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TRANSNATIONAL ACTIVITY AND MARKET ENTRY IN THE SEMICONDUCTOR INDUSTRY

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1. Introduction

a) Basic issues. What are the factors determining the rate of technology diffusion in the host country? What is the connection between transnational strategy and technological change in the host country? How do host-country firms compete against foreign firms that have both cost and proprietory advantages? This section attempts to use the experience of the semiconductor industry to examine these important issues.

The pattern of product innovations is based on the concept of a life cycle process.[1] A model is developed for estimating product life cycles in a way that gives information suitable for assessing induced changes in the host-country industry.[2] The analysis that follows is broken into two parts.

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[1]Several studies are essential reading in this context. See Postner (1961), Hufbauer (1966), Vernon (1966), Hirsch (1967), Gruber, Mehta, and Vernon (1967); chapters by Steven Toulmin and William Gruber, Gruber and Marquis (1969).

[2]The life cycle may be described in several ways: the cycle observed in adjustments towards equilibrium levels of demand and supply; the cycle in imitative behavior by firms or consumers; and the cycle in the time pattern of firms bringing an innovation into the market. For an interesting study carried out from the first viewpoint see the work of Chow (1967), who made use of the Gompertz function, Mansfield (1968) and (1963). Models similar to Mansfield's have been estimated for the Canadian tool and die industry and the paper industry, by Globerman (1973a and 1973b).

Firstly, factors determining the rate of diffusion of the innovations in the host country are examined; secondly, factors determining the positions of individual firms within the life cycle are considered.

The imitation cycle is modeled on the basis of starting months for the commercial exploitation of semiconductor innovations by individual firms servicing the U.K. market. The technological lag between an innovation's first commercial appearance and its introduction to the United Kingdom is measured with two aspects in mind: the time lag in years and months and the entry order of individual market participants.

b) The Data. Data for this analysis have been collected on over twenty commercial semiconductor innovations embodying new process or product technology. These innovations cover three phases of electronic development--discrete devices, bi-polar integrated circuits, and uni-polar large-scale integration. To qualify as an innovation, a new commodity must be sold in the host country in sufficient quantities to be described as a commercial operation. Most, if not all, efforts of individual firms selling in the U.K. are included,[3] but production for in-house use is not completely covered.[4]

The data were gathered from individual firms, technical publications, advertisements, trade journals, and sellers' lists. Over a period of 25 years, many changes have taken place in the industry, with firms continuously entering and leaving. A mail survey was therefore impracticable, but personal visits and

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[3] Cases involving trial offers, and very limited selling are not included. For a definition of innovation similar to that used here see Mansfield et al (1971), pp. 111-2.

[4] Production solely for in-house use has not been common in the U.K., but some manufacture by Newmarket Transistors, English Electric, Standard Telephones and Cables, and a few other firms has been employed in this way.

communications proved fruitful. Over 70 firms and more than 30 innovations came within the scope of the work. A core group of 20 innovations was finally selected from the original list. Since U.K. sales of some innovations were quite limited or, as in the case of thyristors, the specific technical data would not allow sufficient distinction of different underlying process technologies, data on the American industry were collected to serve as a check on the U.K. data, and also to provide information concerning the relationships between company activity in the source and host countries.[5]

2. A Short History

a) Technology, Products, and Corporate Leaders. During the 1950-60 period, innovations in semiconductors were primarily associated with discrete devices, such as single transistors, diodes, or rectifiers. The technological impetus for innovations in discrete semiconductor devices came primarily from America out of research in firms such as Bell Labs of Western Electric, General Electric, Texas Instruments, R.C.A., Philco, Hughes, Clevite, Motorola, and Fairchild.

In addition to the first type of point contact transistor, at least four classifications of device by method of construction came into existence: grown, alloyed, diffused, and electrochemical. Improvements to the basic methods of construction appeared rapidly, and in many cases an improvement in one method led to improvements in another. The major transistor innovations of this period are given in Table 1 along with the dates and principal firms responsible. A transistor family tree is presented in Figure 1 to illustrate the cross fertilization of technical developments arising from the four main methods of semiconductor construction. The creation of other types of active components also

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[5]Information as to which firm was first or earlier to introduce a new product was sometimes a matter of controversy because of parallel developments. Objective sources of information, outside the innovating firms, were sought to help resolve disputes. In the course of the study, more than 1,000 observations were collected.

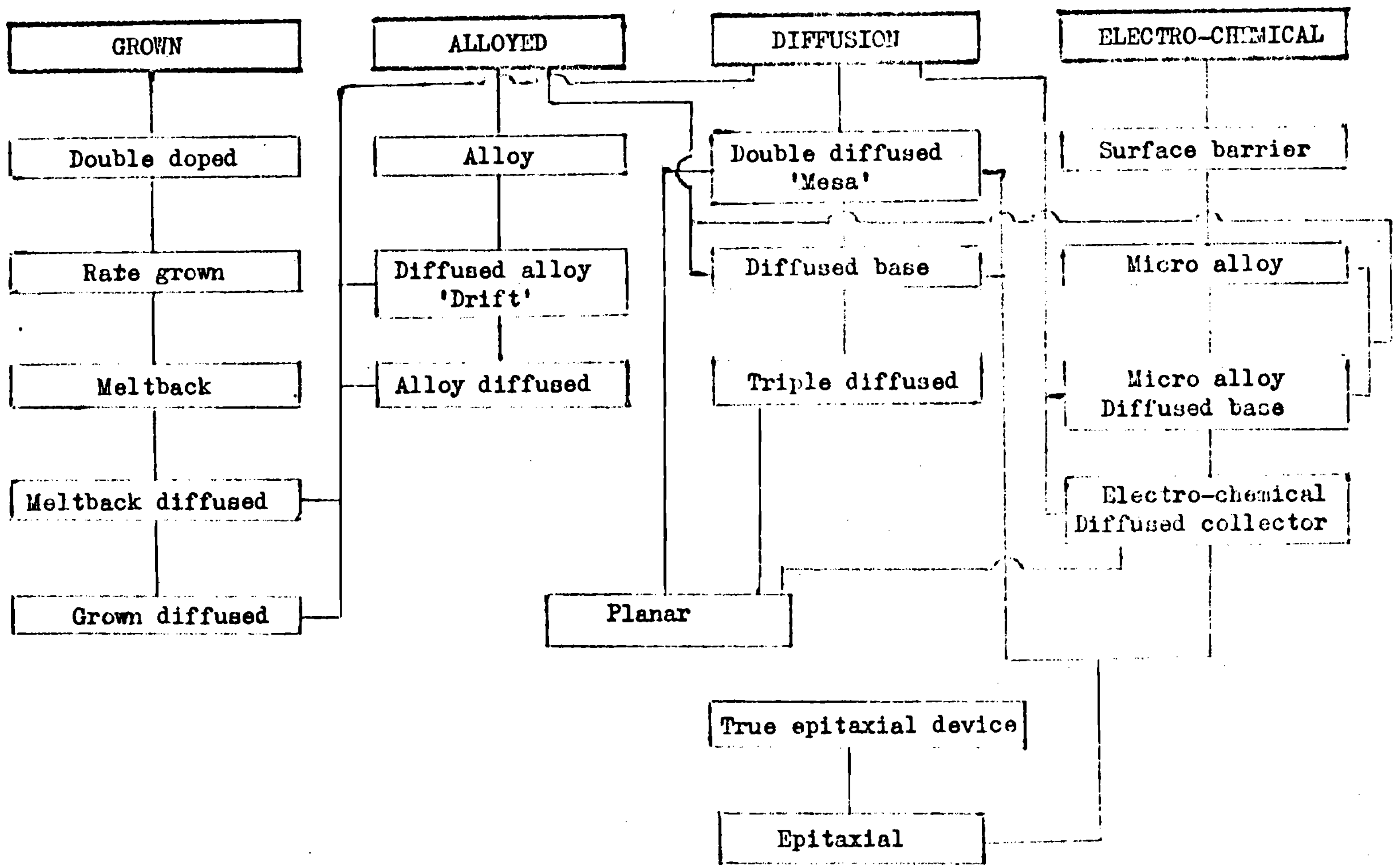
TABLE 1

Major Product Innovations - Semiconductor Discrete Devices

Innovation	Principal Firm Responsible	First Commercial Production	Importance
Point Contact Transistor	Western Electric	1951	First solid state amplifier. More efficient in power consumption and eventually less costly, more reliable, and smaller than tubes.
Grown Junction Transistor	Western Electric	1951	Increased production yield, thus lowering costs. Less electrical noise and greater resistance to shock.
Alloy Junction Transistor	General Electric	1952	Greatly improved transistor capability to perform digital (switching) operations. Encouraged development of second generation computers.
Surface Barrier Transistor	Philco	1954	Increased transistor frequency range and switching speeds; useful in computer development.
Silicon Junction Transistor	Texas Instruments	1954	First transistor not made from germanium. Silicon increased temperature range of operation, thus opening up military market. Also increased frequency range.
Diffused Transistor	Western Electric Texas Instruments	1956	Lower production costs; increased reliability and frequency range.
Planar Transistor	Fairchild	1960	Batch production possible, lowering costs. Improved performance and reliability.
Epitaxial Transistor	Western Electric	1960	Increased switching speed; lower production costs.

Source: John E. Tilton (1971).

FIGURE 1 Family Tree of the Transistor*



* Lines linking the various members of the family tree show the interdependence of the descendants of the four principal transistor structural forms.

Source: Fleet (1965).

also involved the new processing techniques. A list of these other components introduced during the 1950-75 period is given in Table 2.

The early 1960s were an important period in the history of electronic systems design. During this time, several techniques to miniaturization were explored. The development of semiconductor application technology had traditionally been based on devices representing single discrete active components. This tended to favor the component manufacturers. However, with the advent of integrated circuits incorporating large numbers of active and passive elements, design technologies increasingly necessitated the closer participation of systems people in the earlier phase of the development cycle. Systems experts pressed for greater optimization in total circuit composition, especially in the use of integrated circuits to perform particular systems functions.[6]

The development of the planar process at Fairchild in 1959 marked the beginning of the integrated circuit era in electronics, and the evolution of the industry as shown in Figure 3. At first, the planar process was confined to the manufacture of single transistors on a single silicon base known as a substrate or "chip." It became apparent that the process could be extended in several directions, to the manufacture of several transistors in one chip, and to the inclusion of other active devices, for example, diodes, resistors, and capacitors. The first commercially available integrated circuits appearing in 1960 were designed for digital equipment and were based on the need for large numbers of identical circuits. The design of chip circuits tended to

[6]The change in the physical size of electronic systems has been dramatic. A device of an earlier period often becomes simply an element within a device of the following period. Thus, transistors have become elements of integrated circuits, which, in turn, have become elements of integrated electronic components. The actual size of the device for each succeeding period has become considerably smaller. The newer components are composed of transistors that can be seen only with the assistance of a powerful microscope.

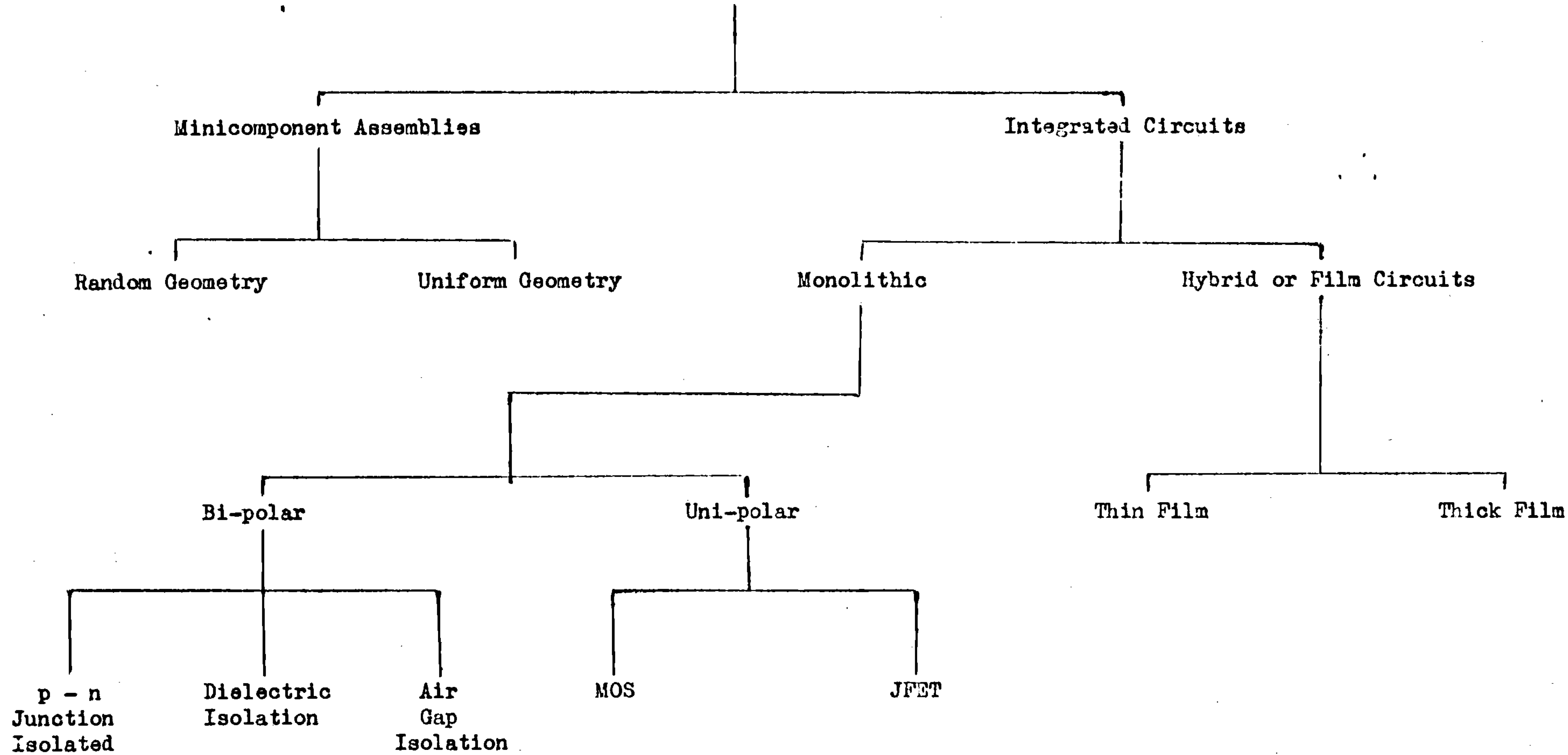
TABLE 2 Product Innovations - Semiconductor Uni-polar and Other Devices

