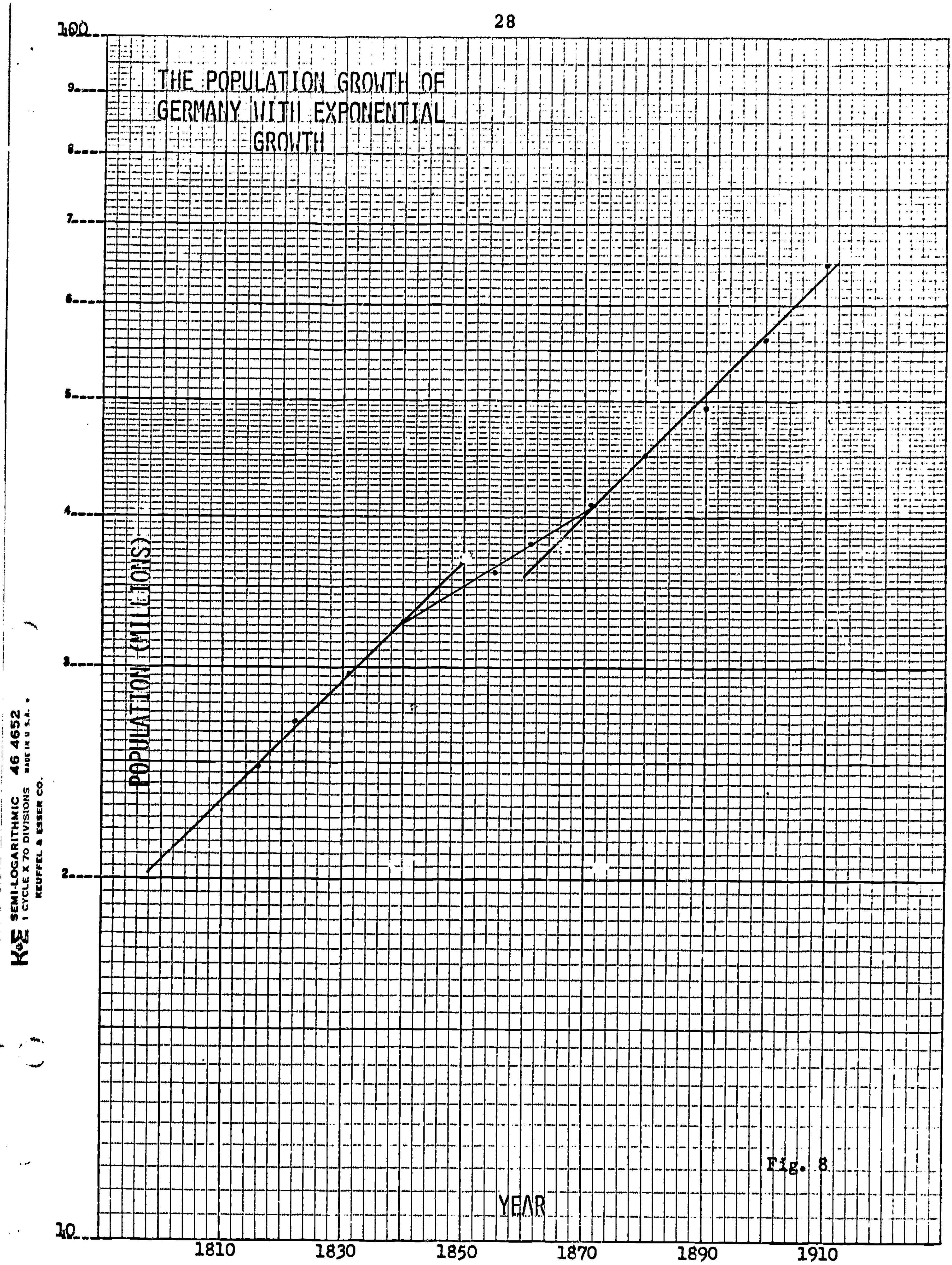


FIG. 7 The population growth of Germany, showing two cycles of growth which have overlapped during the period of census history.

For the period up to 1855, $P(t) = 10.109 + \frac{34.036}{1 + 2.495e^{-0.0394t}}$

From 1855 on, $P(t) = 33.587 + \frac{82.944}{1 + 297.546e^{-0.0472t}}$

Data from Raymond Pearl/JHU, The Biology of Population Growth, Alfred A. Knopf, Inc., New York (1925)21



Source - (Table 8) The Biology of Population Growth, Raymond Pearl function of time, and, with a sufficiently complex variation of this exponent with time, any growth curve can be traced out. But it appears from a study of various important classes of growth curves that the variation of the exponent with time is of a particularly simple nature. It is constant most of the time, but, in reaction to external retarding influences, it makes a transition from its original constant value to another constant value which is compatible with the external circumstances.

Consider, for instance, the population growth of the United States, shown in Figure 9, for the period 1610 to date. Until 1690, growth was extremely rapid and exponential; from 1700 until 1880 growth was again exponential with a remarkable degree of accuracy and consistency. After 1880 a more complex pattern occurs (to be discussed in Section 4). The departure from exponential growth which shows up for the first time in the 1880 census corresponds to what historians call "Turner's thesis," concerned with the closing of the Western Frontier. It is evident that the 270-year period from 1610 until 1880 can be accurately described by two exponentials, thus four parameters.

Population statistics are unusually complete for the United States; most other nations have only recently begun to accumulate accurate population estimates based on census data. Nevertheless, it will be useful to look at the population growth of one other nation. Figure 10 displays the growth of Japanese population since 1872. It can be accurately represented by two exponentials, from 1872 until 1900, and from 1900 to date. There is a sharp population decline, shown by the 1945 census, due to manpower losses in World War II, but this was completely made up by the 1950 census. The long-term trend rate of Japanese population growth has returned approximately to that level that it has held since 1900. In the popular press as well as in demographic literature there has been concern for the rapid growth of the Japanese population since the war, and some relief that it appears to be coming back under control at last. This is misleading; in fact, having retrieved the population lost in the war, the growth rate is now returning to its traditional value. This shows a danger inherent in looking at short sections of time series. The local fluctuations may obscure the general picture and lead to gross mis-estimates of what is happening. Further examples of this type of problem will come up in what follows.

Returning to Figure 2, the Widener Shelf List Volume 7 imprint date distribution, observe its essential exponentiality; Figure 11 displays the same information for the

UNITED STATES POPULATION
1610 - 1965

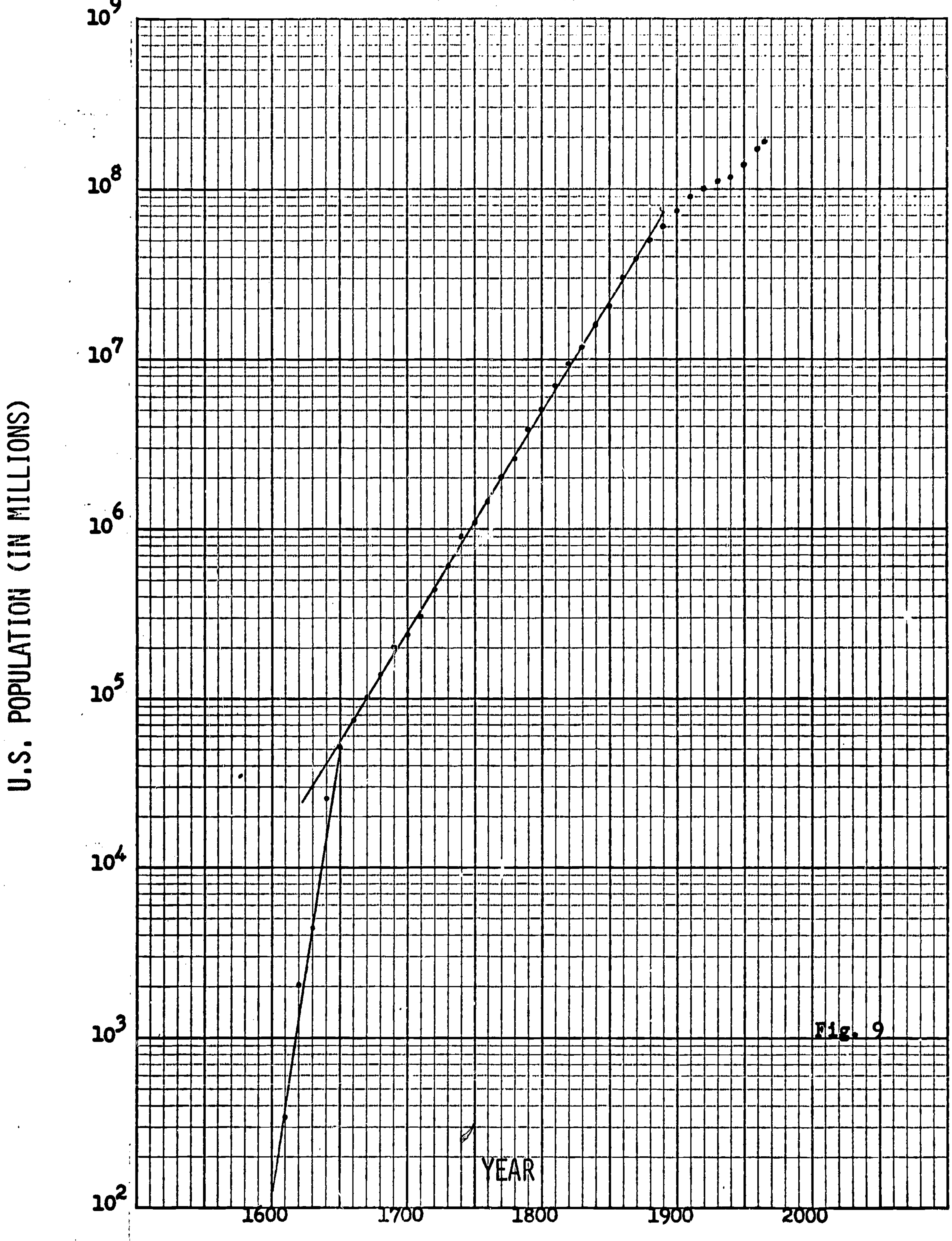
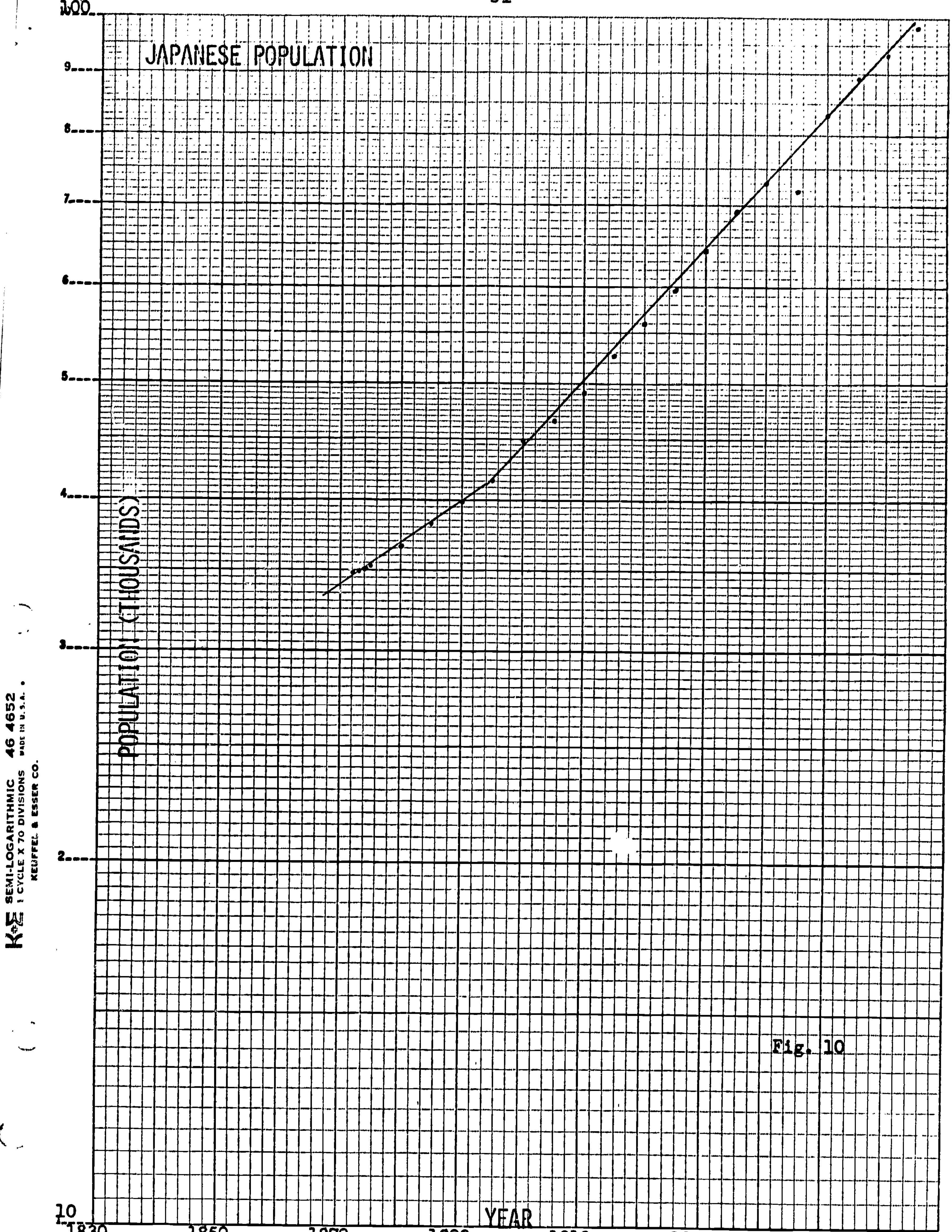