Innovations	Principal Firms Responsible	First Commercial Production	Importance
Alloy junction diode (si)	Western Electric	1952	Rectifying unit, amenable to mass production, small size.
Photo diode	Standard Telephone & Cable*	1952	Absorbs light energy; used in satellites, solar cells.
Power rectifier (ge)	Associated Electrical Ind.*	1954	More efficient than metal rectifier, and smaller.
Power rectifier (si)	General Electric	1955	Can operate at higher temperatures than germanium.
Zener diode (si)	Associated Electrical Ind.*	1956	Controls current in voltage regulator circuits.
Thyristor	General Electric	1956	Replaces thyraton; unidirectional current control valve.
Tunnel diode (ge/si/ga as)	Sony (Japan)	1957	Very fast diode, used in amplification and oscillation.
Unijunction transistor	General Electric	1952-58	Unique voltage control properties; simpler circuits.
Varactor diode	Sylvania	1958	Variable reactance circuit element; used in harmonics.
Light emitting diode	Standard Telephone & Cable*	1963	Visual displays for electronic equipment.
Junction field effect transistor	Fairchild	1962-3	Small uni-polar device, higher yield.
Gunn diode	I.B.M./Associated Electrical* Industries	1965	Replaces klystron and magnetron tubes, smaller solid state.
Schottky-barrier diode	Philips	1968	Stable device with microwave applications. Used in ICs.
Programmable unijunction Transistor	General Electric	1967-8	Faster than unijunction transistor.
Triac	General Electric	1968	Switching device; extension of thyristor.
Bucket brigade devices	RCA	1970	Very fast, consume very little power, used with ICs.
Charge coupled devices	Fairchild/Bell/General Electric	1969-70	Very fast, not as dense as bucket brigade devices.

*Indicates that the innovation was introduced first in the United Kingdom.

FIGURE 3

Microelectronics Tree



Sources: **Dummer (1965), p. 731 and Hnatek (1973), p. 2.**

copy systems already in existence using discrete components. But manufacturers quickly realized that integrated circuits required a new concept of systems design. There followed a succession of circuit families, summarized in Table 3, for which manufacturers sought to optimize the performance and economics of systems, and to make them on a single monolithic chip.[7]

The planar technique was initially limited to bi-polar devices, in which both positive and negative electric carriers are required, but it also led to the development of uni-polar devices, for which carriers of only one type are required, at great space saving. The first integrated circuit to be developed by means of the planar process contained a small number of elements. A larger system could be built by using more than one chip, and this type of system was known as the multi-chip system. However, with the extensive development of uni-polar technology, it became apparent that larger systems could be made on a single chip.[8] Uni-polar technology became the primary basis of what is known as large-scale integration, LSI,[9] while its preceding monolithic competitor,

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[7]Lathrop (1970), pp. 1-1 to 1-11.

[8]There is a continuing debate as to how far the level of integration will go. The uni-polar technology makes possible extremely complex chips, and some see electronic equipment systems on a chip, for example, a TV set, a computer memory, or a spectrum analyzer. They already exist for small calculators, digital clocks and watches. See "Forum on MSI/LSI," Electronic Products, December 1969, pp. 28-38.

[9]This category of device may be split into two groups, random and regular function components. Regular function components are suited to digital systems such as for computer memories where the elements are arranged in a regular fashion. See Lathrop (1970), pp. 1-4.

TABLE 3

Product Innovations - Semiconductor Bi-polar ICs and Other Devices

Innovation	Principal Firms Responsible	First Commercial Production	Importance
Current Source (Saturated) Logic			
RTL (Resistor Transistor Logic	Fairchild	1961	Few active components, comparatively inexpensive, easy to fabricate, adequate for computers, high yield, but fan out ability limited.
DCTL (Direct-coupled Transistor Logic)	Texas Instruments	1961	Simple transistor switching circuit, problems of current hogging and noise need proper operation.
Current Sink (Saturated) Logic			
DTL (Diode-Transistor Logic)	Signetics/Philco	1962	Higher fan out capability than RTL, improved noise margins, eliminates uneven base current problem of RTL and is faster.
TTL, or T^2L (Transistor Transistor Logic)	Sylvania/Transitron Signetics/TRW	1964	Modification of DTL, faster than other forms of saturated mode logic, higher fan out capability than DTL, low cost.
TSL (Tristate TTL)	National Semiconductor	1970	Third stable state permits reliable communication at very high data rates and with excellent noise immunity, high performance replacement for DTL and open collector TTL.
Current Mode (Unsaturated) Logic			
ECL (Emitter-coupled Logic)	Pacific SC/Motorola	1962	Prevents transistor saturation, eliminates storage time, very fast circuit speed, less complex than Schottky-clamped TTL, lower yields due to fabrication needs for best results.
Schottky-clamped TTL	Texas Instruments	1969	High speed of unsaturated logic, with relatively low power consumption of TTL.

Sources: Golding (1971), p. 208, and Finan (1975).

bi-polar technology has had its major impact in less complex integrated circuit termed medium scale integration, MSI.[10] Table 4 outlines the principal families associated with uni-polar technology.

Major improvements in semiconductor processing technology had the effect of pushing semiconductor manufacturers downstream in terms of their end products. Through each new processing technology the product-market strategy of the semiconductor houses has also evolved. The technological requirement in moving downstream gave rise to diversification into downstream know-how, products, and markets. At the same time, the systems manufacturers, threatened by inroads that the upstream firms were making into their product areas, saw in-house semiconductor facilities as a means of combatting such enroachment.

Between successive technologies there is a transition period of technological overlap. It is during these periods that hybrid technologies emerge.[11] The hybrids depend basically on two techniques for making passive circuits, thin film or thick film (Figure 3). They are often a midway solution designed to meet specific user requirements in terms of cost and volume. A complete monolithic replacement requires a considerably larger overhead cost than the monolithic components making up the hybrid.

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[10] Some leading firms in bi-polar technology such as Texas Instruments, Transitron, Sylvania, and Motorola had still by the early 1970s to make significant inroads into large-scale integration. In terms of off-the-shelf devices, Texas Instruments was the only firm of the four making them and had only two. Companies that did not invest as heavily in bi-polar technology such as General Instruments, Philco-Ford, and Hughes Aircraft, had forty large-scale integration devices between them. See Forum, p. 29. R.C.A. leap-frogged bi-polar technology from discrete micromodules to uni-polar complementary devices. Finan (1975), p. 37.

[11] The advantages of hybrid systems are outlined in Hamer and Biggers (1972), pp. 56-68, 332-56, 381.

TABLE 4 Product Innovations - Semiconductor Uni-polar Integrated Circuits

Innovation	Principal Firms Responsible	First Commercial Production	Importance
p-Metal Oxide Silicon (p-MOS)	Fairchild	1962	Increased yield over bi-polar devices, easily fabricated; extremely small component size.
n-Metal Oxide Silicon (n-MOS)	RCA/KMC/Siliconix TRW	1963	Half size of p-MOS, faster and TTL compatible.
Complementary MOS (CMOS)	RCA	1969	Offers good isolation, used for complex processing, larger chip size, faster, TTL compatible, both polarities.
Silicon-gate MOS	Bell Labs/Intel/ Fairchild	1969	Bi-polar compatible, low cost, higher speed than p-MOS and n-MOS, high yield, high packing density.
Silicon-nitride MOS (MNOS)	Advanced Micro Devices/ Texas Instruments	1967	Low cost, low packing density, faster than p-MOS, bi-polar compatible.
Ion-implanted MOS (IMOS)	Hughes/Mostek	1970	Reduced MOS size, higher speed than p-MOS, bi-polar compatible, increased yield.
Refractory MOS (RMOS)	*	*	Probably faster than silicon-gate MOS, still unproven process.
Field shield MOS	*	*	Novel and complex process.
Self-aligned thick oxide MOS (SATO MOS)	Texas Instruments	*	Faster and more dense than MNOS, TTL compatible, useful for RAMS and ROMs.
Double diffused MOS (DMOS)	Signetics	*	High speed applications, ROMs, RAMs, shift registers.
Silicon-on-sapphire MOS	Inselek/RCA/North American Rockwell	1970	High insulation resistance between IC components, very high speed.
Silicon-on-spinel MOS	Siemens	1969	Less costly than SOS and faster.

* Not known.

b) The Semiconductor Industry in Britain. The firms primarily responsible for the technical progress of the U.K. industry over the past 25 years are listed in Table 5. The performance of the individual companies in introducing the 21 innovations is also indicated.[12] For example, Motorola participated in the market by selling products incorporating fourteen of the innovations. The company was second in introducing one innovation, third in two others, fifth in one, and so on.

The story of competition in the U.K. active components industry prior to the mid-1950s is almost a history of the British Value Association.[13] The U.K. industry could be characterized as a "tight" oligopoly dominated by Mullard.[14] With the decision by Texas Instruments to begin U.K. operations in 1957, several other American companies soon followed: Philco, Hughes, and International Rectifier. General Electric and Transitron established export houses. By the mid-sixties, the trickle of foreign firms marketing in the U.K. turned into a small flood, as shown in Table 6. In the meantime, host-country firms had been seeking and making agreements that would give them access to American know-how

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[12] The list of innovations covered is as follows: point contact transistor (ge), alloy junction transistor (ge), surface barrier transistor, diffused transistor (si), diffused mesa transistor (si), planar transistor, epitaxial devices, junction field-effect transistor, alloy junction diode (si), power rectifier (si), zener diode (si), (thristor), tunnel diode (ge/si/ga as), unijunction transistor, varactor diode, light emitting diode, Schottky-barrier diode, RTL (resistor transistor logic), DTL (diode transistor logic), TTL (transistor transistor logic), ECL (emitter coupled logic), and p-MOS devices. The thyristor is not included in the statistics of Table 5.

[13] This was a highly restrictive organization investigated by the British Monopolies Commission in 1954-55. See Monopolies and Restrictive Practices Commission (1956).

[14] Mullard had over fifty percent of the market, and was rivalled by Associated Electrical Industries, 15-20 percent; Standard Telephones and Cables, 8-12 percent; Electrical and Musical Industries, 8-12 percent; General Electric Company, 3-5 percent; and others, Ferranti, Pye, Rank, Automatic Telephone and Electric, less than 2 percent.

TABLE 5 . Frequency Data on Introduction Positions

Firm	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th +	Total	Weighted Index	Age	Index/ Age
Philips – Mullard	1	1	1	2	3	2	1	1				5	17	107	22	4.86
– Pye (Newmarket)		1					1					2	4	19	22	0.86
Texas Instruments	3	3	1	2	2	2	2					2	17	141	18	7.83
R.C.A.	2	1	3	2		1		1	1	1		4	16	106	22	4.82
I.T.&T. – Standard Telephone and Cable	4	1	1	2	2	1		1			1	1	14	118	14	5.36
Motorola		1	2		1	1	1	2	3	1	1	1	14	80	14	5.71
Ferranti	3	2	1		3	1	2					1	13	112	19	8.61
G.E.C. – A.E.I.	2	1	1		2		4					2	12	87	22	7.25
Raytheon	1							1	2	2		4	10	35	14	2.50
Sylvania				1	1			1			2	5	10	31	16	1.94
General Electric (U.S.A.)	2		2		1				1			4	10	60	22	2.73
Transitron		1	1	1	1	1			1			3	10	52	15	3.47
Plessey	1*		1		3	1		1			1	2	10	62	13	4.77
Emihus (formerly Hughes)						1			2	1		5	9	23	15	1.53
S.G.S.– Fairchild		3		2		1				1		1	8	62	13	4.77
G.E.C. – English Electric								1					1	5	18	0.28
– Marconi		1					1	1	1			2	6	28	11	2.54
– Elliot Automation					1			1		1		1	4	17	10	1.70
G.E.C. Semiconductors	1	1	2	2						1		1	8	65	22	2.95
International Rectifier							2			1	1	2	6	19	15	1.27
Westinghouse (U.S.A.)	1		1			1	2				1		6	43	11	3.91
I.T.&T. – Brush Clevite						2	2					1	5	27	19	1.42
Mitsubishi – Melco												5	5	5	7	0.71
National Semiconductor		1									1	3	5	16	14	1.41
Philco (–Ford)	1*									1		3	5	18	18	1.00
Telefunken									1	1		3	5	15	19	0.79
Solitron	1	1				1				1		1	5	34	11	3.09
Siemens (–Halske)					2						1	2	5	20	17	1.18
Teledyne (Crystalonics, Amelco)			1					1				2	4	22	10	2.20
Sesco												4	4	4	13	0.31
Siliconix				1			1	1				1	4	21	10	2.10
General Instruments	1*								1			1	3	17	11	1.54
Lucas Bradley								1	1				2	9	17	0.53
Westinghouse Brake							1					1	2	8	22	0.36

*Introduction not widely diffused.