Fig. 9

Source - Stat. History of the U.S.-Colonial Times to Present
Pocket Data Book USA-1967



Source - Japanese Stat. Yearbook 1966

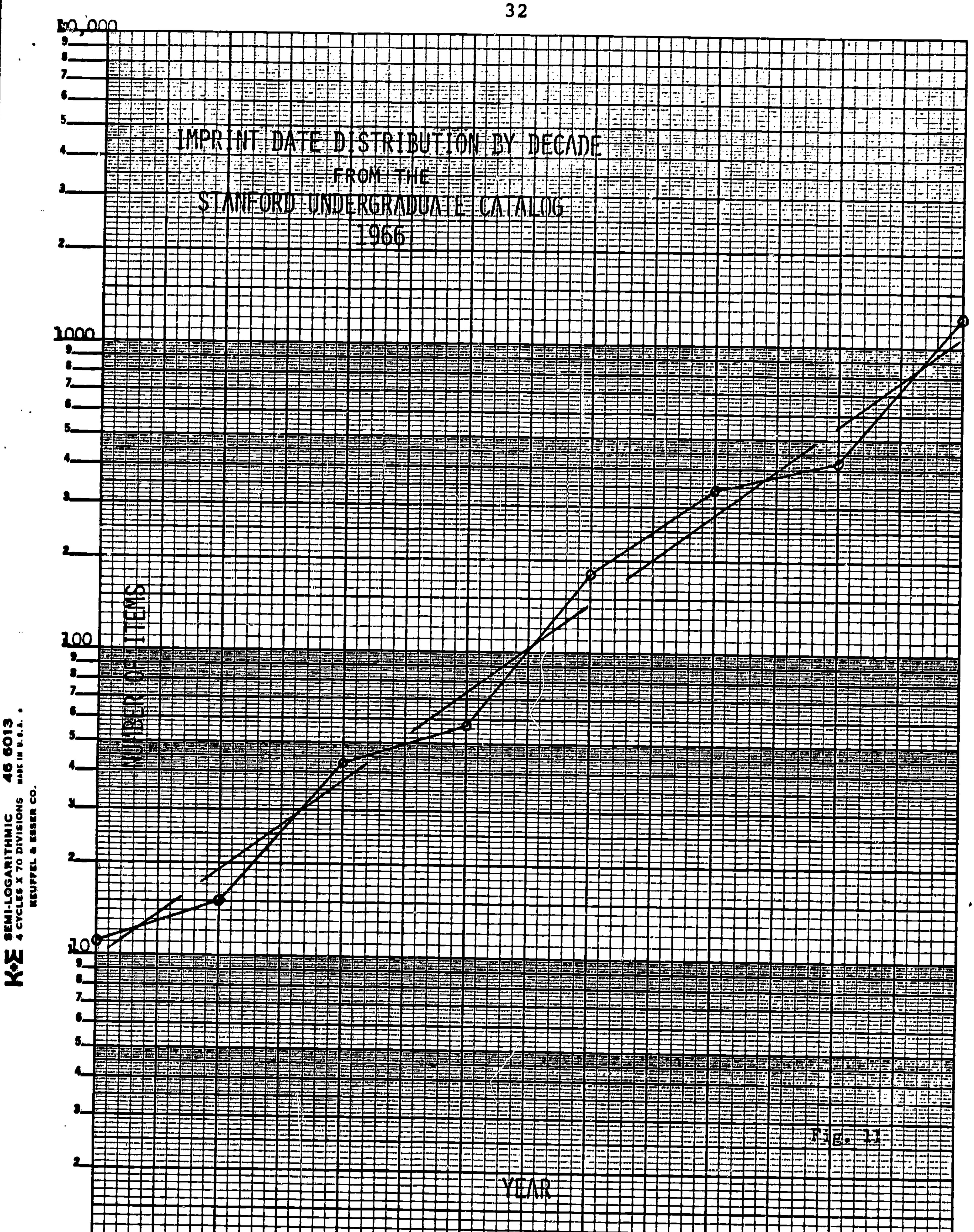

IMPRINT DATE DISTRIBUTION BY DECADE
FROM THE
STANFORD UNDERGRADUATE CATALOG
1966
NUMBER OF ITEMS
YEAR
10,000
1000
100
10
1
1885
1895
1905
1915
1925
1935
1945
1955
K+E SEMI-LOGARITHMIC 46 6013
4 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. 11

Stanford Undergraduate Library. This collection is restricted to recent imprints because of its small size and limited purpose. Nevertheless the usual exponential trend is clearly evident. It appears to make no difference whether a sub-collection of a large library or an entire small library is examined. In Reference 3 it was shown that similar growth occurred in a random sample from a university library of some 300,000 items, exclusive of periodicals.

Figure 12, taken from Reference 2, shows that the number of scientific periodicals and also the number of scientific abstract journals have been growing exponentially, the former for approximately 300 years.

Turning to quite a different type of growth statistic, in recent years the Basic Oxygen Process has been increasingly used for the production of steel in the United States. Growth in the output of BOP raw steel is shown in Figure 13. It consists of two parallel lines on the semi-logarithmic graph paper, separated by about a year. Thus, apart from this fluctuation (which will be discussed in Section 4),[3] this statistic also follows the exponential growth law.

LOCAL FLUCTUATIONS IN GROWTH

All of the graphs that have been discussed show consistent exponential trends for most of their duration, but there are deviations of several types.

1. There are minor fluctuations which appear to have an average value of zero with respect to the underlying exponential trend. These probably correspond to random influences that are of no long range importance, and which cannot be subjected to a deterministic analysis. There is not much that has to be said about them other than that they always exist in natural time series and that there is little that can be done to analyze them. Figure 14 illustrates the residuals of the Widener Shelf List data used for Figure 2 with respect to exponential trend lines. Trends were obtained using least squares methods on the

[3] The datum of 1967 does not lie on the fitting line. Since the most recent statistic in an economic time series is usually revised, this number has been ignored in fitting the exponential.

NUMBER OF SCIENTIFIC PERIODICALS

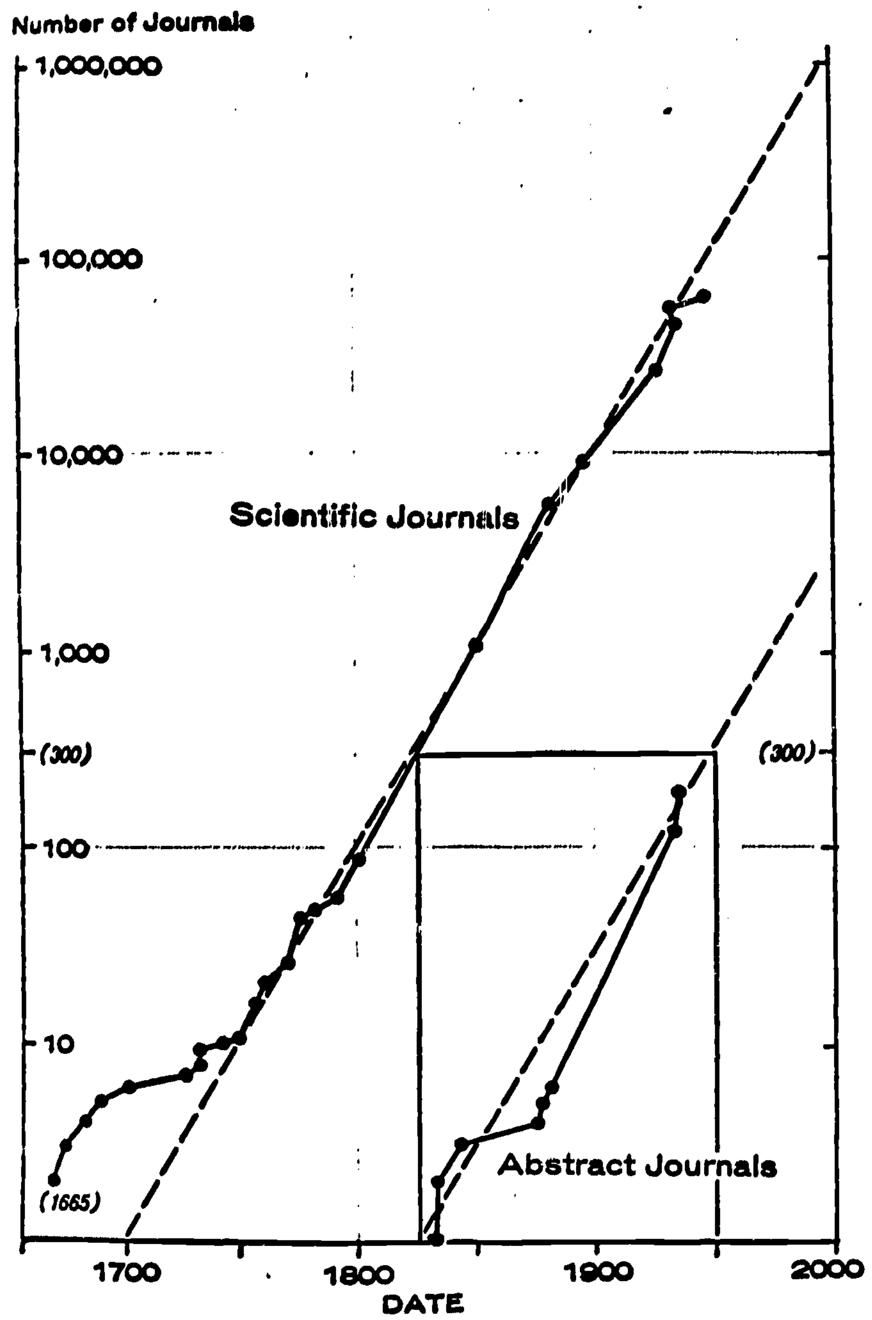


FIG. 12

Data from D.J. De Solla Price, Science Since Babylon, Yale University Press, New Haven (1961)97

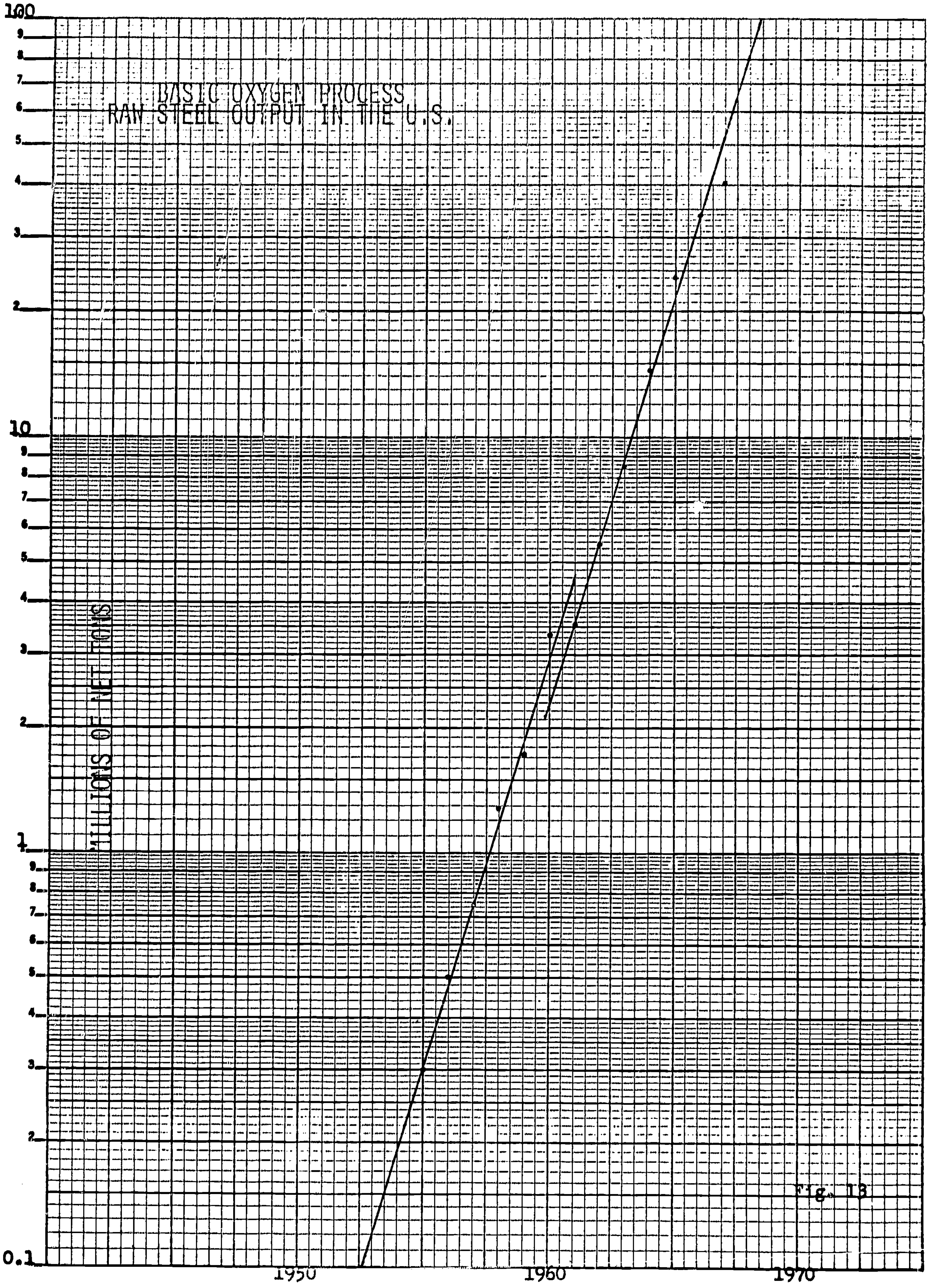
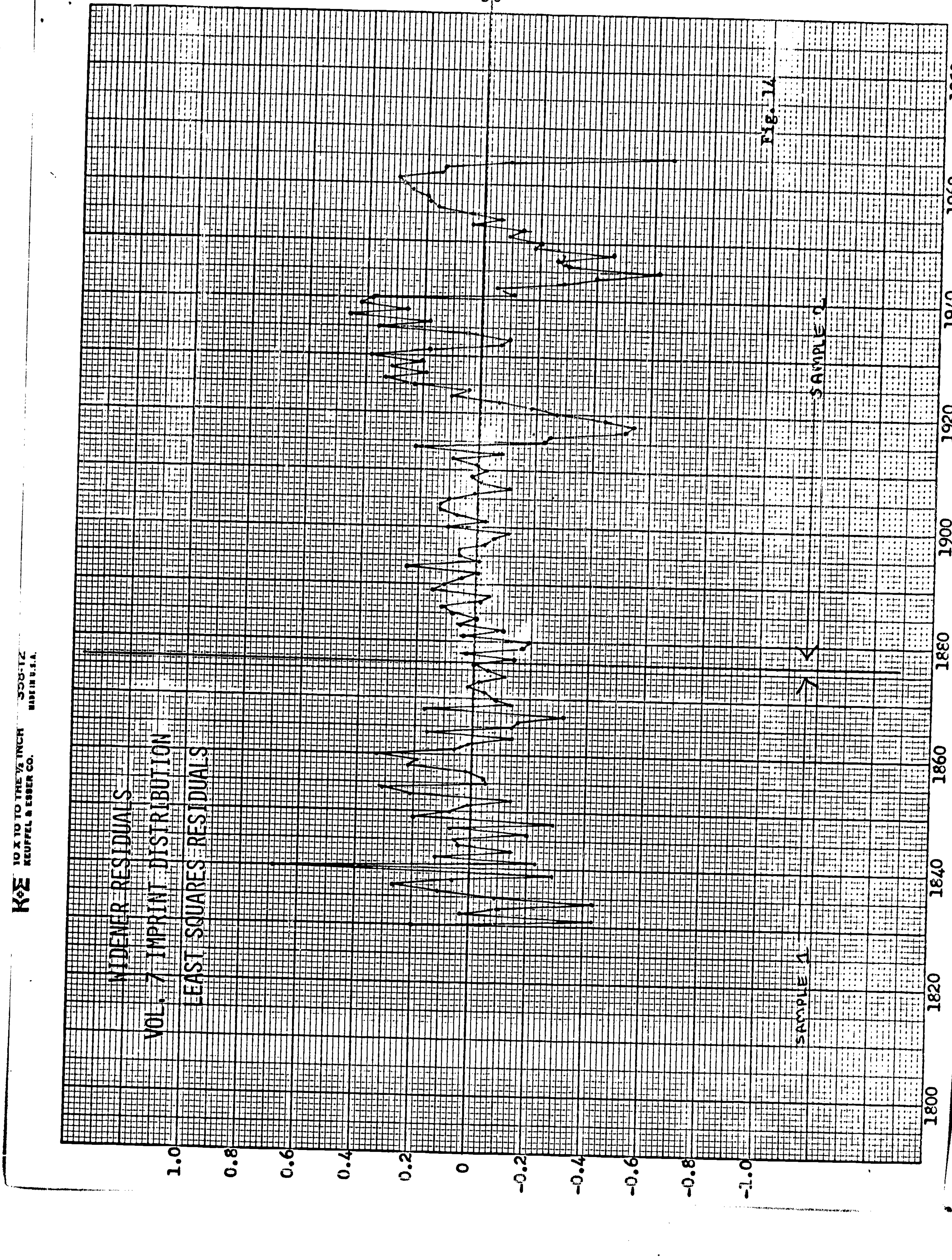


Fig. 13

Source - Ref. 1 (Table p.60)


K&E 10 X 10 TO THE 1/2 INCH 358-12
KEUFFEL & ESSER CO. MADE IN U.S.A.
WIDENER RESIDUALS
VOL. 7 IMPRINT DISTRIBUTION
LEAST SQUARES RESIDUALS
Fig. 14
SAMPLE 1
SAMPLE 2
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980

logarithms of the data for two distinct samples: the period 1830-1876, and the period 1876-1965. The residuals are the deviations of the logarithms of the data from the logarithms of the fitted exponentials. From 1870 to 1914 it appears that the residuals are essentially random; this represents Type-I fluctuation. The three largest residuals occur in 1965, 1945, and 1918. The first is due to the incompleteness of the collection in the most recent years; plotting by imprint date invariably introduces a bias in the most recent figures because items published in any given year are acquired over a span of years following. Technically, this bias extends over the entire collection; however, it is most noticeable in the most recent 5 to 10 years. It would be of interest to determine the distribution of imprint dates for a given year's acquisitions to determine the effect of the bias more precisely. The other two large residuals occur in the final years of the world wars, and are both negative, as might be anticipated. These fluctuations are clearly <u>not</u> Type-I. The large residuals that occur in early portions of the sample (e.g., that in 1840) are of questionable significance because of the small sample sizes for those early years.

2. There are departures from exponential growth which last for a short period relative to the duration of the exponential part, followed by a longer period of stable exponential growth proceeding at a different growth rate. This type of departure from exponential regularity appears to correspond to a change in the underlying environment which requires a readjustment of the growth rate. The readjustment is effected by passing in some (possibly irregular) manner from the initial constant growth rate to the new constant rate by means of a transition period of relatively short duration. Two examples of this type of process are shown in Figure 9 (U. S. Population), one in Figure 10 (Japanese Population), and two in Figure 1 (LC holdings).

3. The third type of fluctuation is perhaps the most interesting. It is represented by a period of regular exponential growth which is followed by a transition period of relatively short duration. The transition period precedes another period of

stable exponential growth (as in Type 2 above) which proceeds at the same rate of growth as the exponential preceeding the transition. Thus, on semi-logarithmic graph paper, the initial and final exponentials will appear as parallel lines; the transition corresponds to a curve connecting the two exponentials which can be irregular. The two exponentials may actually be parts of one; this is shown in Figure 10, where the transition is constituted by the rapid decrease in Japanese population from 1940 to 1945 followed by an even more rapid increase from 1945 to 1950, bringing the population back up to the exponential trend line as if World War II had not occurred. In other cases, the two parallel lines representing exponential growth do not coincide; usually, the terminal line lies below the initial one, which means that although the population growth rate has returned to its initial state, there has been an unrecovered absolute loss in population. This is well illustrated by Figure 13 (Basic Oxygen Process Raw Steel Output in the U. S.) which shows an unrecovered loss which can be interpreted as having set the industry back by slightly more than one year.[4]

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[4]The Kennedy confrontation with the steel industry concerning its pricing policies occurred after the sharp transitional drop in BOP steel output growth rate in 1960-61. The proposed price increases may have been a reaction to this transition. Had it been known at the time that the transition was of Type-III but not of Type-II, and that it would last for only 1 year in its depressive phase, the industry might not have reacted with its proposed non-transitional price increase. This example illustrates the importance of studying the causes of transitions and learning how to distinguish the various types as they occur.

This problem also illustrates the importance of further statistical study of the procedures to be used in interpreting growth data. It is possible to "fit" the BOP steel output data with a single straight line that effectively "hides" the transition period of 1960-61. The procedures for testing the improvement introduced by the notion of a break in the growth function are fairly obvious. Isolation of the period involved, given that a break occurred, is also straightforward. However, the problem of finding break points when there is no *a priori* information as to how many are present does not appear to have been studied at any length.

There are other types of departure from exponential growth, but they are not so easily characterized nor do they seem to play an important role in the types of populations that are under consideration in this chapter.

Fluctuations of Type-III and their connection with unrecoverable losses are worth some further discussion. An important example is furnished by population and economic time series for the United States encompassing the period of the Great Depression, which is a Type-III fluctuation.

Figure 15 shows the population of the United States during the 1880-1960 period, as given by the decennial census. In connection with Figure 9, it was pointed out that a Type-II transition occurred about 1880, corresponding to the closure of the frontiers; the effect of this transition is visible in the first three data points of Figure 15; the next three lie on a line, which is not remarkable since two points determine a line. The remaining three points lie on another line which is nearly parallel to the first. Therefore, the data from 1910 to 1960 can be interpreted as indicating a constant growth rate with a Type-III fluctuation occurring between 1930 and 1940, the decade of the depression. Pursuing the implications of this interpretation, shift the 1940-1960 line to the left so that it coincides with the 1910-1930 line, and measure the number of years of shift required to obtain this coincidence; it is approximately 6 years (we will use 5.89 years). Figure 16 shows the same data used for Figure 15 with a 5.89-year shift to the past for post-1930 data. The six points corresponding to the population figures from 1910 through 1960 now lie on a line with very good precision. It is possible to interpret this Type-III fluctuation as implying that the effective duration of the Great Depression was about 5.89 years. In other words, the non-recoverable population loss due to the depression was equivalent to 5.89 years of exponential population increase at the previously and subsequently prevailing rate. It should be observed that World War II had as little effect on U. S. population as it had on Japanese population (cp. Figure 10).

As a check on the notion that there was really a non-covered loss of population during the Great Depression, we can investigate the behavior of the Gross National Product (GNP) on the assumption that there is a close relation between the two time series. This can be done either by assuming the 5.89-year gap and testing the departure from linearity using this gap, or by deriving the gap (if any) from the GNP data directly.

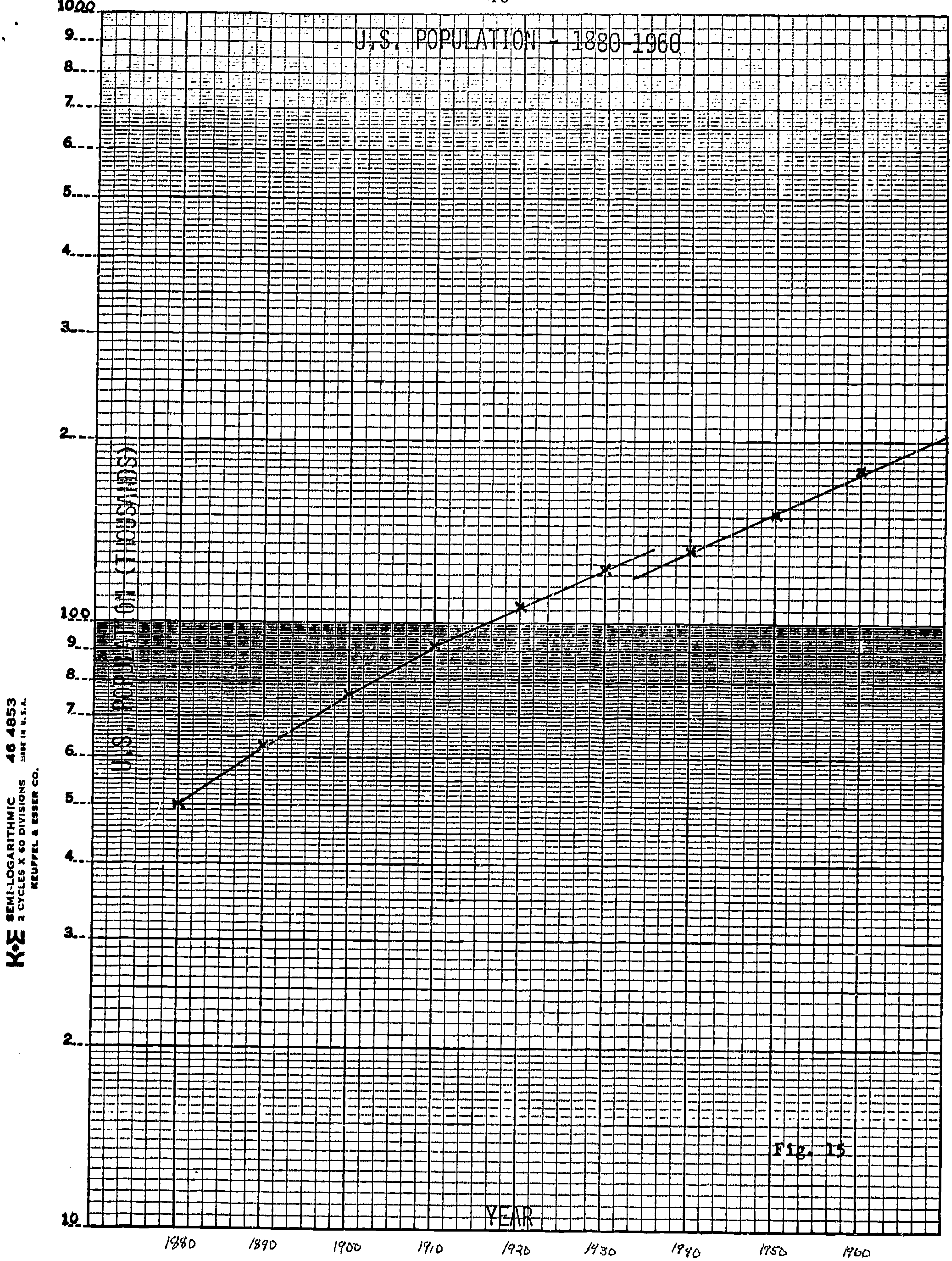

U.S. POPULATION - 1880-1960
U.S. POPULATION (THOUSANDS)
YEAR
1880
1890
1900
1910
1920
1930
1940
1950
1960
1000
9
8
7
6
5
4
3
2
100
10
K•E SEMI-LOGARITHMIC 46 4853
2 CYCLES X 60 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. 15