Innovation and imitation in the semiconductor industry for twenty one product innovations. The commercial success of the individual company's products depends not only on the use of new technology, but also on the speed at which it can reach the market on a commercial basis. Time-cost relationships, as apparent in lead times, are an important aspect of individual company strategy. The weighted index above is derived by weighting the timing positions, i.e. 12 for the 1st, 11 for the second, and so on to 1 for ones greater than the 11th. The "age" or length of time the company has been active in the U.K. market has been derived.

TABLE 6

Semiconductor Devices

Numbers of American Firms Marketing in the U.K. for the First Time

Year	Discrete Devices No.	Discrete Devices Cum. No.	Monolithic ICs: Bi-polar IC Devices No.	Bi-polar IC Devices Cum. No.	Uni-polar IC Devices No.	Uni-polar IC Devices Cum. No.	All Devices No.	All Devices Cum. No.
1950	0	0	0	0	0	0	0	0
1951	0	0	0	0	0	0	0	0
1952	0	0	0	0	0	0	0	0
1953	2	2	0	0	0	0	2	2
1954	0	2	0	0	0	0	0	2
1955	0	2	0	0	0	0	0	2
1956	0	2	0	0	0	0	0	2
1957	2	4	0	0	0	0	2	4
1958	0	4	0	0	0	0	0	4
1959	3	7	0	0	0	0	3	7
1960	3	10	0	0	0	0	3	10
1961	5	15	0	0	0	0	5	15
1962	3	18	0	0	0	0	3	18
1963	5	23	0	0	0	0	5	23
1964	8	31	0	0	0	0	8	31
1965	5	36	2	2	2	2	9	40
1966	8	44	1	3	2	4	11	51
1967	1	45	0	3	5	9	6	57
1968	1	46	0	3	3	12	4	61
1969	1	47	0	3	4	16	5	66
1970	1	48	1	4	2	19	5	71
1971	3	51	0	4	3	21	6	77

The above table outlines the primary process of manufacture underlying the first appearance of the American firms to the U.K. The list is derived from indexes, trade journals, and promotional publications of individual firms.

and manufacturing rights. A list of licensing agreements is given in Table 7. Considerable amounts had also been spent by them on research and development, e.g. by Mullard, A.E.I., English Electric, S.T.C., Lucas, and Ferranti. The U.K. firms, although not unprepared for the arrival of new American products, needed to compete with American companies in product cost and variety. The only way to match these advantages was by expensive R&D to improve methods of manufacture, and to obtain the economies of increased scale of operation.

American participation in the British semiconductor market has tended to come in waves of new firms. The successive waves are associated with both new processing technology that supersedes its predecessor and new products made possible by the new processes. A visual scenario of the major product life cycles for discrete semiconductor devices is presented in Figure 4. Among other things the cycles reflect the switch from germanium to silicon as the primary base material.

c) Choice of Technology and Market Strategy. Most semiconductor houses, in particular American firms, pursued an aggressive pricing strategy. Often they were simultaneously straddling newer and older technologies and frequently managing to earn only a small return on their investment in the preceding technology.[15] Moreover, most firms wanted to be well positioned with respect to the growing markets where economies of large scale could be achieved, and to the newer technologies for the most profitable development of these markets. Most firms sought the internal economies that could be achieved through improved organization around the new design technologies, for example, computer

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[15]See "Special Report," Business Week, April 20, 1974, p. 78, and Integrated Circuit Engineering Corp. (1966), p. 7, and Finan (1975), pp. 27-34.

TABLE 7 **Licencing Agreements of American Firms with U.K. Manufacturers of Discrete Semiconductors**

U.K. Manufacturers	Bell	R.C.A.	G.E.	Philco	General Instruments	Westinghouse Electric
A.E.I.	1952-	1959-63	1953-68			
G.E.C.	1956-		1957-62			
English Electric	1952-	1947-				
Ferranti	1956-	1961-66				
Plessey				1957-61**	1958-61	
S.T.C.*	1952-					
Mullard (Philips)	1952-					
Pye	1952-67				1955-58	
Westinghouse Brake	1959-	1955-59				1957-
Joseph Lucas	1957-					
Texas Instruments*	1957-					
I.R.C.**	1959-					

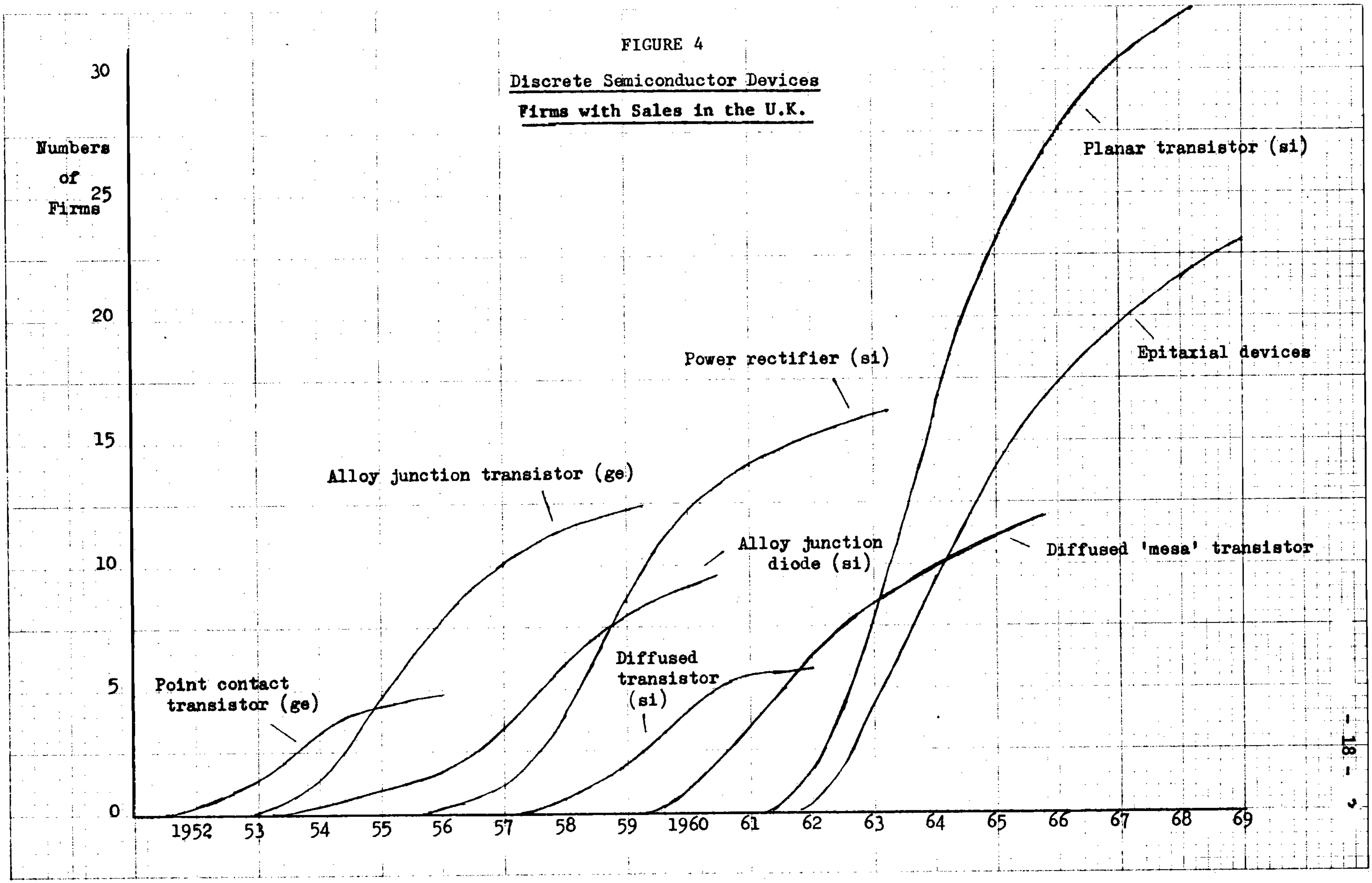
** joint venture, US/UK Companies * subsidiary of US Company

Source: A. Golding, op. cit., Table 9-5, p. 303.

FIGURE 4

Discrete Semiconductor Devices

Firms with Sales in the U.K.



aided design and optimal systems for interfacing with component users.[16] Finally, many firms saw a need for basic research, but the trade-off tended to favour developmental research. This was especially true in view of the growing risks involved for firms that created their own proprietary products and processes.[17] The main gains resulted from five types of economies, namely: 1) miniaturization, 2) improvements to production yields, 3) economies of scale and associated learning economies, 4) product-market strategy, and 5) vertical integration economies.

1) Miniaturization meant that the number of semiconductor elements on a single chip could be increased. Design technologists initially experimented with various types of logic and then chip structure to both reduce the space required per semiconductor element and improve the overall performance of the chips with respect to speed and power dissipation. As Figure 5 illustrates, the density and speed of a chip are related. The overall effect of miniaturization has been to reduce the cost of the elements on the chips. Element cost is related to packing density or the number of elements per chip. The progress in reducing costs this way is illustrated by Figure 6 showing the period 1960 to 1968.

2) Production yield is associated with the number of chips that are eventually usable out of a given supply of processed substrate. For any given chip substrate there are likely to exist defects proportional to its area. The same number of defects in a given substrate meant that the relative yield in

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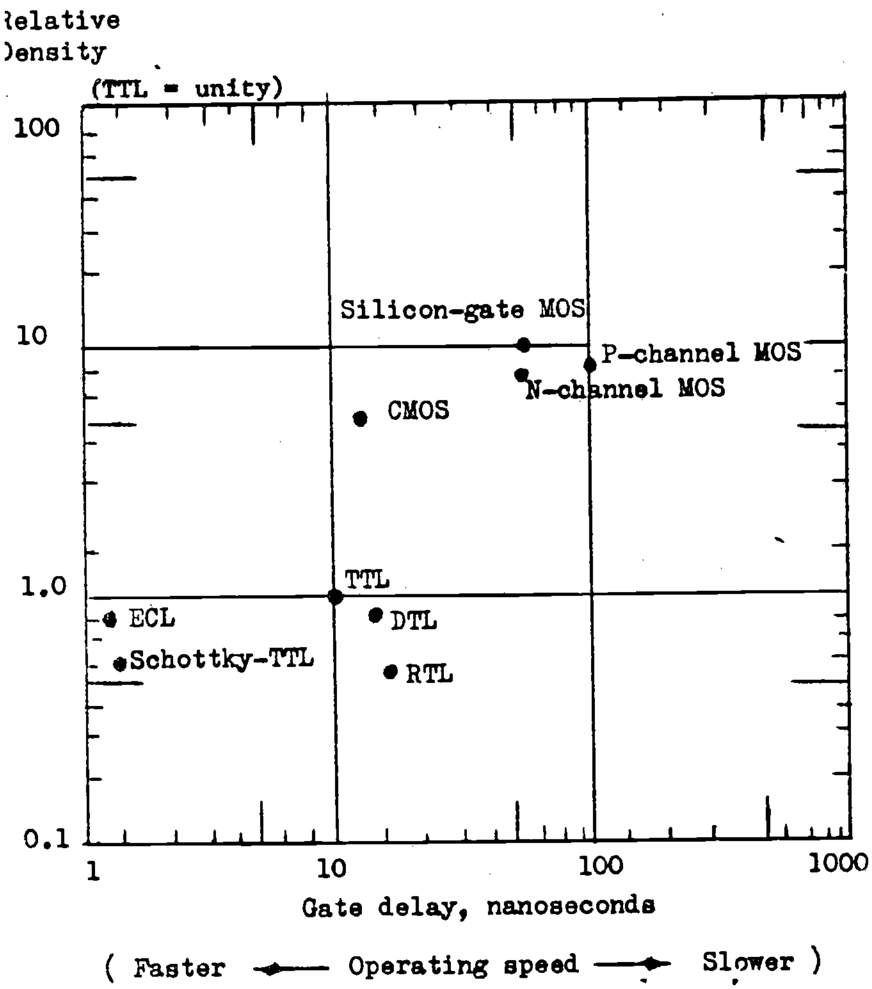
[16] Lathrop (1970), pp. 1-4 to 1-6, and Foss (1970), pp. 8-1 to 8-6.

[17] The protection of patents from immediate imitation within six months became very difficult, and a new process therefore had to incorporate a secret that could not be broken. Camenzind (1969), p. 10.



RTL Resistor-transistor logic
DTL Diode-transistor logic
TTL Transistor-transistor logic
ECL Emitter-coupled logic
MOS Metal-oxide-silicon logic
CMOS Complementary MOS logic

FIGURE 5 The density and speed of a monolithic chip are related. In terms of density the uni-polar ICs lie to the top while bi-polar ICs are at the lower level, however the faster devices are the bi-polar ones. Source: Quantum Industry (1974), p. 28.