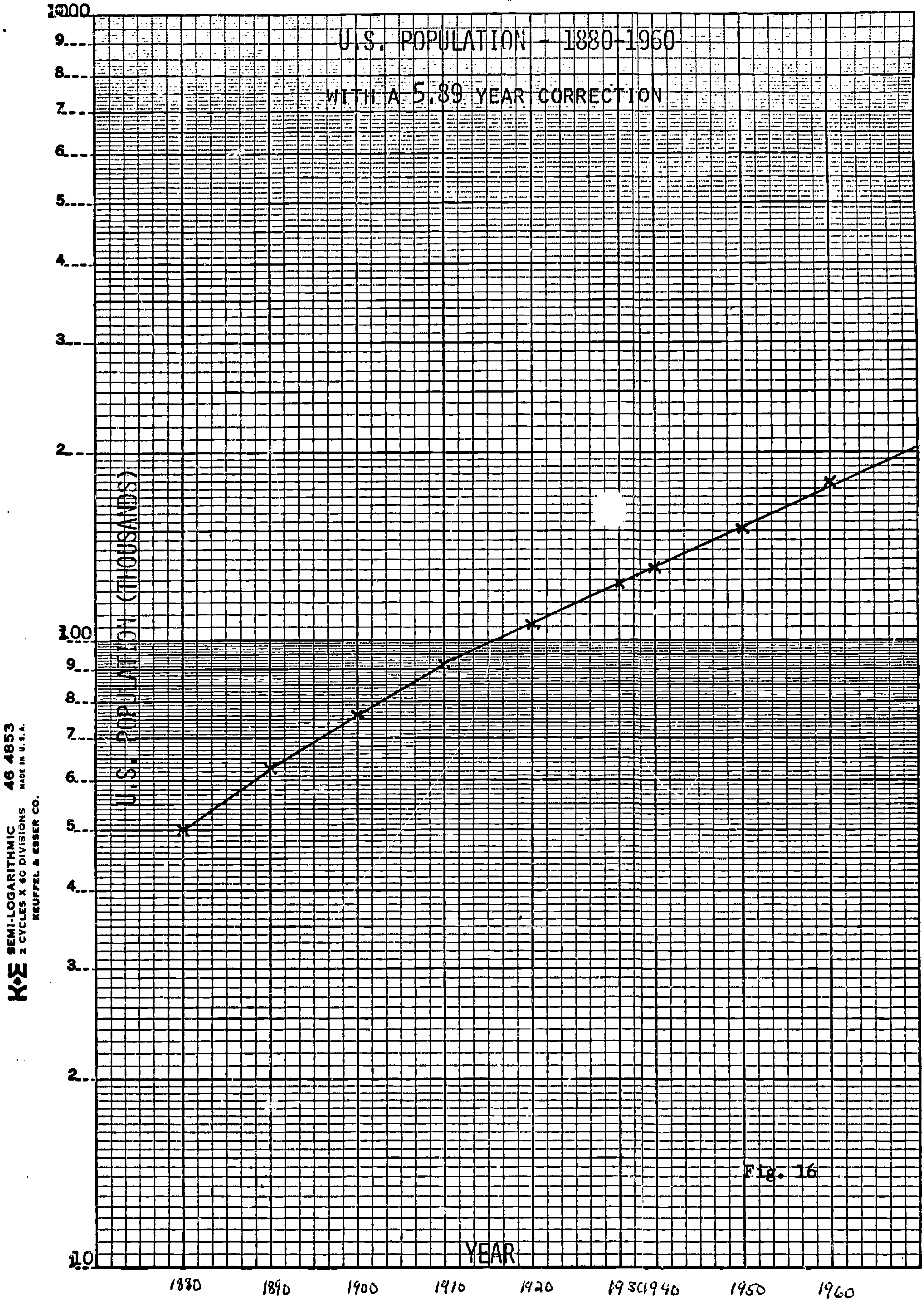

U.S. POPULATION - 1880-1960
WITH A 5.89 YEAR CORRECTION
U.S. POPULATION (THOUSANDS)
YEAR
1000
9
8
7
6
5
4
3
2
100
10
1880
1890
1900
1910
1920
1930
1940
1950
1960
K+E SEMI-LOGARITHMIC 46 4853
2 CYCLES X 60 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. 16

Figure 17 shows the GNP (in current dollars) for the period 1894 to 1965. The values up to 1921 are 5-year averages; the subsequent values are by individual years. The data prior to the first World War and the data subsequent to the second World War are quite consistent with the general hypothesis of exponential growth. The intervening period (1914-1945) exhibits rather wild fluctuations--as might be expected. From this superficial examination alone it is quite clear that GNP does not possess the stable growth pattern shown by population growth.

Figure 18 shows the same data with the 5.89-year interval in the 1930's removed. Even with the larger variation of the GNP data, it is clear that this data is not inconsistent with the "depression gap" hypothesis. In fact, a good portion of the data for the 1920's is included within the rough limits of variation sketched in Figure 18. One could conjecture that the real roots of the Great Depression are to be found in the "excessive" growth of the GNP in World War I, or, more precisely, in the difficulty in guiding the GNP back to its basic growth rate without losing momentum.

Derivation of the depression gap value from GNP alone leads to some problems. If one uses the 5-year averages for the two periods of evident linearity before World War I and after World War II, one obtains a depression gap of 2.05 years. This can be explained in part by the variation introduced by the Korean War: if the 5-year period including the Korean War is eliminated, the estimate of the gap becomes 3.29 years. Better agreement might be obtained were it possible to obtain GNP figures for individual years prior to World War I or if the study were based on real rather than on current data.

However, our main interest in this data is in showing the need for careful analysis of long-term growth as well as growth in the short term. Without sufficient long-term statistics, a Type-III fluctuation may be misinterpreted as one of Type II, and an underestimate of the trend growth rate may be made. Indeed, this has often happened in the past 30 years; libraries and other institutions have rapidly outgrown facilities constructed under the misapprehension of future lower trend growth rates due to an analysis of insufficient portions of their growth records.

Figure 19 exhibits the history of United States Invention Patents issued from 1790 through 1966 (cp. Table 3). This complex graph (see third page following) contains

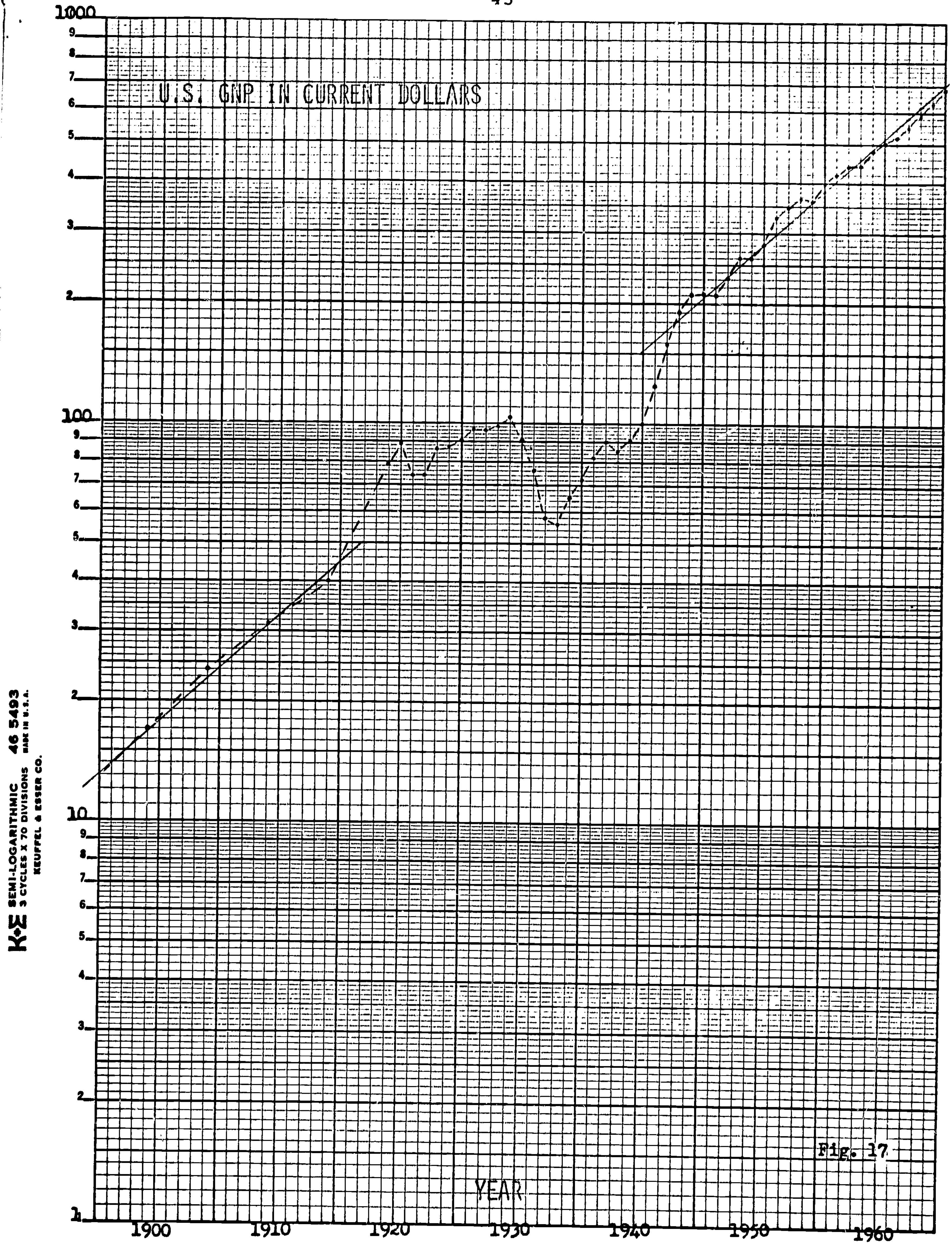
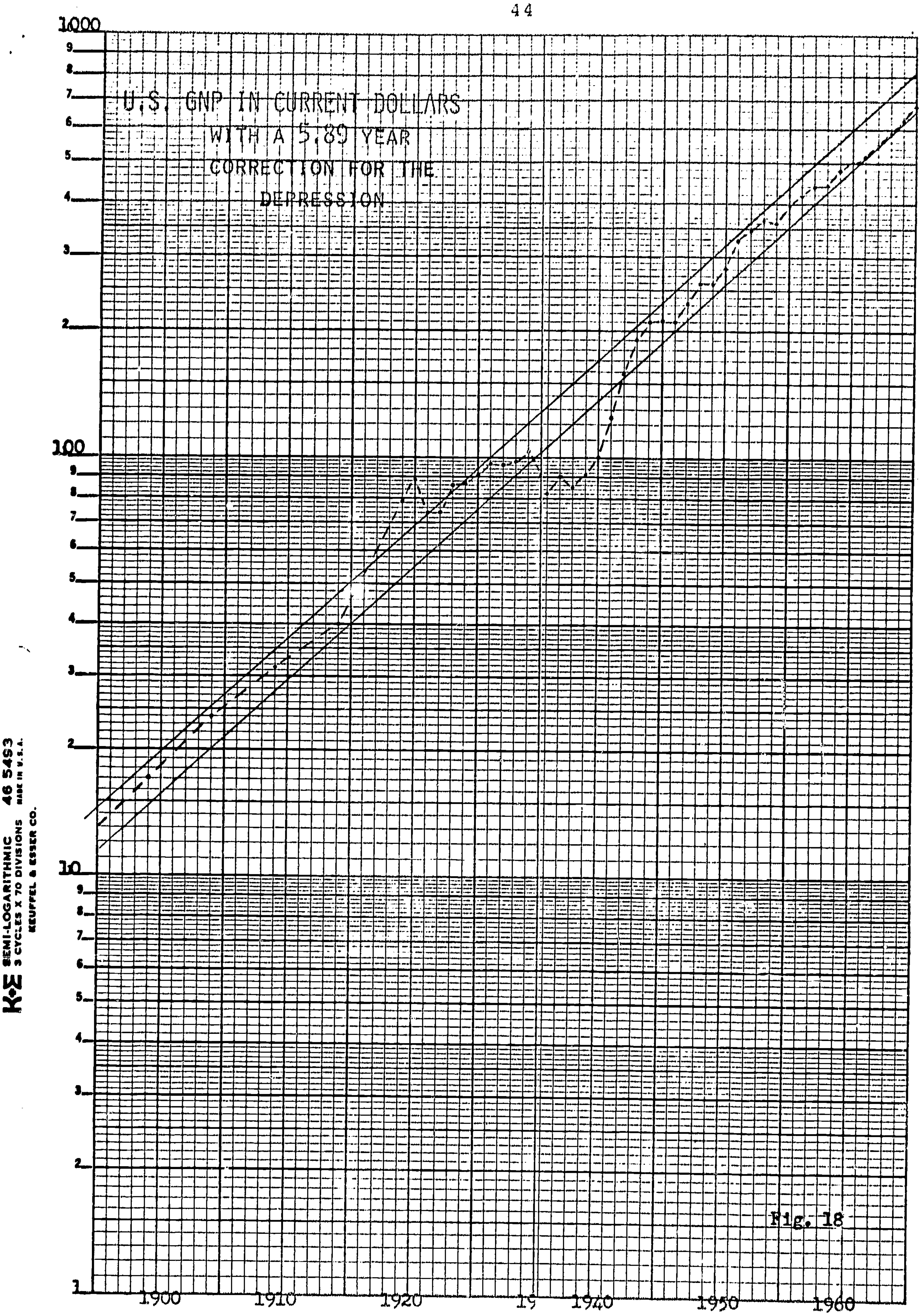

U.S. GNP IN CURRENT DOLLARS
1000
100
10
1
9
8
7
6
5
4
3
2
1900
1910
1920
1930
1940
1950
1960
YEAR
K+E SEMI-LOGARITHMIC 46 5493
3 CYCLES X 70 DIVISIONS MADE IN U.S.A.
KEUFFEL & ESSER CO.

Fig. 17



Source - Stat. History of the U.S.-Colonial Times to Present & Pocket Data Book USA-1967

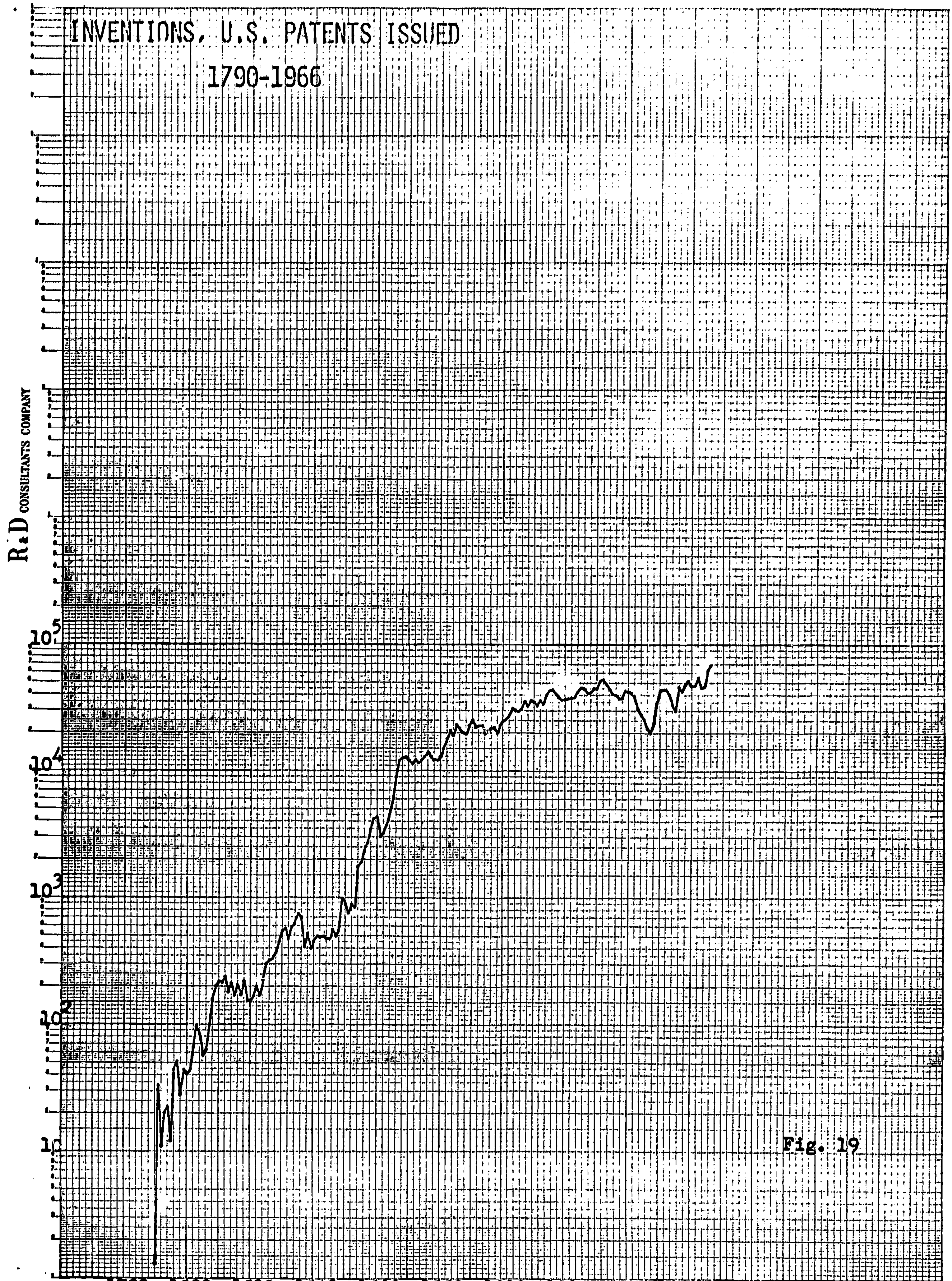

INVENTIONS, U.S. PATENTS ISSUED
1790-1966
R&D CONSULTANTS COMPANY
10^5
10^4
10^3
10^2
10
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980

Fig. 19

TABLE 3

U. S. INVENTION PATENTS ISSUED

1790 - 1966

Date	Number	Date	Number	Date	Number	Date	Number	Date	Number
1790	3	1830	544	1870	12137	1910	35141	1950	43040
1791	33	1831	573	1871	11659	1911	32856	1951	44326
1792	11	1832	474	1872	12180	1912	36198	1952	43616
1793	20	1833	586	1873	11616	1913	33917	1953	40468
1794	22	1834	630	1874	12230	1914	39892	1954	33809
1795	12	1835	752	1875	13291	1915	43118	1955	30432
1796	44	1836	702	1876	14169	1916	43892	1956	46817
1797	51	1837	426	1877	12920	1917	40935	1957	42744
1798	28	1838	514	1878	12345	1918	38452	1958	48330
1799	44	1839	404	1879	12125	1919	36797	1959	52408
1800	41	1840	458	1880	12903	1920	37060	1960	47170
1801	44	1841	490	1881	15500	1921	37798	1961	48368
1802	65	1842	488	1882	18091	1922	38369	1962	55691
1803	97	1843	493	1883	21162	1923	38616	1963	45679
1804	84	1844	478	1884	19118	1924	42574	1964	47376
1805	57	1845	473	1885	23285	1925	46432	1965	62857
1806	63	1846	566	1886	21767	1926	44733	1966	68406
1807	99	1847	495	1887	20403	1927	41717		
1808	158	1848	583	1888	19551	1928	42357		
1809	203	1849	984	1889	23324	1929	45267		
1810	223	1850	883	1890	25313	1930	45226		
1811	215	1851	752	1891	22312	1931	51756		
1812	238	1852	885	1892	22647	1932	53458		
1813	181	1853	844	1893	22750	1933	48774		
1814	210	1854	1755	1894	19855	1934	44420		
1815	173	1855	1881	1895	20856	1935	40618		
1816	206	1856	2302	1896	21822	1936	39782		
1817	174	1857	2674	1897	22067	1937	37683		
1818	222	1858	3455	1898	20377	1938	38061		
1819	156	1859	4160	1899	23278	1939	43073		
1820	155	1860	4357	1900	24644	1940	42238		
1821	168	1861	3020	1901	25546	1941	41109		
1822	200	1862	3214	1902	27119	1942	38449		
1823	173	1863	3773	1903	31029	1943	31054		
1824	228	1864	4630	1904	30258	1944	28053		
1825	304	1865	6088	1905	29775	1945	25695		
1826	323	1866	8863	1906	31170	1946	21803		
1827	331	1867	12277	1907	35859	1947	20139		
1828	368	1868	12526	1908	32735	1948	23963		
1829	447	1869	12931	1909	36561	1949	35131		

fluctuations of all three types. There is an important Type-III fluctuation during the Great Depression which increases in its effect during World War II, and two others, from about 1812 to 1822, and 1830 to 1845. There is a basic change in the trend growth rate, a Type-II deviation, at about 1870 which appears to correspond to the Type-II transition observed in the U. S. population curve (Figure 9) about 1880. And there are the inevitable Type-I, random fluctuations throughout the graph.

SPECTRAL ANALYSIS OF GROWTH TIME SERIES

In recent years numerous efforts have been made to apply Fourier transform techniques to the analysis of time series. Reference 5 presents a treatment of applications to economic time series, which are closely related to the various types of growth curves that should be of concern to library planners. Most of the spectral analysis techniques--as these applications of Fourier analysis have come to be known--are designed for trendless data, and therefore are not directly applicable to growth curves, although some studies have been made which discuss the problem of removing trends from the data so as to create a trendless series. From what has been said above it is evident that most of the growth curves that pertain to library problems will consist of a number of distinct exponential portions as well as certain transition regions. If these distinct regions can be delimited, then the trends can be extracted and the residuals (such as those illustrated in Figure 14) can be spectrally analyzed to detect any periodic components that may be present. For growth curves that are piecewise exponential (apart from transition intervals of short duration), an analysis of the logarithms of the data after removal of the (then linear) trends should prove to be the most promising means for obtaining spectral analyses that can be interpreted in terms of meaningful causes and effects.

This is perhaps an appropriate place to remark that sequences of overlapped short-term Fourier transforms are likely to have more predictive value than the transform of a long-term series, which is insensitive to local transitions.

CONCLUSIONS

In Section 1 three problems were stated. The answers that have been given above are all tentative because they have been based upon a study of limited proportions. It does appear to us that future research of a more complete and detailed nature will bear out the following conclusions:

1. Exponential growth of library holdings will persist for the foreseeable future. To maintain current growth rates, automation of the production of portions of the intellectual content, as well as the production of books and equivalent forms of stored information, will increase.

2. Growth curves of importance to library management consist in general of piecewise exponential segments connected by transitional fluctuations. Determination of the nature of the current and short-term future portions of the curves is necessary for realistic and practical planning purposes. Piecewise exponential approximations are the simplest techniques for exhibiting the structure of these growth curves.

3. As far as growth rates are important for planning purposes, fluctuations of Type III must be detected and ignored in the evaluation of future requirements of a library.

4. Much more detailed studies of the time series associated with library operations must be made. Analytical methods that will permit the objective determination of the points of transition from periods of one type of growth to another must be developed as well as the interrelation of statistical information pertaining to different types of growth statistics.

5. As discussed in Sections 2 and 3, it seems clear that there is a connection between the growth of the library archives and the growth of various estimators of the state of civilization. It ought to be determined which is cause and which is effect. More precisely, the role of the preservation and transmission of information in the development of civilization certainly ought to be investigated not only as a subject of abstract intellectual interest but also to provide a working tool for those responsible for allocation of

national resources. Furthermore, as the details of this relationship become clarified, library management will be in a better position to improve the means of accessing the information archive.

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CHAPTER 2

AN ANALYSIS OF COST FACTORS IN MAINTAINING AND UPDATING CARD CATALOGS

J. L. Dolby, V. J. Forsyth
and H. L. Resnikoff

AN ANALYSIS OF COST FACTORS

IN MAINTAINING AND UPDATING CARD CATALOGS

INTRODUCTION

One of the more interesting side benefits of the present interest in library automation is the amount of attention now being given to the study of the traditional methods of librarianship. This phenomenon is hardly unique to librarianship: in almost every field of human endeavor where attempts have been made to introduce the use of computers, workers in the field have suddenly discovered that they did not understand some of their long standing methods quite as fully as they had believed. The source of this seeming anomaly is easy to find: to program a computer, it is necessary to specify the work to be done in much greater detail than is necessary to explain the same problem to a human being, that curious human phenomenon known variously as "common sense", "maturity", or "experience" making up the difference. Thus it has not been uncommon over the past decade to hear many survivors of the "automation experience" admit that one of the main benefits achieved through the use of the machine was the acquisition of better procedures through a more detailed understanding of the process involved.

The improved knowledge of "processes about to be automated" extends to the cost of the process as well, and with added force. If one is to substitute one procedure for another in a cost-conscious atmosphere, it behooves one to proffer sound financial reasons for doing so. Not only are computers expensive devices, but they also represent the expenditure of a different kind of money: capital or lease funds in place of labor expense. Thus, although one can still hear the occasional cry that it is difficult to obtain reasonable cost data on various parts of the library operations, it is becoming increasingly difficult to pick up an issue of almost any library journal that does not include at least one piece of cost information.

Our concern in this paper is with the cost of maintaining and updating card catalogs. As we have observed elsewhere (Ref. 1) the cost of computing is going down at a rather spectacular rate while the cost of labor is increasing. If this trend continues, almost every library shall be forced to automate certain aspects of the catalog operation, at some point in time. In that same report we also provided some information about the cost of computerized library catalogs. By adding a summary of the cost factors in the use of card catalogs, we hope to place in slightly better perspective the more difficult problem of deciding (in the context of a particular library) when the crossover point between manual and automated methods is to be reached.

Our plan of attack remains essentially the same as in our previous report: rather than attempt time and motion studies of our own, we have selected from among the growing number of papers on the subject those which, in our opinion, provide comparable sets of cost information which are pertinent to the various cost elements of the card catalog operation. It is appropriate, therefore, to begin this study with a brief description of the difficulties in comparing cost statistics in this way.