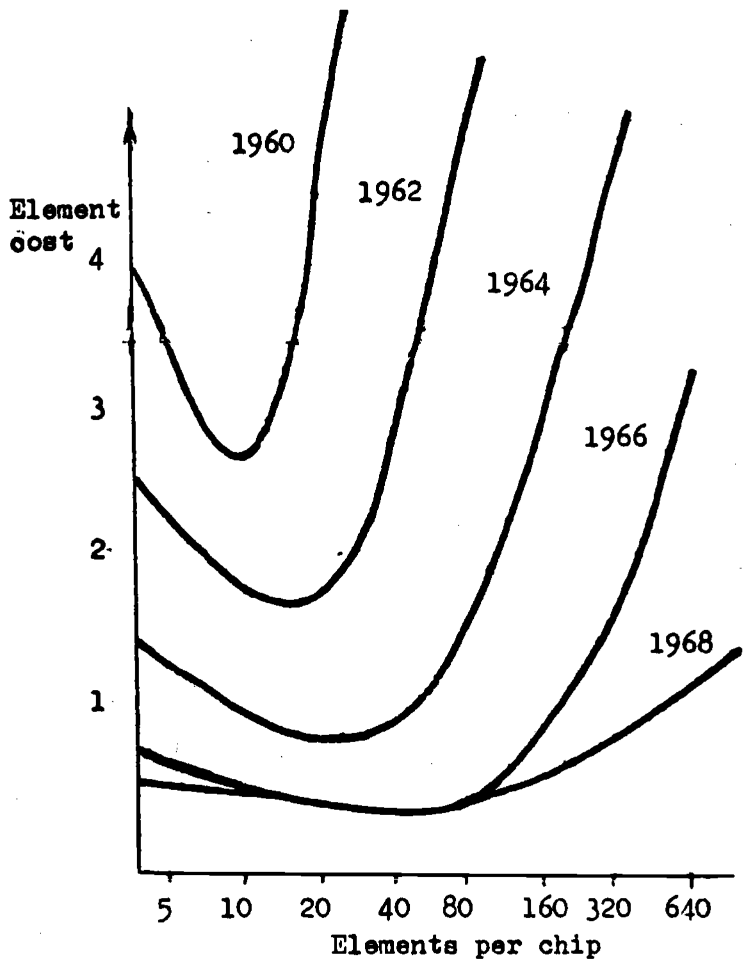


FIGURE 6 With the increase in the number of elements possible per chip the economics of integrated circuits have changed over the years. Chip density and costs are related. Source: Hamer and Biggers (1972), pp. 59-61.

manufacture of larger bi-polar devices would be considerably lower than for the manufacture of smaller uni-polar devices.[18]

A formula for the derivation of yield can be defined. If we let D represent the average number of spot defects per unit of area, and A represent the area of the device, then the probability of producing functioning circuits, namely, the yield, Y becomes:

$$Y = e^{-DA}$$

This relationship is shown in Figure 7. By using a method of manufacture that reduces the circuit size, as in the case of the uni-polar device, the yield is increased. It is obvious that the concept of yield relates directly to the costs of manufacture.[19] This is illustrated in Figure 8 for which the cost per function is related to chip size. With the yield concept, a notion of the optimal economic circuit size was also born. If the optimal size is exceeded, the yield becomes so small that the cost per circuit rises excessively. It is easy to understand why innovations designed to increase production yield have become the object of much research.

3) Economies of scale and associated learning economies are another important aspect in the choice of technology and the selection of a product-market strategy in the semiconductor industry. Figure 9 illustrates economies achieved under various technologies. The minimum-of-minimums, or lowest average cost

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[18] Improvements in yield have followed a trend associated with the introduction of new processes moving from less than 1%, 1960; 10%, 1965; 40%, 1970; to 80+%, 1975. See Finan (1975), pp. 21-26; Integrated Circuit Engineering (1966), pp. 8, 76-78, 164-65, and Camenzind (1972), pp. 45-56.

[19] It is possible to specify more than one type of defect mechanism operating. Using an alternative formula, we have yield as follows: $Y = 1/(1+AD_{\cdot})$, which expands with n defect mechanisms to reduce yield accordingly: $Y = 1/(1+AD_o)(1+AD_1)(1+AD_n)$. Finan (1975), pp. 20-24.

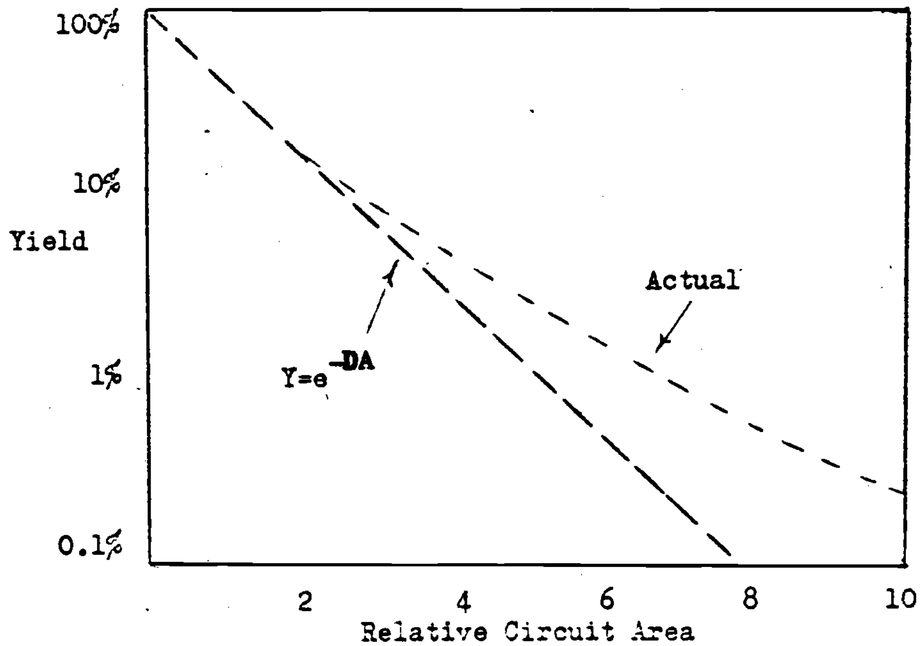

FIGURE 7 The yield observed in practice is perhaps larger than suggested by an exponential relationship. Source: **Camenzind (1972). p. 48.**

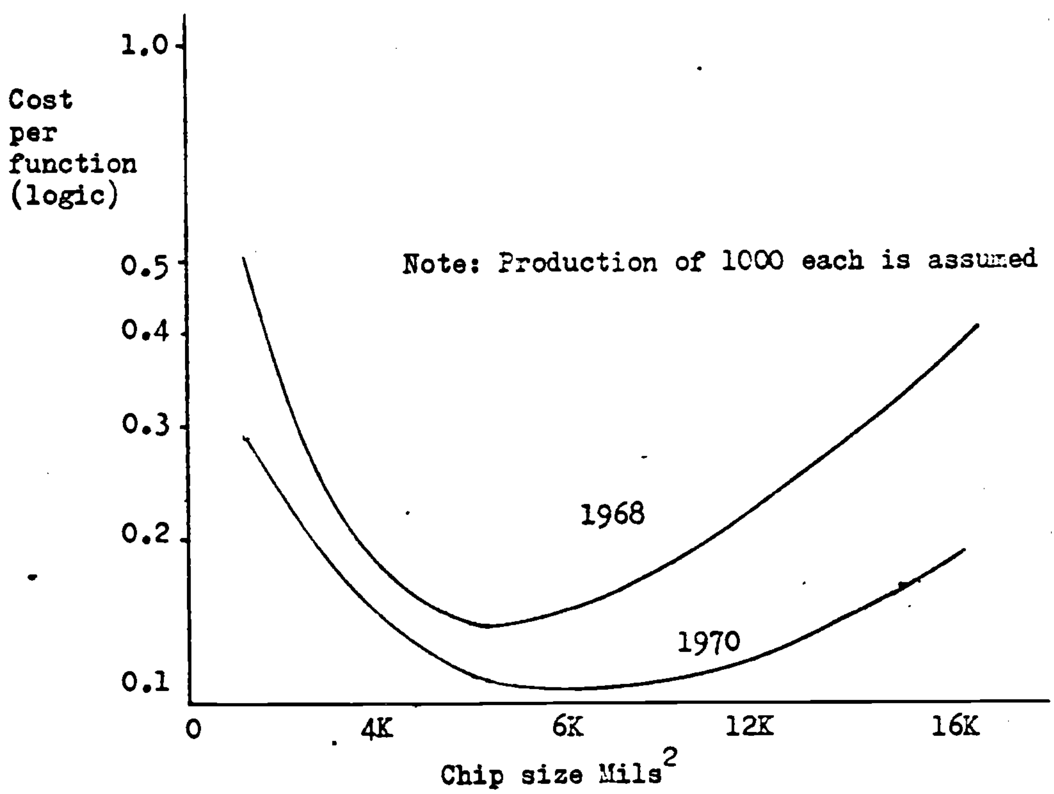

FIGURE 8 The cost per electronic function is related to chip size and time because of yield and yield improvements over time. Source: **Farina (1969). p. 89.**

curve for the production of an individual integrated circuit by a firm is illustrated by the line aa' in Figure 10. It is made up of three portions reflecting parts of the cost curves associated with, a) the superseded technology, for low volume production, b) the hybrid technology, for intermediate volume production, and c) the new superseding technology, for high volume production. In the absence thus of learning economies, the choice of processing technology is a function of the firm's expected throughput. In the presence of learning economies, the cost will be pushed downwards. The downward shift may depend on the frequency of production runs at specific volume levels, and hence may influence the shape of the cost curve disproportionately in certain regions.

4) Product-market strategy in the microelectronics industry generally involves the selection of design characteristics as well as the selection of product and market areas. A strategy can include 1) a process mix, with the choice of the proportions of output made by the various superseded, hybrid, and superseding technologies, 2) a volume mix, involving, for example, the numbers of products with low, intermediate or high volume throughputs, and 3) a design mix, including the choice of products with standard, off-the-shelf, or custom design.

An electronic system in theory can be composed either of a very complex single chip, a system of simple chips, or some combination of these.[20] This has different economic implications for users and producers. The systems house, or user, would like to have only one unique component so as to minimize the costs of interconnection.[21] The specialist components manufacturer, in

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[20] Custom components are designed to fill a specific requirement and tend to be electrically optimized for that requirement only, whereas standard components are generally advertized in catalogues as off-the-shelf stock.

[21] Camenzind (1971), p. 49 and (1972), pp. 45-56.

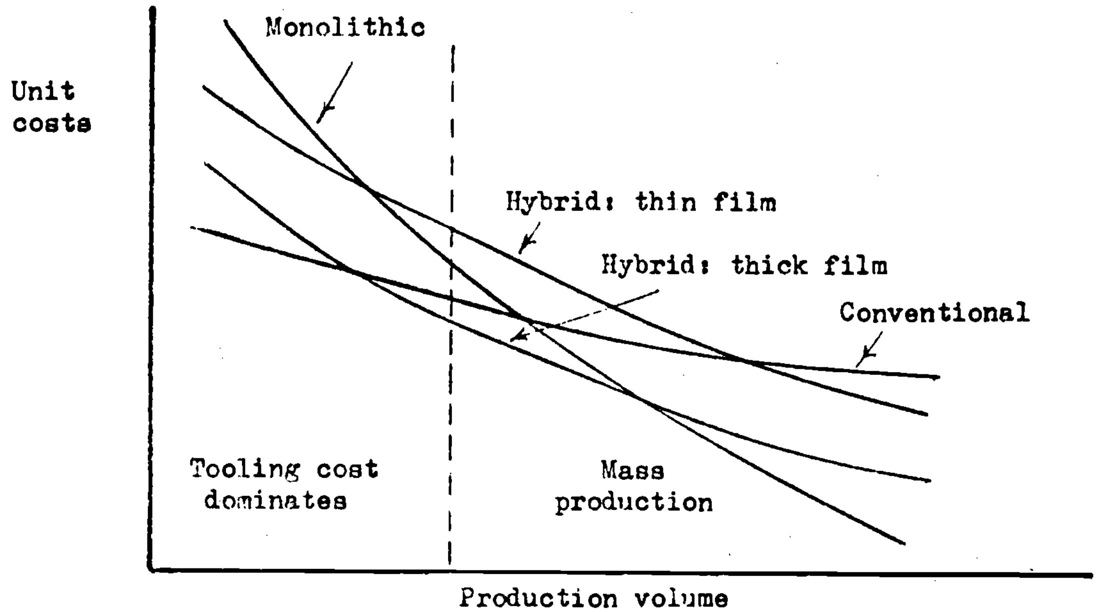

FIGURE 9 Comparison of circuit costs at various production levels. The costs of manufacturing different kinds of IC are compared to those of manufacturing conventional circuits.