PROBLEMS OF COMPARATIVE COST STUDIES

Although comparative cost studies have much to recommend them, they are also fraught with certain difficulties (see, for example, Reference 2). In the first place, few librarians would group the elementary cost operations in precisely the same way. Thus one library may consider a particular element of cost as part of the acquisitions operation, a second as a part of the cataloging operation, while a third may ignore it altogether or include it in the burden or overhead cost. Nor is this mere capriciousness on the part of the members of the library community. Library operations not only differ from one another, but they also change with time.

Consider for example, the problem of obtaining a set of catalog cards for a particular monograph. Any or all of the following alternatives might be in use at a given library:

1. the cards may be supplied with the book as a service provided by the bookseller at some extra cost

2. the cards might be ordered from the Library of Congress

3. the cards might be provided by a centralized cataloging operation serving several libraries (as in a county or state library system)

4. the cards may be prepared by catalogers working in the library

5. the cards may be generated by computer program from standard listings (e.g., from MARC tapes).

Comparing any two of these procedures within a given library does not present any overwhelming problems, though minor questions of definition do occur (for example, how much of the cost of ordering should be allocated to the acquisitions department and how much to the cataloging department when both the book and the catalog cards are obtained simultaneously from the same source?). However, when one wishes to compare costs from two different libraries, each with a different "mix", it is essential to know what proportion of each source was used by each library. Fortunately for the purposes of this study most libraries are presently using a mix of method 2 (LC) and method 4 (own catalogers) and at least some provide sufficient information to enable us to determine the appropriate mix for each. However, the problem is indicative of one of the essential difficulties in comparative cost analyses, and a difficulty that, although eased, would not be eliminated by having all libraries band together and adopt a standard costing procedure.

A second difficulty arises from temporal and geographic differences in the cost of manpower. On the surface, this problem can be eliminated--or substantially reduced--by having all studies based on manhours spent rather than on dollars required per item, and a number of writers have suggested such a change in reporting procedure. However, the problem is not quite this simple. In the first place, determining the number of manhours spent, say, on cataloging adds cost to the study that tends to reduce the number of libraries willing to report; those that do report may or may not be a representative sample of the total.

However, there is a more basic problem. In almost all libraries the real restraint is financial: there are just so many funds available for cataloging and these must be used to at least keep the backlog of uncatalogued material down to the amount of space available to store this material. Suppose, for instance, that the amount of material to be catalogued increases by 10 percent from one year to the next and that the catalogers are fortunate enough to obtain 10 percent salary increases over the same period. It is not impossible to consider that in some libraries the catalogers may be forced to "earn" this raise by absorbing at least a part of the increased load without extra help. The question of balancing salary increases by productivity increases is, of course, a familiar one in industry and it may well exist in the library. As evidence that such an effect is present, we shall note later in this report that three studies made in three rather different libraries over a period of 6 years showed costs of from $0.228 to $0.235 per card for preparation, production, and filing.

The total range ($0.007) represents only 3 percent of the average cost per card ($0.230). Such close agreement would be startling if it were found in three simultaneous studies of three nearly identical library operations. Yet we hesitate to set this agreement aside as pure coincidence. It seems more reasonable to assume librarians are forced to operate under strong financial constraints and that they adjust their performance to those constraints through hiring of less well-trained personnel[1], increased time pressures on all personnel, etc. If this is the case, "standardized" reporting through time figures might be quite misleading unless cost figures were reported as well.

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[1] The notion that certain things should have a fixed cost regardless of changes in their surrounding costs is not novel. Since its inception in the 1920's, the major appliance industry has found that it could never sell major appliances in maximum quantities if they were priced over $500. Just why the American public should figure that major appliances should never cost more than $500 is not quite clear, particularly when the average family income has increased considerably over the same period. Yet the sales pattern of color television sets has provided recent evidence that the $500 barrier is still in effect.

Finally, there is the question of allocation of burden or overhead. Potentially, burden could present a severe problem--and occasionally it may. However, in most of the reports cited here, burden is either ignored or separately stated and we find no reason to suspect that the results given in the summaries are noticably biased by unseen burden differences. Nevertheless, it would be of interest to determine proper overhead figures for library operations as the switch to automation (which we are convinced is inevitable) will entail the use of more machines and fewer people, which in turn may drastically alter the overhead structure.

THE USE OF COST INFORMATION

Having noted some of the difficulties that tend to cloud cost comparisons, it is perhaps useful to investigate how cost information is likely to be used. The nature of the problem can be illustrated by two rather different situations.

1. Library A, a large public library of some years standing, is considering the possibility of changing from its present manual procedures to some form of automation, and wishes to determine a reasonable strategy for implementing such a change over the next 5 years.

2. Library B, a comparable public library, has been keyboarding the catalog records of its current acquisitions for the last 3 years and has now decided to convert its retrospective catalog and wishes to choose the most economic procedure for this step.

The differences in the problems facing two such library situations are basically the classic differences between strategy and tactics. Library A must lay out a long-term plan, taking into account the growth in its collection over the 5-year period, likely changes in equipment and personnel available to it, increases in labor costs, decreases in equipment usage costs, etc. Library B, on the other hand, is in the position of making a specific set of decisions as to whether the work should be done in-house or subcontracted; whether they should use punched cards, punched paper tape, or optical character-recognition devices; and so forth.

In terms of cost, Library B has to prepare a specific budget request for its funding agency and it is reasonable to assume that that funding agency will require assurance that the task is to be accomplished at the minimum cost consistent with the designated quality level. Thus, cost differences of as little as 5 percent may be quite important to Library B. General cost summaries can be of use only in helping with the enumeration of the possible alternatives. Even the accounting procedures in effect in the local system will have a bearing on the final decision.

Thus, the primary utility of a general cost summary such as we are attempting here to the library about to commit itself in a tactical situation is the information it can provide about the problem statement: which cost factors have other libraries been able to identify in similar situations; which of the various alternatives may be safely eliminated from consideration on the grounds that their present costs are considerably higher than other existing methods; and so forth. The likelihood that any general study, or, for that matter, any particular study, will be sufficiently like the library now undertaking the problem to enable that library to take over cost structures unchanged seems remote.

A library, like Library A, faced with establishing a long-range plan, has much more flexibility available to it. Its interest in specific costs will be established by some gross notion as to what quantity of funds are likely to be available over the period under plan. Some procedures may be seriously considered because they are relatively new and untried and hence of potential interest to national funding agencies who would not consider funding further experiments with procedures that have been thoroughly tested. Access to good cost information of such well-tested procedures will help in establishing the likely costs for important aspects of the overall plan. Of even greater interest is the possibility that certain costs are likely to undergo substantial change over the planning period. For instance, in Reference 1 it was noted that OCR may be a very attractive long-run option for catalog conversion problems precisely because it is so new and hence has not had time to allow a sufficient number of service centers to spring up to provide truly competitive service capabilities. Computer typesetting with the new generation of hardware is in much the same category.

In both situations it is clear that what is most needed is the enumeration of cost elements on the one hand and operating cost experience on the other. Precise estimates of any one cost element are of relatively little importance, either because they are so likely to change over the long run or because they are likely to be not appropriate to a specific application even in the short run.

Comparative cost information thus would seem to provide a good basis for either application. The comparison forces an enumeration of cost elements precisely because one must evaluate the cost structure of each source to be sure that a reasonable comparison is possible. The reporting of the actual experience of several libraries provides a range of experience, not only over several libraries but also over time so that the extremes reported give an indication of the variability that must be allowed for. In what follows, therefore, we shall concentrate on the problems of cost element definition and on the reporting of as many sources as we have managed to find to be comparable in the broad sense. Because precise estimates are not only difficult to obtain, but also unlikely to be relevant to most users, we shall make no attempt to provide formal estimates either of the average cost figures or of their underlying variability.

THE COST OF CATALOGING

The preparation of catalog information for a given monograph is perhaps the most sophisticated operation in the entire catalog operation. As such it is probably the last to be considered a candidate for automation, although it is not unreasonable, even now, to consider the use of computers as aids to the cataloger. Thus in many operations the cost of cataloging will continue to be an invariant regardless of whether automation is introduced into other aspects of the catalog operation or not. Nevertheless, it is useful to study the cost of catalogs both to establish the relative cost of cataloging and the subsequent processing steps and to establish the line of demarcation between the catalog step and the subsequent steps.

Any enumeration of the detailed steps involved in a complex process must be tentative. This is nowhere more true than in the cataloging operation. Fortunately the number of descriptions in detail is growing. For the cataloging operation, we have used three sources of information:

<u>Lockheed</u> (Ref. 3): A detailed analysis made as part of an overall time and motion study of the operations in the Lockheed Research Library.

<u>New York</u> (Ref. 5): A detailed study of the cataloging and processing activities of the New York Public Library as a preliminary to possible automation of some of these operations.

<u>Columbia</u> (Ref. 6): A detailed study of the acquisitions, cataloging, and other processing operations of the Columbia University Science Libraries.

(Because many of the studies cited here will be cited in a number of sections of this report, we shall refer to them by the underlined title of each entry. A summary of these studies is given in Table 1.)

In addition to the eight items in Table 1, the Lockheed Library study included five other items that we have chosen to include in subsequent operations.

It is generally true that professionals do not like to have their jobs subjected to the minutia of time and motion study. There is always the ugly feeling that the creative (and most important) aspects of the job cannot be subjected to simple measurement. Nevertheless, cataloging is a continuing effort in most libraries and it is possible to establish some average production rates in terms of number of books cataloged per month or the number of minutes needed per book. The problem, as with most statistical studies, is not with the establishment of objective measurements but rather in the manner in which they are interpreted. Use of comparative statistics does not eliminate the possibility of misinterpretation but it does tend to minimize it.

The comparative studies selected for the cataloging operation, in addition to those already cited, are:

TABLE 1

CATALOGING COST ELEMENTS

Columbia University Science	New York Public	Lockheed Research Laboratory
(with LC information) 1. Assign class number 2. Compare book and card, check entries in general catalog, establish subjects, etc. 3. Make necessary changes in LC proof slip, or type temporary slip giving brief descriptive information and class number 4. Completed books revised and sent for shelflisting (without LC information) 1. Supply descriptive cataloging 2. Subject analysis, classification and authority work 3. Type workslip for processing section	1. Review work done by searcher. Reconcile conflicts and approve new entry forms 2. Full descriptive cataloging 3. Assign subject entries 4. Assign divisional catalog designators 5. Check authority files and establish new authorities and cross references 6. Determine classmark	1. Get book and analyze for subject. Obtain Dewey and Cutter numbers 2. Check shelflist for duplicates and copy number 3a. (with LC information) Insert and type copy slip and temporary catalog card, check LC subject headings and other references. Descriptive and subject catalog book. Pencil call number on title page 3b. (without LC information) Insert and type descriptive part only on copy slip and temporary catalog card. Write subject data only on catalog card. Pencil call number on title page 4. Tear and separate copy slips and temporary cards. Proof and correct as necessary 5. Take report to reports cataloging 6. Travel to library, check national union catalog or other reference book 7. Count and tally titles cataloged

Colorado (Ref. 2): A study based on average cataloging times for 11 librarians from 6 cooperating libraries.

Southern California (Ref. 4): A study of ordering, cataloging, and preparations in several Southern California libraries.

The catalog cost information for these five studies is summarized in Table 2.

TABLE 2

COMPARATIVE COSTS OF CATALOGING

Library Source	Date	Average Time, min.	Cataloging Cost	Implied Avg. Salary (per hour)
Lockheed	1967	10.0	--	--
Colorado	1969	28.6	$ 2.07	$ 4.34
New York	1968	39.8	6.30	5.25
Southern California	1961	44.8	2.23	2.98
Columbia	1967	84.0	5.85	4.17

In the Lockheed and Colorado studies, basic times of each operation were studied and then "standard" time factors were added to allow for nonproductive time. The standard factors increased the Lockheed times by 13 percent and the Colorado times by 48 percent. (The times in the table include these allowances.) The figures for New York were derived from their reported statements that they processed 65,000 books using 49 catalogers at a total cost of $409,500 (not including fringe benefits). The Columbia figures have been reduced by 20 percent to eliminate fringe benefits. The implied average salary for each source was obtained by dividing the total cataloging cost by the average time and multiplying by 60 to convert to cost per hour.

The simplest conclusion to reach from a study of Table 2 is that cataloging costs vary widely from one library to another. Average times differ by more than 8 to 1 and

CARD PROCESSING COSTS

If cataloging is the least likely part of the library operation to be automated in the near future, the procedures that immediately follow cataloging are precisely the opposite in character. Card preparation, production, and filing all involve time-consuming routine operations that can be done automatically, thus relieving the library community of a significant proportion of manhours that could be applied to problems of greater intellectual content. However, the cost factors must nonetheless be considered.

As with cataloging, the description of the basic cost elements will vary from one library to another. For a detailed breakdown in this case we again make use of the Columbia and New York studies previously cited and add data from an unpublished study kindly made available to us by Neil Barron of Sacramento State College Library (see Table 3). Barron's cost elements are given in finer detail than in the other studies used here. To achieve maximum compatibility with the other studies, we have grouped both the New York data and the Sacramento data into three categories: preparation, production, and filing.

In addition to the Sacramento and New York data, we have included data from four other studies:

> Stanford (Ref. 7): A study of existing cost factors made prior to the preparation of the undergraduate catalog by machine methods.
>
> Ontario (Ref. 8): A study of manual costs made in conjunction with early machine methods.
>
> Air Force (Ref. 9): A comparative study of manual methods and a special-purpose machine procedure.
>
> Yale (Ref. 10): Results of experiments made using computers to produce cards for subsequent manual filing.

The results of these six studies are summarized in Table 4. The costs are here taken on a "per-card" basis rather than on a title basis, as differing library requirements show averages ranging from 3.0 cards per title at Stanford to 9.8 cards per title at New York.

TABLE 3

PROCESSING COST ELEMENTS

Columbia University	New York Public	Sacramento State
1. Card production	1. Receive and distribute planning sheets	1. Type master cards from handwritten slips
2. Card Set completion	2. Type headings for added entries and subject entries	2. Produce subject cross reference cards
3. Sorting and preliminary filing	3. Mark designators and sort completed cards	3. Maintain guide cards
4. Shelflisting	4. Distribute cards to filing section	4. Card production and purchase
5. Typing of book pockets	5. Paint edges of cards when required	5. Complete card sets
6. Filing	6. Glue and separate batches	6. Proof
	7. Type masters for offset printing	7. Alphabetize
	8. Prepare copy for Itek masters	8. File and revise
	9. Check format of entry on masters	9. Card shifting
	10. Check letter for letter on planning sheet	10. Update existing cards
	11. Gather statistics and keep log of card preparation	11. Correction of problems
	12. Prepare Itek masters and print cards on offset	12. Withdrawals
	13. File	13. Weed order slips
		14. Assembly of statistics
		15. File temporary slips
		16. File permanent slips
		17. Shelf list shifting
		18. Blank catalog card stock

TABLE 4

COMPARATIVE COSTS OF CARD PROCESSING

Date	1968	1969	1966	1965	1963			1968
Library	NYB	SSC	SUL	ONULP	AFCRL			CHY
Cards per title	(9.8)	(4.6)	(3.0)	(~9)	(7)			(9.3)
					(local)	(LC) cataloging	(machine)	
Card prep.	0.140	0.116	0.093	0.114	0.233	0.166	0.075	0.088
Card prod.	0.186	0.064	0.090	0.079				
Card filing		0.052	0.040	0.042		0.043		---
Totals	0.336	0.232	0.223	0.235	0.276	0.209,	0.118	---
					0.228			

The most significant fact that is evident from Table 4 is the extraordinary agreement among three of the studies: the total processing costs range from 22.3¢ per card to 23.5¢ per card for these three sources even though the reports were prepared over a 6-year period, including significant changes in the cost of labor and materials. Furthermore, these costs are reasonably constant for the individual categories in these four sources: card preparation varies from 9.3¢ per card to 11.4¢ per card; card production varies from 7.9¢ per card to 9¢ per card; and card filing varies from 4¢ per card to 4.3¢ per card. In one sense this close agreement should not be surprising: if it is indeed true that cataloging involves relatively high intellectual content that is difficult to automate, and card processing involves straightforward operations that are relatively easy to automate, it is reasonable to argue that the latter should show much less variability from one operation to the next.

The fact that the New York operation has significantly higher costs can be partially explained by the following observations. The New York costs are based on the supposition that all cards are locally produced. The other libraries indicate that a significant proportion of their work is based on the acquisition of LC cards. The breakdown for the Air Force study is shown in Table 4 and the breakdown for Sacramento is approximately the same. Secondly, New York is clearly the largest of the operations under consideration here and it is not unreasonable to expect that the size of the file will have an effect on the cost of filing. In fact, if we assume that the New York cost of preparation and production is the same as that for the Air Force locally produced cards (27.6¢) and assign the rest of the New York cost to filing, the latter figure becomes 10.3¢ per card or a little more than twice the average for the other four sources (4.4¢ per card). If this is the case, it would be of interest to know whether the problem is one of sheer size of the catalog or rather one of increased density that naturally occurs in larger files (e.g., is it more costly to file Smith, Adrian J. in a file with 100 Smith's or 1000 Smith's).

Finally, in the two cases of partial automation (the Air Force and Yale studies) the cost of card preparation and production is significantly lower (7.5¢ and 8.8¢) than that indicated for LC cards (16.6¢) or the average for the four closely agreeing sources (21.6¢). This observation alone should point the library community strongly towards automation of the card processing function. Nor is this observation new: both of the authors of the two preliminary studies at Air Force and Yale made the point more than adequately. Furthermore, as we shall see shortly, the cost of filing is also reduced in an automated system.

Several factors may be contributing to the slowness of the library community to introduce changes to achieve such cost savings. First, there is inevitably a substantial initial cost involved in any automation project. Second, although the potential cost saving is a substantial proportion of the processing cost, it is still small when compared to the cost of cataloging: a librarian under pressure to reduce costs could gain more by cutting back on the time allowed for cataloging without the initial investment necessary for automation. Third, there is a persistent difficulty in finding trained personnel in the automation field. Finally, librarians are certainly aware of the rapid changeover in equipment in the computing field with the concomittant costs of adapting programs to new equipment.

CASE AND SPACE

In the preceding discussion, we have provided some notion as to the cost of obtaining the required cataloging information, encoding it on catalog cards, and entering those cards in a catalog file. These costs can be compared with other possible approaches to the problem, including those that involve some degree of automation. There are, of course, a number of associated costs that must be taken into account to obtain a full picture of the cost of card cataloging. Such costs would include, at a minimum, the cost of the:

1. space occupied by the catalog
2. catalog filing cases
3. user of using the catalog
4. library of maintaining the catalog in usable form.

The allocation of capital expediture costs to a form comparable to the costs per title and the costs per card used in the earlier sections of this report raises certain difficulties. Accounting procedures vary from one institution to another. Further there is the real but difficult to measure problem of comparing funds of various types in a particular situation. Nonetheless, it is useful to know whether under any reasonable accounting system the cost of space and cabinets is of sufficient magnitude to make it worthwhile to consider these costs in the overall evaluation. Let us assume, therefore, that a filing case capable of storing 72,000 cards fully packed costs $800 and occupies approximately 30 square feet of space, including room for aisles and access area. Let us further assume that land and construction costs are approximately $30 per square foot. Then the total cost of the cabinet and the space it occupies would be approximately $1,700. Finally, let us assume that on the average a catalog is approximately 60 percent full. Then the initial cost of space and case is of the order of 4¢ per card. Four cents a card is not negligible, but it is only about 15 to 20 percent of the cost of producing the cards and an even smaller fraction of the total cost when cataloging is included. Hence, it seems reasonable to put this in the category of a secondary cost item that will favor book catalogs, microfilm catalogs, and other high-density forms; but it is unlikely to be the determining factor unless other cost factors are very closely balanced.

USER COSTS

Among all the various cost factors involved in cataloging, the most difficult to assess objectively is the cost to the user. The problem is that no one really knows what a user does in a library, nor what impact a given change will have on the utility to the user. Whether they like it or not, library users do use the card catalog, and it is thus a usable device for providing access to library materials. Equally, many libraries in times past and again more recently have used book catalogs; hence they are also viable devices. But which is better?

Perhaps an enumeration of the advantages of each, relative to the other would shed some light on the problem.

1. Updating. A card catalog is updated by the simple expedient of entering the recently obtained cards in the file. A book catalog is updated by periodically printed revisions. Hence any search for a particular item will in general require fewer specific searches in the card catalog than in the book catalog, if the proper information is available to the searcher.

2. Accessibility. Card catalogs are large and costly and there are few savings to be had over the original cost in producing a second copy. Reproducing books after the first copy is relatively inexpensive. Thus libraries with many branches or a decentralized set of users will provide better service with book catalogs.

3. Flexibility. Whether cards or books are used, the existence of a machine-readable catalog provides much greater flexibility as time goes on. Revisions of cataloging practice become much simpler if the revisions can be programmed on a computer.

4. File Extension. The added cost of maintaining more than a few files is heavy with cards and light with books.

In sum, machine-readable catalogs appear weak only when immediate updating is the primary criterion for comparison.

COMPARATIVE COSTS OF CATALOG CONVERSION

Table 5 is an extension of Table 6 of Reference 1. Two new columns have been added to incorporate information from the Library of Congress (Ref. 11) and the New York Public Library (Ref. 5). The previous horizontal entries of "punched cards" and "coding sheets" have been merged into the single entry "supplies". Two new horizontal entries have been added: "sort and merge" under computer costs and "supervision".

With seven sources of data representing three public libraries and four university libraries and with data gathered for the most part independently over a 4-year

TABLE 5

COMPARATIVE CONVERSION COSTS PER TITLE

	Mar. 68 LC 446 char.	1968 LACP ~450 char.	1964 ONLUP 400 char.	1968 NYP 300 char.	1966 UC/B 317 char.	1964 CHY 243 char.	1966 SUL 180 char.
Coding/editing	$0.169	--	--	--	$0.080 1/	--	$0.044
Keying	0.207	$0.480	$0.307	$0.450	0.188	$0.198	0.183
Re-keying	0.033		0.259		0.030	0.117	
Proofing	0.125	0.127			0.085		0.103
Rental	0.156	0.084	0.650 2/		--	0.036	0.037
Conversion & List		0.020	0.096	0.046	0.020	0.024	0.104 3/
Edit List	0.359	0.084		0.141	--	--	
Sort & Merge		--	--	0.165	--	--	0.121
Supplies	0.080	0.036	0.508 4/	--	--	--	0.033
Supervision	0.183	--	0.580	--	--	--	--

1/ Includes provision for keypunch rental, and supplies

2/ Full keypunch rental absorbed by pilot project

3/ Includes use of automatic error-detection routines

4/ Includes cost of magnetic tapes and other supplies period, it is worth making a number of separate comparisons within the data to test it for consistency.

1. Perhaps the most outstanding comparison is between the encoding costs for the Library of Congress and the Los Angeles Public Library. For records of essentially the same average length (446 characters versus 450 characters) the coding costs agree to the penny! Yet the methods of production are significantly different. The Library of Congress invested heavily in the coding and editing operation and used paper tape typewriters with their relatively high rental. As a result their costs in this area are significantly higher than LACP. On the other hand these procedural changes resulted in significantly lower keying costs so that the overall cost for encoding was the same.

2. The encoding costs of UC/B (University of California at Berkeley), CHY (the Columbia, Harvard, Yale study), and SUL (the Stanford Undergraduate Library) are all very close (within 3 cents per title) even though there is a fair range of record size (from 180 for SUL to 317 for UC/B) and these three studies probably provide a more reasonable picture of the underlying variation in cost than the unusually close figures for LC and LACP.

As a check on these five studies, we can plot the average cost versus the average record length (in characters per record) (Figure 1). The rightmost point is the average for LC and LACP, the center point is for the three studies--UC/B, CHY, and SUL. The line is simply drawn through the origin (zero dollars, zero cost) and the LC/LACP point. The other points added are as follows:

1. The New York Public point of $.45 for a 300-character record. This point is not "real" because it is not based on actual NYP experience but rather on a study of information from other studies. Its proximity to the line suggests that NYP's analysis of existing information comes to similar conclusions to ours.

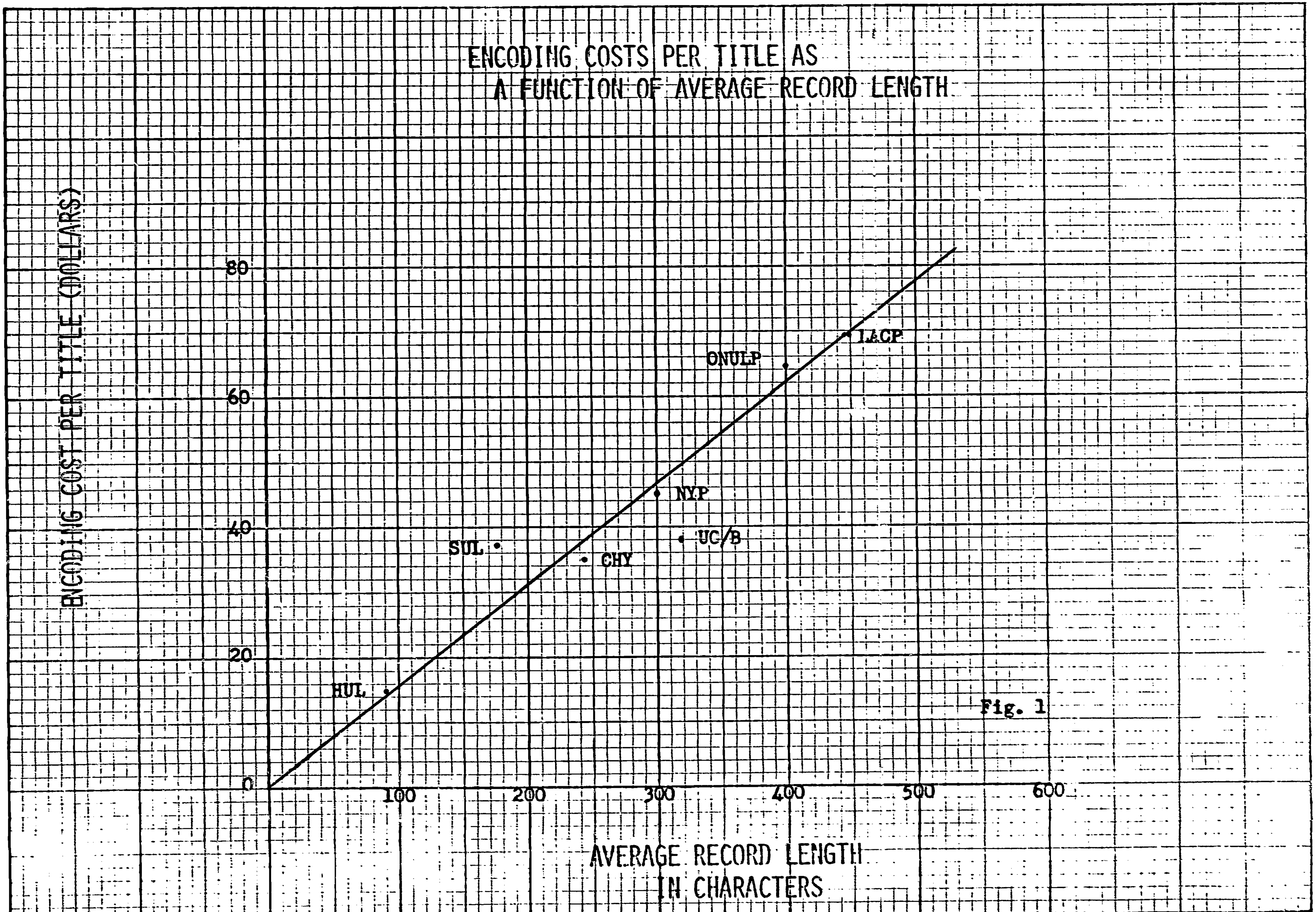
ENCODING COSTS PER TITLE AS
A FUNCTION OF AVERAGE RECORD LENGTH
ENCODING COST PER TITLE (DOLLARS)
0
20
40
60
80
100
200
300
400
500
600
AVERAGE RECORD LENGTH
IN CHARACTERS
HUL
SUL
CHY
NYP
UC/B
ONULP
LACP

Fig. 1

2. The Ontario New Universities Library Project (ONULP) point does not include the full rental charge indicated in their study because they wrote off the entire cost of keyboard rental on the project even though the machines were not nearly fully used. We have arbitrarily chosen $.08 per record for machine rental in plotting this point.