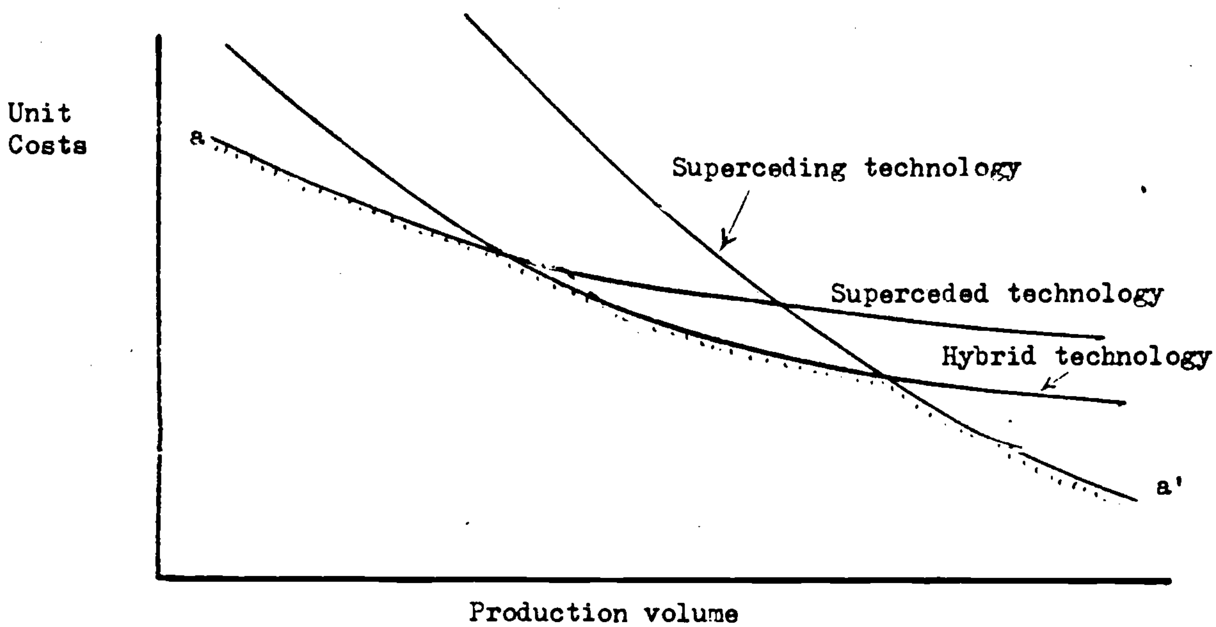

FIGURE 10 Technological overlap exists so long as the hybrid is preferred on a cost and performance basis. Learning economies associated with the superceding technology moves its cost curve down and to the left.

contrast, prefers to manufacture a small number of unique components at high volumes. The cost considerations which can affect the choice between the two approaches are illustrated in Figure 12. The outcome in terms of the size distribution of components is illustrated by Figure 11.

5) Vertical integration economies are achieved through an inhouse, as compared to a buying-in operation. Systems manufacturers have developed in-house integrated circuit capabilities, especially in hybrid technologies.[22] However, these are generally confined to a narrow area of semiconductor technology since the small value added element of components in total costs usually justifies only one or two semiconductor technologies.[23]

3. The Microeconomics of Market Entry

a) General Considerations. It is generally realized that new knowledge is not evenly distributed either internationally or between firms. The production functions of individual companies may thus differ substantially from one another.[24]

The uneven distribution of knowledge and skills affects the timing of commercial introductions embodying new technology. Consider Figure 13 which represents the discounted values of cumulative revenues R(t), cumulative costs C(t), and cumulative profits P(t) associated with the timing of the commercial introduction of product-innovations. For each timing, a separate set of discounted

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[22] In 1969, approximately 80% of American hybrid integrated circuits were manufactured in-house. This was three times the value of in-house monolithic integrated circuit production. See Integrated Circuit Engineering Corporation (1970).

[23] The risks of a systems house pursuing the wrong semiconductor technology are thought to be high.

[24] The study by Rapoport (1971), pp. 135-56, of costs associated with lead times has been useful in developing concepts discussed here.

Level of integration
(gates per component)

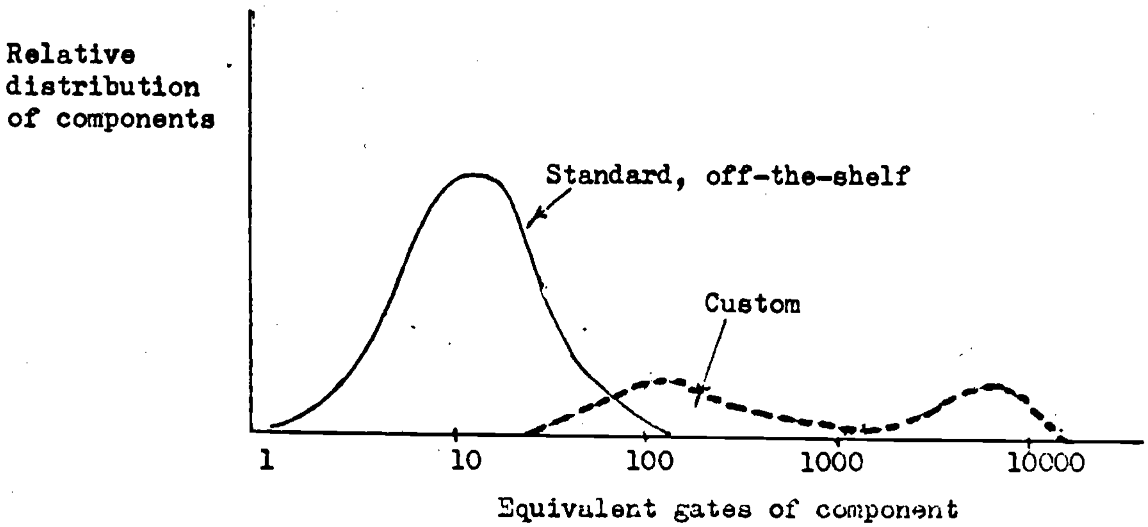

FIGURE 11 **The expected distribution of digital components in the 1970's. Source: J. W. Lathrop.**

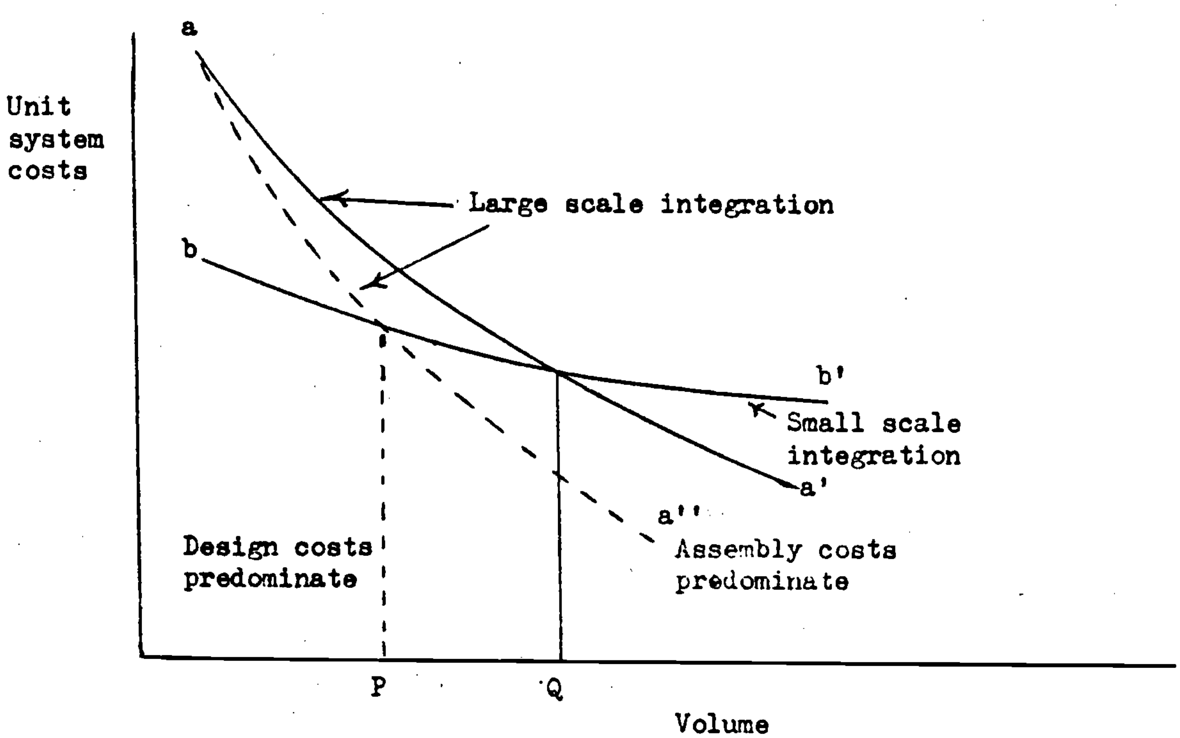

FIGURE 12 The level of integration in systems design is reflected in systems costs and is related to the volume of production. Systems built on small scale integrated components incur substantial assembly costs associated with interconnection. On the other hand large scale integration involves considerable design costs. **It therefore requires volume production.**

values applies. A curvilinear relationship for cumulative costs and a linear relationship for cumulative revenues are assumed. Early introduction of a product-innovation is associated with higher cumulative revenues and costs.[25] If the firm begins commercial production at a very late stage, its discounted costs are lower but its profits may also be lower. Indeed, if the firm introduces the innovation after t_z, cumulative costs will exceed cumulative revenue, and a loss will be incurred. To maximize profits, the firm will introduce the product at time t^*. The uneven distribution of knowledge implies that the curves $C(t)$ and $R(t)$ differ between companies. Differences exist between companies both in the generation and application of commercial knowledge. Figure 14 represents the case where two companies a and b have the same know-how and costs associated with bringing a product innovation to market, but differ in their respective levels of proprietary marketing ability. Firm b knows how to make good on a market entry while firm a is less capable. Thus, even when firm b enters the market at a later date, say t^*_b, its eventual profits are greater. Firm a, on the other hand, maximizes profits by entering the market earlier, incurring higher costs, and deriving a lower cumulative profit.

The decision facing the British based firm has often been a choice of either being a licensee of an American firm or developing its own in-house capability. Generally, the American licensor derives returns from its proprietory know-how in the form of a royalty. Normally, a royalty is expressed as a percentage of sales, often between 3 and 8 percent, but frequently provision is made for a

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[25] The values of $R(t)$, $C(t)$, and $P(t)$ may be thought of as the discounted expectations of the individual firm for introducing the product-innovation at time t. The expected cumulative discounted profit is as follows:

$$P(t) = R(t) - C(t)$$

To maximize cumulative profits, the first-order condition is that $dC/dt = dR/dt$. Thus given that the expectations of the firm are correct, the "optimal" or profit-maximizing timing of market entry is t^*.

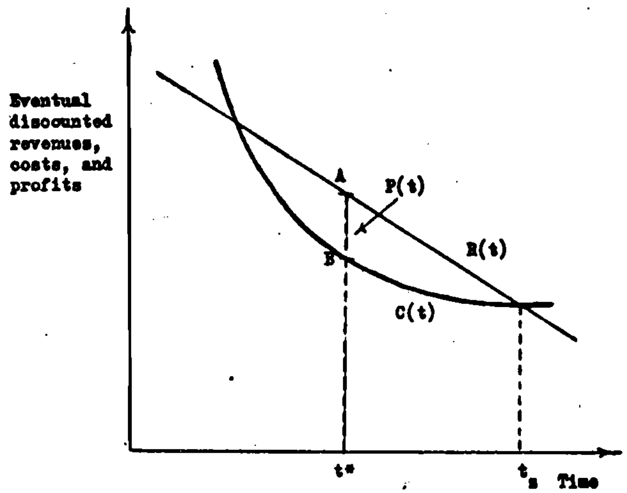

Figure 13 The timing of market entry influences the eventual revenue, costs, and profits of the firm for the new product.

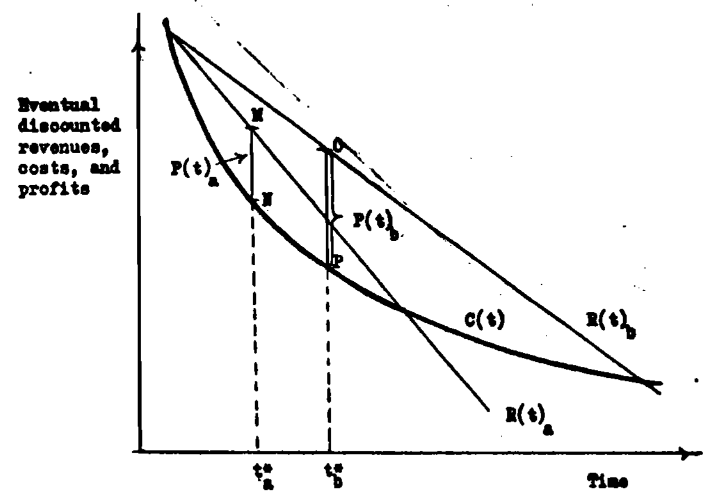

Figure 14 The optimal timing of firms with the same cost situation but differing proprietary know-how in marketing is illustrated above.

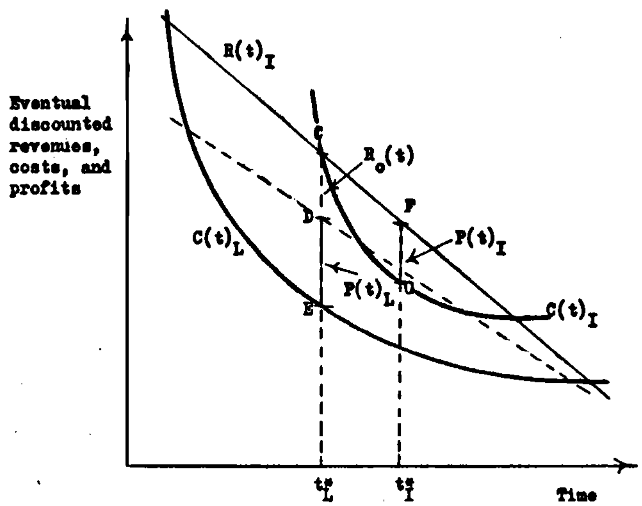

Figure 15 The host-country firm can choose either to become a licencee, i.e. subscript L, or go-it-alone in developing and exploiting the new technology, i.e. subscript I.

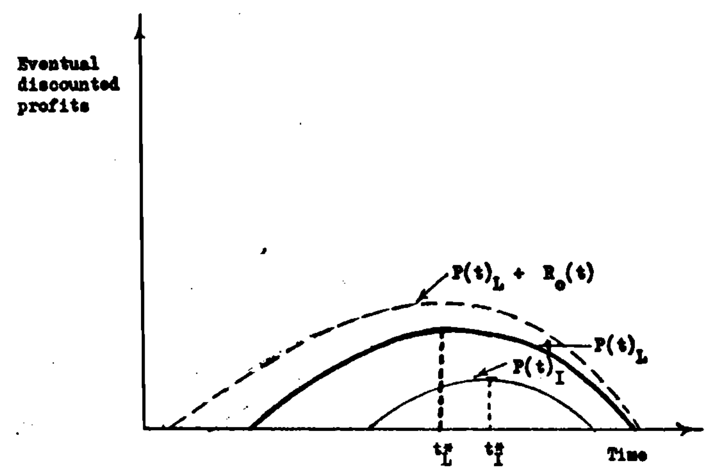

Figure 16 The optimal strategy for the host-country firm is associated with the timing of market entry, and its decision whether or not to arrange a licencing agreement. As a licencee, and timing its introduction a time t^*_L, it maximises profits.

lump sum payment at the beginning and a minimum payment over the license period. The royalties usually last for a stipulated period, after which the licensee is independent. It may then shake off the licensor's control, and become a competitor. However, in many instances, the licensor is so far ahead technically that the licensee finds it advantageous to arrange a new licensing agreement.[26] Consider Figure 15 in which the discounted eventual costs of going-it-alone, $C(t)_I$, and as a licensee, $C(t)_L$, are represented schematically. The independent programme is assumed to be more costly. In the illustration, we also assume that $R(t)_I$ and $R(t)_L$ are equal. Because some of the licensor's proprietary marketing knowledge may form part of the licensing agreement, the curve $R(t)_L$ may, in fact, be drawn above $R(t)_I$. Some appreciation of marketing factors is furthermore also likely to be contained in the product technology itself. A proportion of $R(t)_L$ is paid to licensor as royalties, indicated in the diagram as $R_o(t)$. The licensee ends up with the residual profit $P(t)_L$. The eventual discounted profits for alternative timings of market entry are represented in Figure 16. The points t^*_L and t^*_I represent the times at which the host-country firm may maximize its profits given the strategy either of licensing or of going-it-alone. The diagram is drawn to show that as a licensee, the host-country firm accelerates its optimal timing of market entry from the alternative strategy of going-it-alone, though that need not always be the case.

Competition amongst rival American firms and between firms of the source and host country has the effect of pushing forward the period of profitable market entry. This effect of competition on introduction behaviour may be observed in the time pattern for the numbers of firms marketing a new commodity in the United Kingdom. Figures 17 and 18 portray imitation cycles for selected major bi-polar and uni-polar semiconductor devices which display an S shape curve

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[26] Bradshaw (1972).

FIGURE 17

Monolithic Integrated Circuits: Bi-polar Devices

Firms Marketing in the United Kingdom

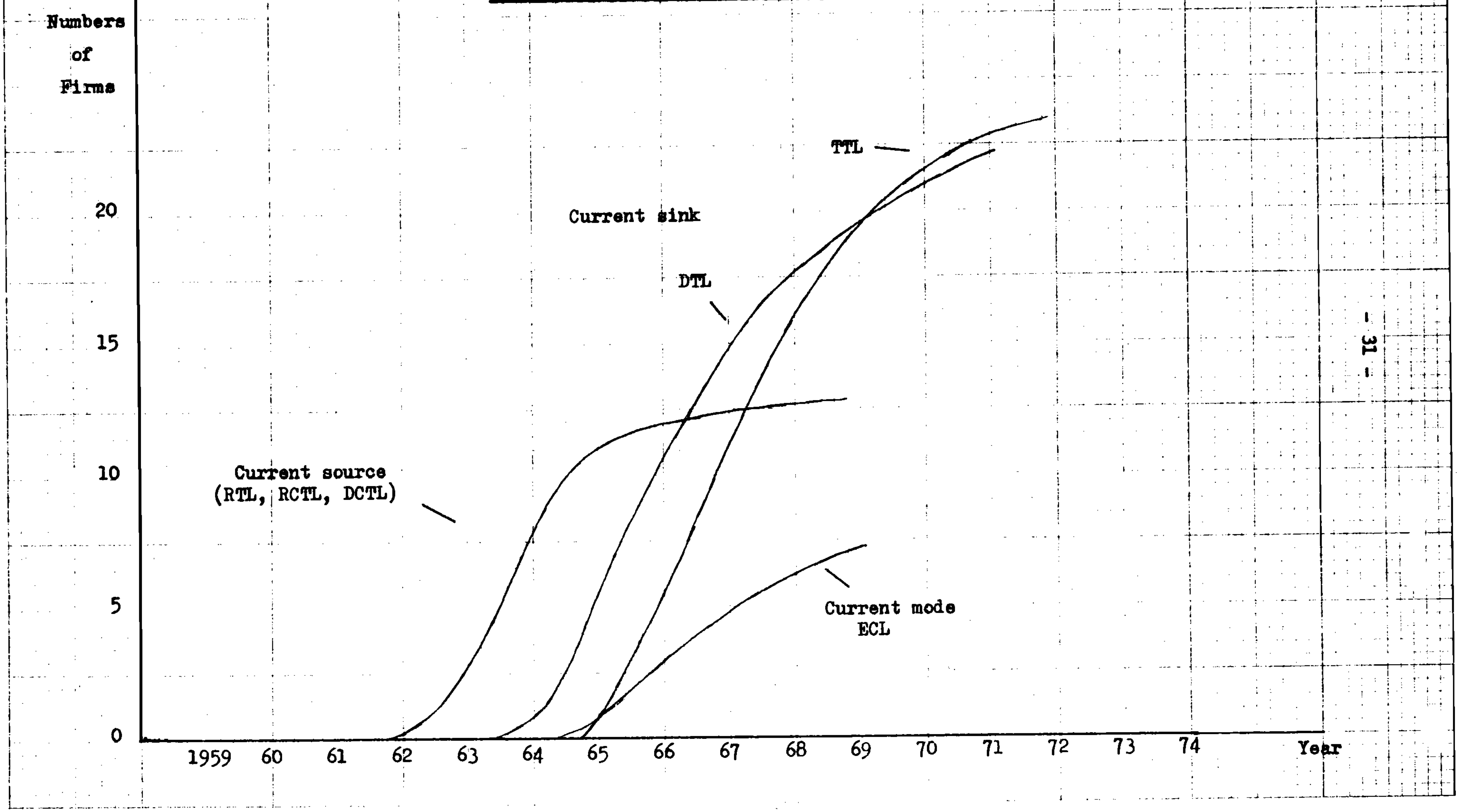
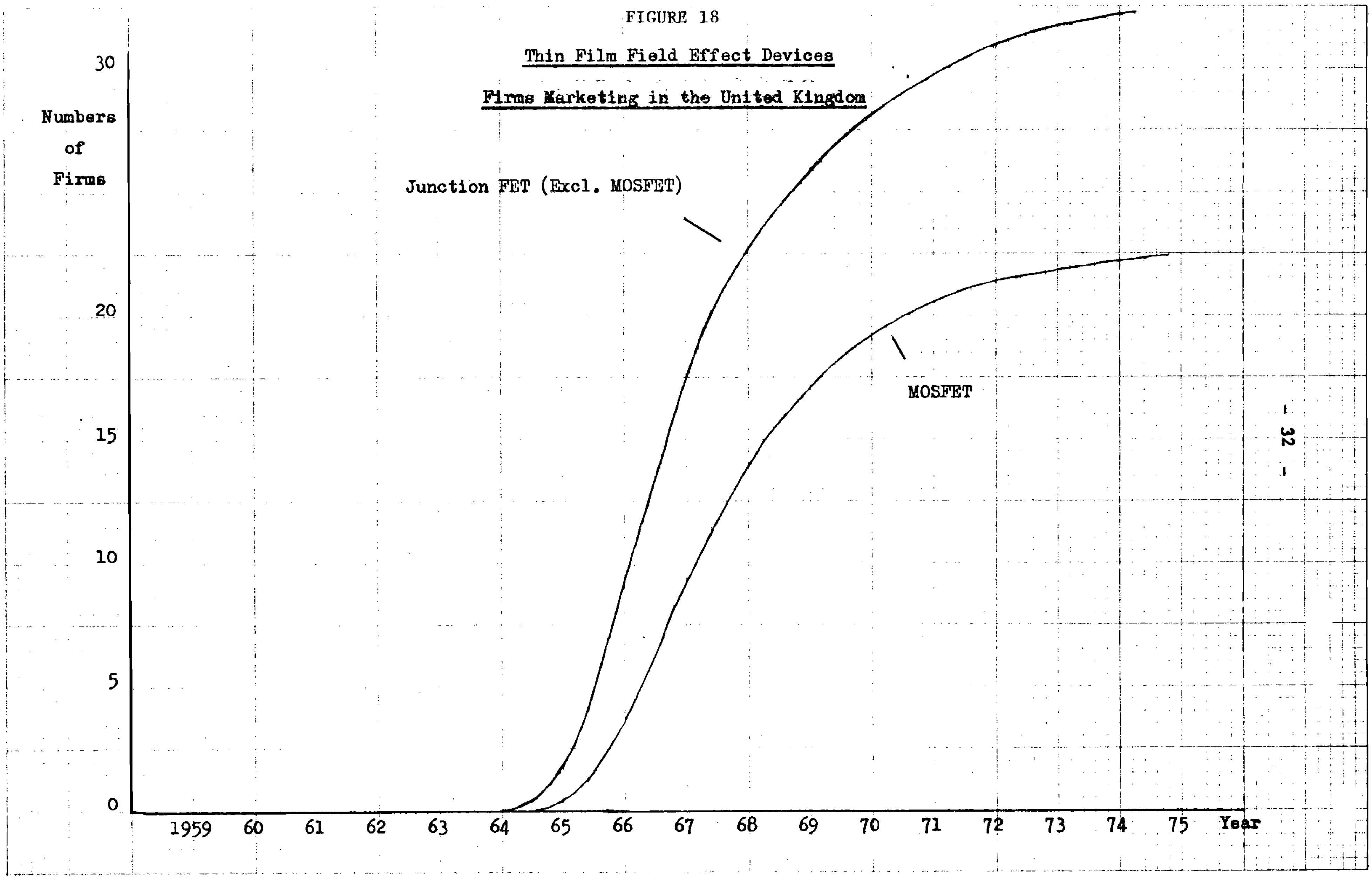


FIGURE 18

Thin Film Field Effect Devices

Firms Marketing in the United Kingdom



skewed to the left. The licencing activities of U.K. firms for integrated circuit technologies associated with these devices are presented in Table 8.

(b) American Firms in the British Market. The uneasy fact of life for British firms is that the pace of product change in their markets has been set by foreign competitors. American firms dominate Europe in electronic technology from computers to semiconductors.[27] Even large established British companies have experienced great difficulty in the struggle to survive.[28] The American challenge has been too great, but why?

The size of the American market relative to European markets is an important factor behind the success of American firms. Figures for 1973 are given in Table 9 demonstrating the comparative sizes of domestic markets. Taken as a whole, the total European market is less than one third that of the United States. The U.K. sales seem tiny in comparison to those of America. This difference in relative sizes of markets plays an important role in explaining the country's slower pace in a highly technological industry.

What is the relationship between technology-product innovation or imitation and the size of market? It can be argued that they are both essential parts of a circular phenomenon. Since the semiconductor industry is one in which economies of scale are of fundamental importance, companies selling to the large American market derive certain economic advantages. The size of the market acts to permit

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[27] An informative commentary is contained in an editorial by Payne (1969), pp. 74-78.

[28] The number of independent wholly owned British manufacturers of semiconductors has dwindled from twelve to three: General Electric Co., Plessey, and Ferranti. Three came under the control of G.E.C.: Associated Electrical Industries, English Electric, and Maconi-Elliot Microelectronics. Two were taken over by foreign firms: Pye by Philip's of the Netherlands, and Brush Crystal by Clevite and then I.T.&T. Three remaining firms are sitting, more or less, on the sidelines: Westinghouse Brake (licensed by Westinghouse (U.S.A.), Lucas, and Thorn (which was never very large in semiconductors).

TABLE 8

Licencing Agreements of American Firms with U.K. Manufacturers of Integrated Circuits

U.K. Manufacturers	Fairchild	Texas Instruments	Westinghouse Electric
English Electric	1968-		
Standard Telephone and Cable* (I.T.&T.)	1964-	1960-63	
Elliot Automation	1964-68		
Associated Semiconductor Manufacturers	1969-		1964-
S.G.S.- Fairchild**	1961-68		
S.G.S.	1968-		
International Rectifier Co.**	1965-		
Texas Instruments*	1966-		
Emihus**	1965-		

The above figures give the years over which licencing agreements between American companies and companies manufacturing in the U.K. have run. * indicates the firm is a U.S. subsidiary, and ** indicates it is a U.S./Foreign joint venture. The principal source of this data was Golding (1971), Table 9-5, p. 304, and Table 9-8, p. 313-15. A general discussion of role played by some of the above agreements in the strategy of individual firms can be found in Payne (1969), pp. 74-78.