3. The point for the Harvard University Library (HUL) is based on information received from them in a private communication.

Although there is a significant amount of variation from one study to the next it seems reasonable to conclude that the cost of encoding is in the order of $.15 per title per hundred characters.

The cost of computation is not as well-documented. There are basically three computational operations common to those studies that reported computer costs at all:

1. The cost of conversion and listing. This cost included the cost of converting the original machine-readable form (be it cards or paper tape) to magnetic tape form. In most cases a by-product of this operation was a listing (all-caps only) of the material on the tape.

2. The cost of an edit run including a listing in upper and lower case. The latter was eschewed in a number of cases because of the added costs. However, many libraries would require a proper edit run and many librarians would prefer to edit from an upper/lower case printout than an all caps printout.

3. The cost of sorting and merging the tapes. Many of the early studies did not explicitly report on this cost because they were primarily concerned with the cost of converting the retrospective list. However, in an on-going operation this would be a continuing cost of some magnitude.

The available information points to a uniform cost of approximately $.02 per record for conversion and list, and approximately $.08 per record for editing. The two studies where both these costs are given indicate that a ratio of 4 to 1 is appropriate. The only study giving a ratio between the sort and merge operation and the edit operation is the NYP study and this is based on before-the-fact-information only. Their figure is approximately 8 to 7. For convenience, we will assume that this ratio is unity, thus giving us an overall ratio of 4-4-1. The most complete history of total computer cost is given by LC: a total of $.36 per record for 446 character records. Using our rough breakdown for their total we obtain a breakdown of $.04 for conversion and list, $.16 for editing, and $.16 for sort and merge. Extending the Stanford cost of $.12 for conversion and list and editing we obtain a total cost for SUL of $.22 for their 180 character records. This figure is considerably more than 180/446 parts of the LC cost.

One other pertinent piece of information is available from the SUL data. In the production of their annual catalog, Stanford estimates a cost of $.121 per title for what is roughly comparable to the cost of sort and merge. This cost is then roughly 1.2 times the SUL cost for conversion and list and editing, thus verifying the notion that the cost of "sort and merge" is in the same general order of magnitude as the cost of editing.

The ratios of SUL costs to LC are .367/.690 for encoding (=.532) and .225/.359 (=.625) for computer time. This suggests that the means of computing average record length may be different for the two institutions. If we take the LC figures as the standard and assume that both computing and encoding costs are strictly a function of record length, then the SUL record length should be between (.532x446=) 238 and (.625x446=) 279. This discrepancy may be a result of one source (presumably LC) counting all delimiter and other non-printing characters while the other does not. NYP indicates that the ratio of printed characters to total characters is in the order of 3:4. If the SUL figure of 180 is expanded by one third we obtain the figure of 240 which agrees well with the lower limit (based on encoding costs) given above.

The cost of sort and merge is a function of the size of the data base, not the amount of material being put into it. The Library of Congress points this out in their study (Ref. 11) and report on an average month (where their data base grows for a period and then is reduced to zero.) Stanford Undergraduate Library figures are based on their second year of operation where they added 16,000 titles to form a total base of 41,000 titles. The actual cost of this step in the operation will therefore depend strongly on the operating strategy employed. Clearly, the number of times one has to sort and merge the entire data base should be minimized, particularly when one takes into account the fact that sorting costs go up faster than linearly. Thus if the master file is arranged in n orders (author, subject, title, class number, etc.), it will generally be less expensive to sort the updating material into those n orders and make n merge runs with the sorted master files than to make a single merge with a single ordering of the master file and then sort the master file n times to obtain the required updated orderings of the master file.

THE COMPARATIVE COST OF MANUAL AND COMPUTER PROCESSING

Our objective was to try to shed some light on the various factors that enter into the cost calculations to determine the relative costs of manual and computer processing of catalog information and to report on the present indicated cost values for those factors. At the expense of possible oversimplification, let us now compare the actual costs for these two alternatives for a "typical" library, i.e., a library whose cost structure approximates the average costs of those presented in the preceding tables.

From Table 5 we obtain average figures for two cases: catalogs with approximately 425 characters per entry and catalogs with approximately 250 characters per entry; let us call these "full entries" and "short entries," respectively.

From Table 4, we can compute similar figures for "full catalogs" and "short catalogs" by clustering the three larger cases (those having 9.8, 9.0, and 7.0 cards per title) and the three smaller cases (those having 3.0 and 4.6 cards per title). For the full catalogs we find that the average cost of processing is 26.7¢ per card and 8.6 cards per title, or a total cost of $2.29 per title. For the short catalogs we find that the average cost of processing is 20.3¢ per card and 3.8 cards per title, or $0.78 per title. Combining these two sets of figures we obtain the results in Table 6.

TABLE 6

COMPARATIVE COSTS OF MANUAL AND COMPUTERIZED PROCESSING

	Short Entries	Full Entries
Manual	$0.78	$2.29
Computer	$0.84	$1.31

From Table 6 we see that our hypothesized "typical" library would be slightly better off with manual methods if it chose the short form entries and noticeably better off with the machine if it chose the full form of the entry.

In making this quick comparison, we have not considered several factors that should obviously be taken into account even in this simple example. First, we have not included either the initial cost of programming or the initial cost of converting the retrospective records. Either or both of these costs could be substantial, but they are one-time costs and as libraries are basically long term institutions, such costs should be written off over a relatively long period--even though they must be financed out of a given year's budget.

Second, we have not included the cost of printing the catalog (assuming a book catalog is in fact to be used in the computerized system). Thus the comparison in Table 6 is between a card catalog and a catalog in machine-readable form. Such a comparison is complicated by the fact that a card, once filed, stays in the catalog indefinitely, subject only to long-term wear and tear and a certain rate of attrition due to unauthorized removal, misfiling, and so forth, while the machine-readable catalog must be updated periodically and supplemented by interim publications. And, of course, the comparison is also complicated by the corresponding low cost of producing a number of copies of the book catalog where this is useful for a given system.

However, to put the printing cost in some degree of perspective, let us make a quick calculation based on the production of a single book catalog using a standard upper-lower case print chain. At present commercially available prices this would cost between 35¢ and 50¢ per 10,000 characters or approximately 9¢ per entry for the full form entries and 5¢ per entry for the short form entries (assuming four complete listings for author, title, subject, and class number listings). This added cost would make the comparison between manual and computerized methods even less favorable for the short form but still substantially better for the long form entries ($1.40 to $2.29).

CONCLUSION

The conclusion of this study is that the card processing operations in typical libraries can be automated economically in many situations today. Libraries using the short form of a catalog and having no immediate need for multiple copies of the catalog may find it desirable to wait a year or two, depending upon their local situation, the availability of trained personnel and, of course, the availability of capital to finance the initial cost of programming and retrospective conversion.

However, libraries using the full form in their catalogs or those needing multiple copies of their catalogs will almost certainly find that there is a substantial economic advantage to computerization at the present time. Even when allowance is made for substantial departures from the "typical" costs found in this study, it is difficult to visualize any library using full form information not finding significant economic gains in computerization.

When one adds to this the greater flexibility available in machine-readable records, the greater services that can be offered to the user, and the fact that machines costs are decreasing while labor costs are increasing, one is led to the conclusion that more and more libraries will move towards automation of their catalog.

Tables 7 to 11 are reference tables for calculating costs.

TABLE 7

COST/CARD — LIBRARY OF CONGRESS CATALOG CARDS (July 1968)

LC Cards Ordered by/for	1-2 cds only	1st cd of 3 or more order	Add'l copies same cd ordered same tm.	All titles specific subject	Subsc for all cds	Extra chgs/title all orders lacking req info
1) LC #	$ .22	$ .10	$ .06	$ ---	$ ---	
2) Author & Title	.27	.15	.06	---	---	
3) Series	---	.10	.06	---	---	
4) Subject	---	.10	.06	---	---	
5) Chinese/Japanese/Korean	.22 - .27	.10 - .15	.06	---	.04	$ .04
6) Motion Pictures & Filmstrips	.22 - .27	.10 - .15	.06	.10	.04	
7) Phonorecords	.22 - .27	.10 - .15	.06	.10	.04	
8) Revised & Cross Ref.	---	---	---	---	.04	
9) Anonymous		$ .04				

Source - LC cds, July 1968-GPO

TABLE 8

CATALOG CARD COSTS

CARDS	COST/CARD	COST/HOUR	TIME
LC Cards	$.22-.27 (min order 1-2 cds) .10-.15 (1st cd - 3 or more order) .04-.06 (add'l copies same cd-same order) } $.04 extra chg all orders lacking req. info.		
Blank Cards	< 3-< 4 for $.01		
Original Card Preparation	$.20-2.34	$2.40 - 4.70	5-30 min/cd
Card Checking Before Filing	$.21	$4.20	3 min/cd
Correcting Detected Errors	$.12	$2.40	3 min/cd
File	$.024 .03 .047	$2.40 3.00 4.71	100 cds/hr 100 cds/hr 100 cds/hr
Store	$.01		
Reproduce	$.0023-.00208 (AB Dick Offset Press =$.125/bk(54-60 cds) .045 (Xerox - 1K-100K cds)		

TABLE 9

CARD CATALOG MAINTENANCE COSTS

Requirement Space		Estimated Cost/Sq Ft	Cost/Mo	Cost/Year
Card Catalog Cabinet	- 6 sq ft	$ .42	$ 2.52	$ 30.24
Room for Users	-16 sq ft		6.72	80.64
Aisles	- 3 sq ft		1.26	15.12
Catalog Table	- 5 sq ft		2.10	25.20
	30 sq ft		$ 12.60	$ 151.20

Source - E. Graziano/Univ. Calif. at Santa Barbara and R&D Consultants Co.

TABLE 10

(ESTIMATED) ANNUAL COST OF 1000 SQ FT OF STORAGE SPACE

1) Minnesota State Dept. of Education (1968) - $520

Source - Private communication

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2) R&D Estimate

$$\frac{\text{1968 Construction Cost}}{\text{\$30 sq ft x 1000 sq ft}} = \frac{\text{\$30,000}}{\text{100 yrs (life of bldg)}} = \text{\$ 300/yr}$$

+ Maintenance Costs, clean up, etc. ($1 yr/sq ft) = $ 1000

$ 1300/yr

$$\frac{\text{1974 Construction Cost}}{\text{\$50 sq ft x 1000 sq ft}} = \frac{\text{\$50,000}}{\text{100 yrs (life of bldg)}} = \text{\$ 500/yr}$$

+ Maintenance Costs, clean up, etc. ($1 yr/sq ft) = $ 1000

$ 1500/yr

Source - E. Graziano/Univ. Calif. at Santa Barbara

TABLE 11

CARD CATALOG COST/YEAR

Given the following variables, 1 card catalog case with a maximum card capacity of 72,000 cards (purchase price-$789) - the cost/card to store would be $ .01. Therefore we also find the following to be true:

	Estimated Cost/sq ft Rental @ $.42 sq ft/mo Cost/Yr	Construction Cost $30/sq ft ÷ 100 yrs life bldg Cost/Yr	Maintenance Est. @ $1/sq ft Cost/Yr	Cost/Yr
Cabinet (6 sq ft)	$ 30.24	$ 1.80	$ 6.00	$ 38.04
Room for Users (16 sq ft)	80.64	4.80	16.00	101.44
Aisles (3 sq ft)	15.12	.90	3.00	19.02
Catalog Table (5 sq ft)	25.20	1.50	5.00	31.70
				$190.20
	+ 72,000 cards @ $ .01 (to store)			720.00
			TOTAL COST/YR	$910.20

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APPENDIX A

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