TABLE 9

Size of the American Relative to European Markets

1973

	Discrete Semiconductors	Integrated Circuits Total	Bi-polar & Hybrid	MOS
Ratio: U.S. Market/Country Market				
West Germany	8.1	8.0	6.3	28.2
United Kingdom	16.3	13.6	11.1	40.9
France	18.8	17.8	12.3	50.9
Italy	44.7	42.9	33.9	144.2
Netherlands	122.3	62.8	42.0	629.2
Spain	137.5	257.3	203.5	869.1
Switzerland	149.6	104.9	86.5	300.9
Belgium	149.6	133.4	121.4	288.4
Denmark	152.7	292.0	276.8	576.7
Sweden	161.6	122.8	97.5	407.1
Norway	266.7	292.0	247.2	769.0
Finland	295.2	540.3	384.5	3460.5
E.E.C. (incl. U.K.)	3.6	3.2	2.5	6.0
Total Europe	3.2	3.0	2.4	5.5
Size of U.S. Market $mn.	2,213.8	1,080.6	692.1	388.5

The above table defines the relative size of American to the European markets. The British market ranks as second largest in Europe, nevertheless it is considerably smaller than the American, i.e. the American market for discrete devices is 16.3 times that of the British. The above comparisons are based on McGraw Hill data of 180 companies. See Electronics, January 10, 1974.

higher levels of R&D than could be justified by the expected sales and profits in the U.S. market. In the larger American market not only can more be spent on more individual projects, but more can be spent to introduce them into the market at an earlier date. Selling to a large market permits American firms to offer a more advanced product earlier, or a similar product at the same time, but with a greater servicing and reliability record, than firms confined to only the U.K. market.[29] The process is circular since a larger market can promote a faster technological pace, which in turn can produce a larger market by extending the scope of technological application.

To derive a comparable "golden circle" firms located in Europe need the total European market, but this entails its own difficulties. The European market is a highly complex one: two trading blocs, four major languages, fourteen currencies, effective nationalism with customs duties, separate taxes, laws, and non-tariff barriers. The American market is relatively simple: one trading bloc, one language, one currency, and no trade barriers. The simplicity of the American market permits firms to conduct certain aspects of business, such as marketing, without the difficulties experienced in Europe.

As a small counter-balance to the advantages enjoyed by American firms, British companies have relied on the relatively lower salaries of British designers and engineers to reduce the threshold "application area" below levels for comparable markets in America. However, Japanese competition may in the future make greater inroads in selling similar components in the U.K.

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[29] To justify discrete circuits the sales of systems could have been in the thousands, but for integrated circuits they need to be in the tens of thousands. British firms have received less in the way of military/space contracts and smaller government subsidies than the closest American competitors.

4. A Lognormal Model of the Product Cycle

a) Features of the Model. The reason for developing a model of market entries and imitation is to provide estimates of the parameters that describe the way diffusion has occurred. The characteristics of the population over which diffusion takes place are not initially specified, but the parameters of the model can be related to these characteristics by means of regression analysis.

What models can be used? At least four possible types of imitation model, derived from the Gompertz, logistic, normal and lognormal distributions, are potential candidates.[30] All four models can be estimated by ordinary least squares methods or by special formulations. Of the four, the lognormal distribution has the most intuitive appeal since its parameters are allowed greater flexibility in relation to the rate and clustering of introductions. The logistic and Gompertz functions constrain the observations towards a mode of 50 or 37 percent respectively of the upper asymptote. The lognormal distribution can offer these modes as special cases, but can also exhibit a mode of less than 37 percent, or between 37 and 50 percent.[31]

What does the pattern of imitation based on the lognormal model look like? In its cumulative form it produces a sigmoid (or S) curve that is skewed towards the left as observations tend to cluster towards the beginning of the cycle. The model can be described either in terms of density, as in Figure 19, or in terms of cumulative density, as in Figures 20 to 22. Unlike the normal model, the lognormal model assumes that densities of market entry are skewed to the left. The lognormal model may be represented by the following equation:[32]

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[30] Bryant (1966), pp. 193-199.

[31] Aitchison and Brown (1957).

[32] Aitchison and Brown (1957), or Bain (1964).

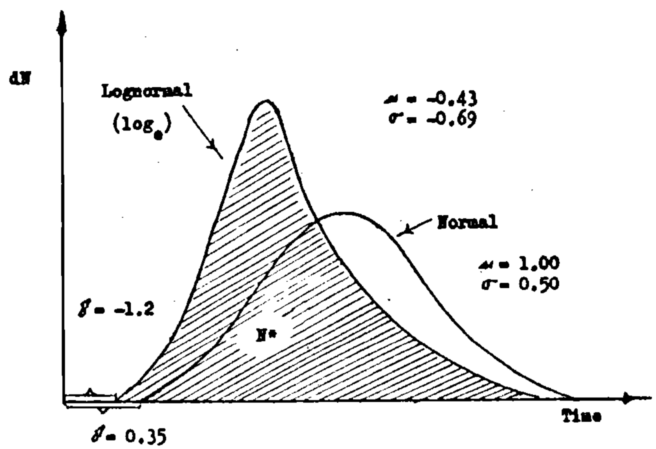


Figure 19 The above diagram illustrates the normal and lognormal distribution functions used in the modelling of technology diffusion. The variable N represents the cummulative number of firms selling a new product, and dN, above, represents the number of firms selling for the first time, i.e. over dt.

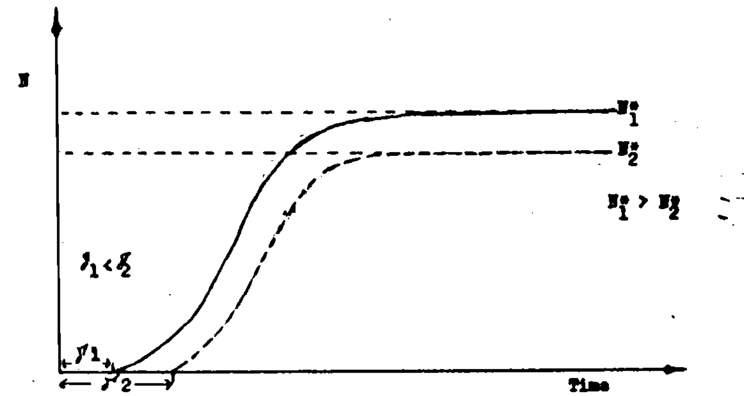


Figure 20 The shape of the cummulative lognormal distribution function is influenced by the values of the variable N and the parameter delta. The effect is illustrated above. Values of the other parameters are assumed constant.

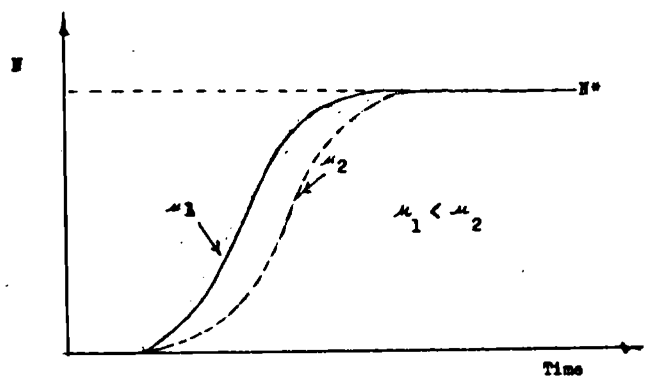


Figure 21 The above diagram illustrates the effect on the shape of the lognormal distribution function of a change in the parameter mu, i.e. μ .

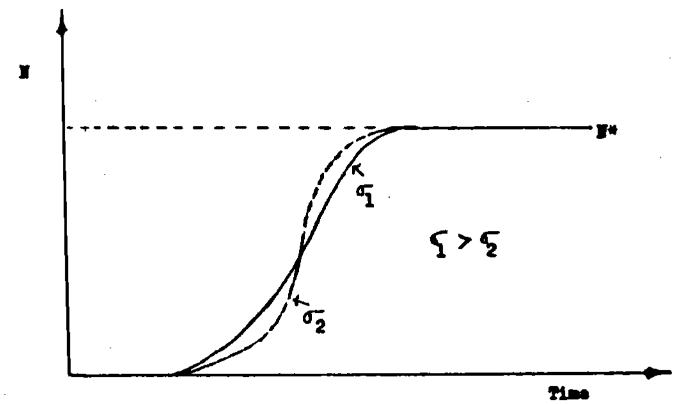


Figure 22 The value of the parameter sigma affects the shape of the bummulative lognormal distribution function as illustrated above.

$$\Lambda(t/\mu,\sigma^2) = {}_0\int^t \frac{1}{(2\pi\sigma^2)^{1/2}\,\theta} \exp\left\{\frac{-1}{2\sigma^2}(\log\theta - \mu^2)\right\} d\theta. \qquad (1a)$$

Whereby:

$$N_t = N^* \left\{\frac{1}{(2\pi\sigma^2)^{1/2}\,\theta} \exp\left[\frac{-1}{2\sigma^2}[\log\theta - \mu]^2\right]\right\} d\theta \qquad (1b)$$

The variable θ may be defined as appropriate.

N is the number of firms which have entered the market up through time t, and N* is the eventual number. The model has two parameters, μ and σ, which may differ from innovation to innovation. Each parameter represents a characteristic of the diffusion process. The parameter μ indicates the average (in natural logarithms) of the number of years required for all firms to enter the market (Figure 21). The parameter σ represents the clustering of entries; a smaller σ indicates a tighter bunching of market entries (Figure 22). Another useful parameter, not part of the above lognormal model, is δ, which measures the time between an innovation's first commercial appearance anywhere and its first appearance in the U.K. (Figure 20). Our analysis of market development will use the cross section experience of semiconductor innovations in an attempt to explain the determinants of N*, δ, μ, and σ.

The model is set up by letting observations of the lag time between an innovation's first commercial appearance anywhere and its introduction by individual firms to the U.K. market, be defined by MS. The model is then estimated by ordinary least squares as follows[32] with MS as the variable θ:

$$\ln MS = \mu + \sigma z + e \qquad (2)$$

[32] Aitchison and Brown (1957), or Bain (1964).

The variable z is defined as normal equivalent deviates; e is the error term (the expected value of e is zero).

b) Application of the Model

What is the pattern of technology-product imitation in the host-country? Estimates of the rate and timing of technology-product introduction in the host country have been made using the lognormal model. The pattern of technology import and imitation via exports, subsidiary production ventures, and host-country licencing and investment are reflected in the estimated parameters of the imitation cycles. Examples of the curves derived are presented in Figures 23 to 27. A statistical summary of the results for the 21 semiconductor innovations is given in Tables 10 and 11. These are generally favorable to the hypothesis that market entries form a sigmoid (or S shaped) cummulative pattern over time. The average $\bar{R}^2$ was greater than 0.8 and for more than half the innovations it was greater than 0.9.

The numbers of firms imitating individual semiconductor innovations has been quite variable. Of the innovations listed, the planar transistor has attracted 37 firms, the largest number for a single innovation. Six of the cycles estimated have more than twenty imitators. Of the rest there are several where the number of firms participating has been as small as one or two: for example, the grown junction transistors (superseded by the alloy process) and germanium diffused transistors (superseded by silicon devices using a similar process).

The pattern of technology imitation has also shown variability over the semiconductor innovations covered in this study. Consider the values of δ, μ, and σ as they are presented in Tables 10 and 11. The range of variation in the case of δ extends from zero years, indicating innovation in the United Kingdom, to 6.6 years. The variation in μ extends from 1.3 years to 9.2 years. Similarly σ, over the same innovations, has been 1.3 years at its lowest and 5.5 years at its highest. The "average" imitation cycle for the industry, derived from the

FIGURE 23

Planar Transistor (si)

Firms Marketing in the U.K.

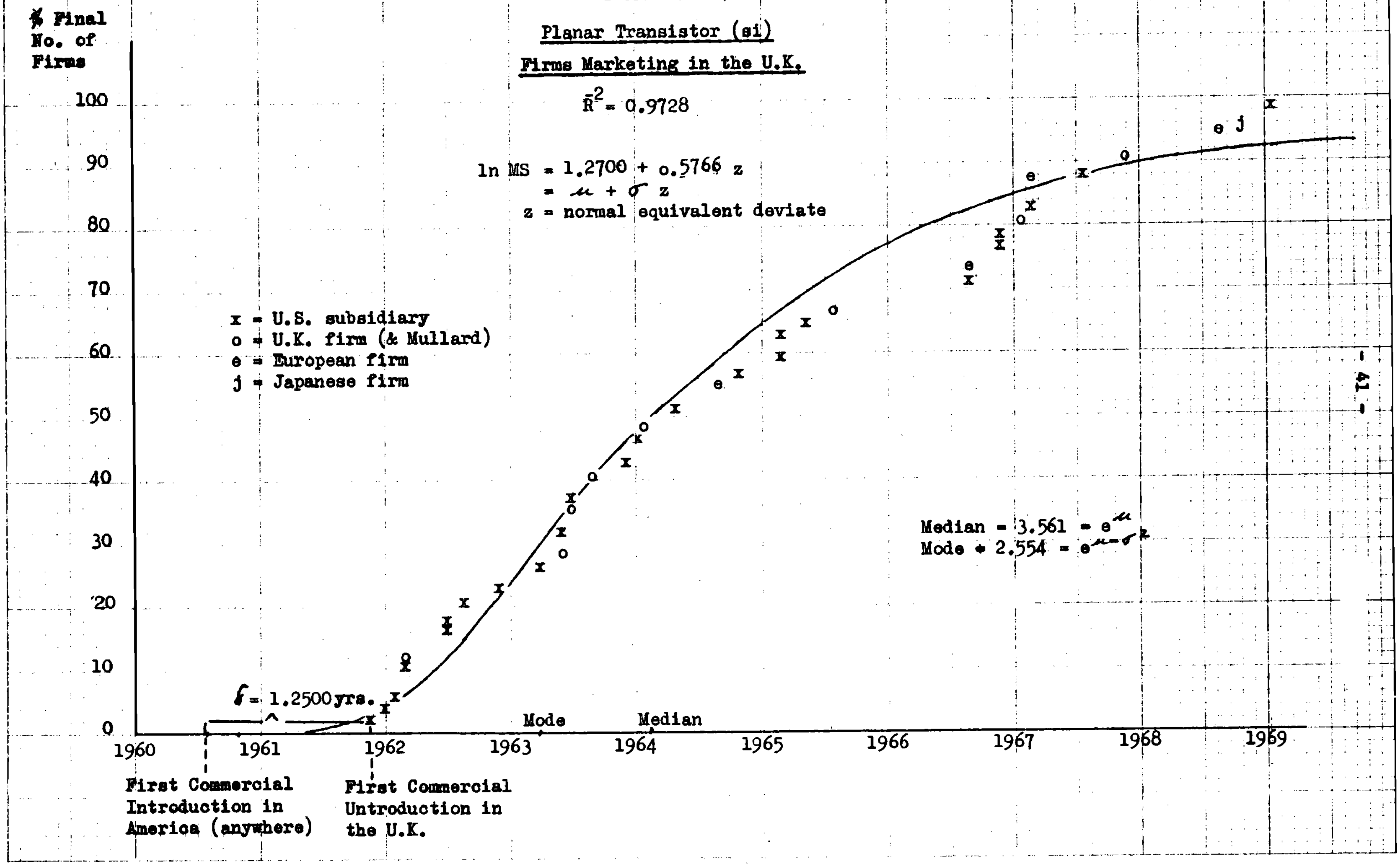


FIGURE 24

Alloy Junction Transistor (ge)

Firms Marketing in the U.K.

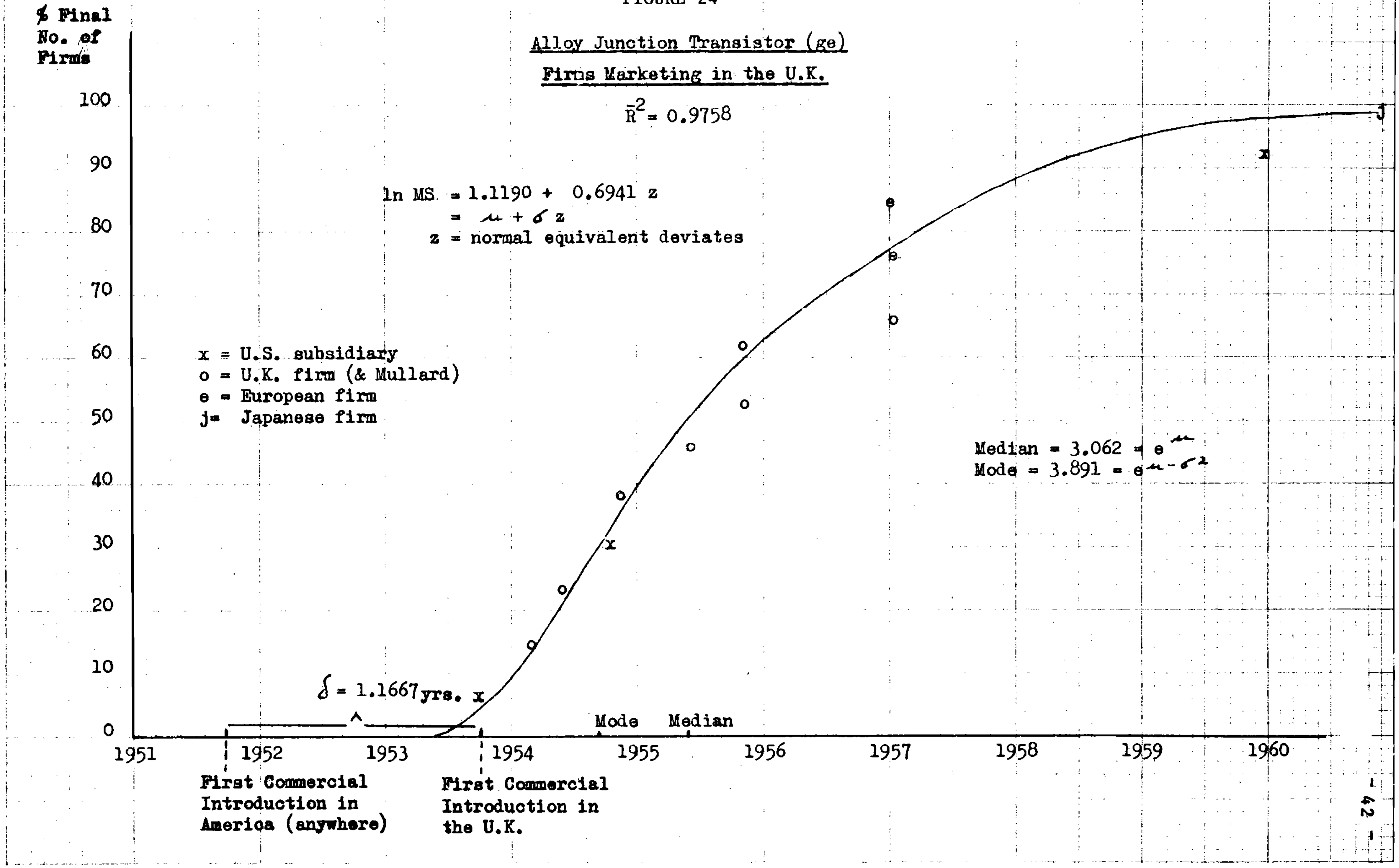


FIGURE 25

Diffused 'Mesa' Transistor (ge/si)

Firms Marketing in the U.K.

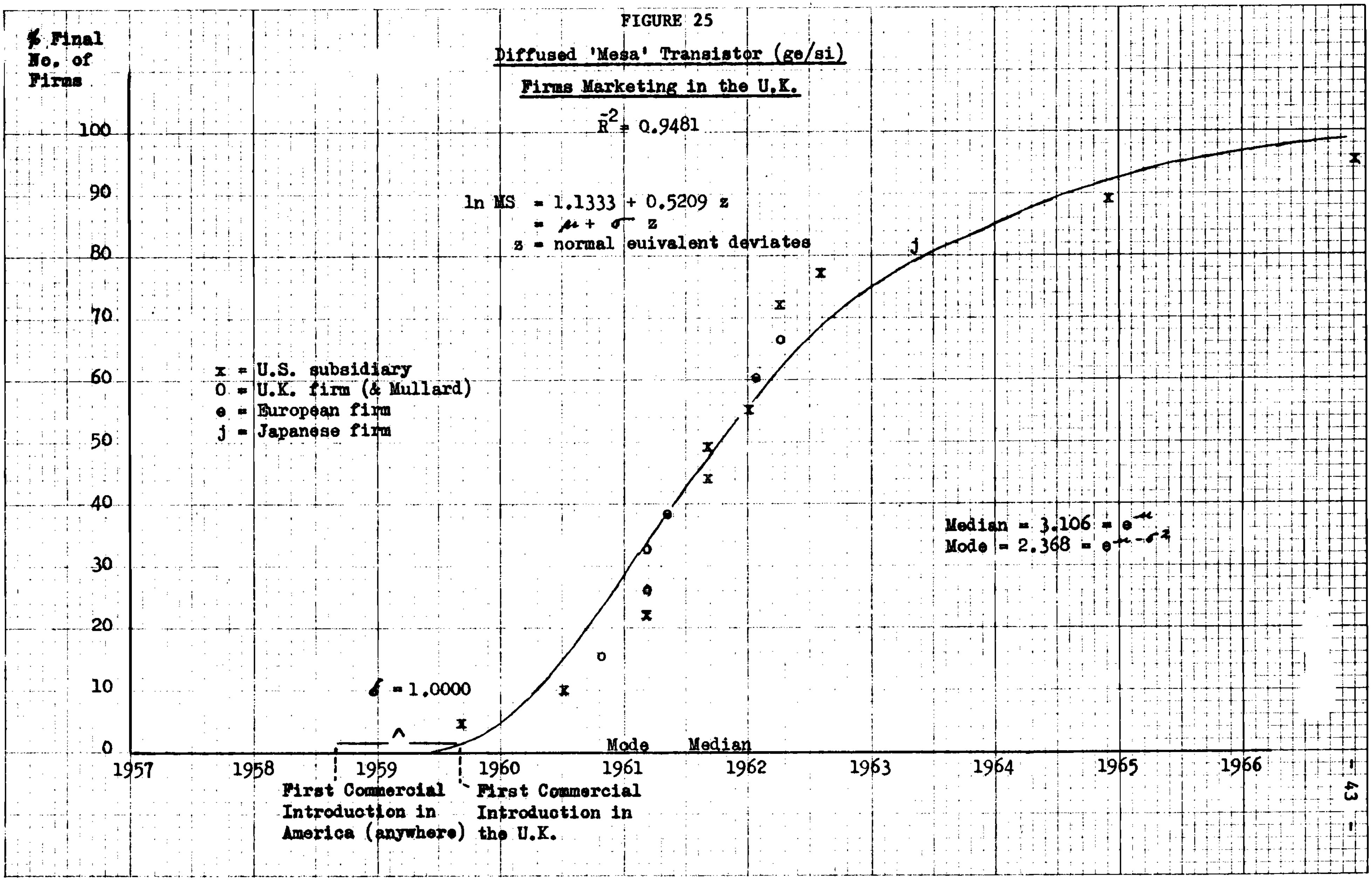
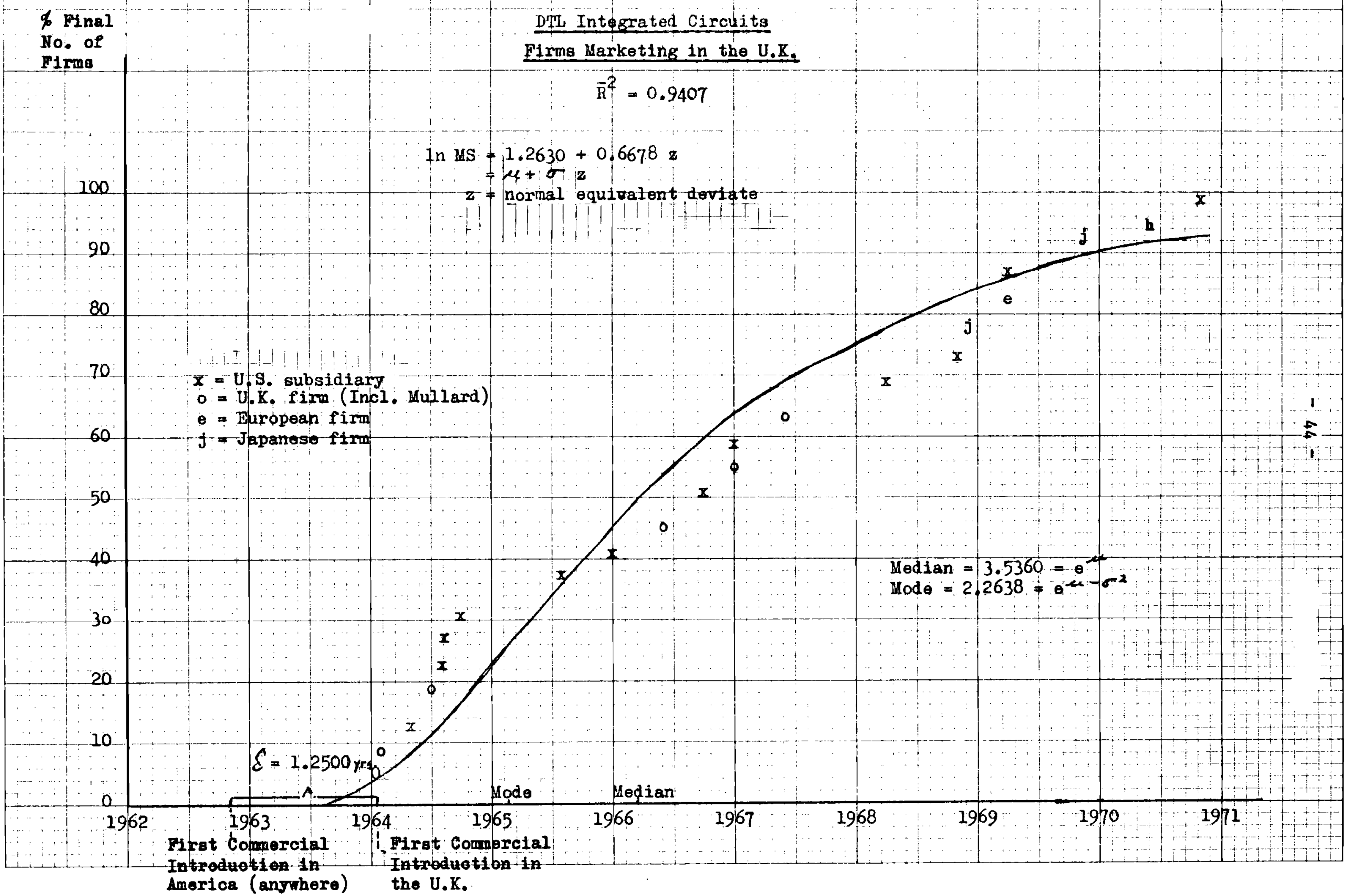


FIGURE 26


DTL Integrated Circuits
Firms Marketing in the U.K.
$\bar{R}^2 = 0.9407$
$\ln MS = 1.2630 + 0.6678\,z$
$= \mu + \sigma\,z$
z = normal equivalent deviate
% Final No. of Firms
0
10
20
30
40
50
60
70
80
90
100
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
x = U.S. subsidiary
o = U.K. firm (Incl. Mullard)
e = European firm
j = Japanese firm
$\delta = 1.2500$ yrs.
Mode
Median
Median = $3.5360 = e^{\mu}$
Mode = $2.2638 = e^{\mu - \sigma^2}$
First Commercial Introduction in America (anywhere)
First Commercial Introduction in the U.K.

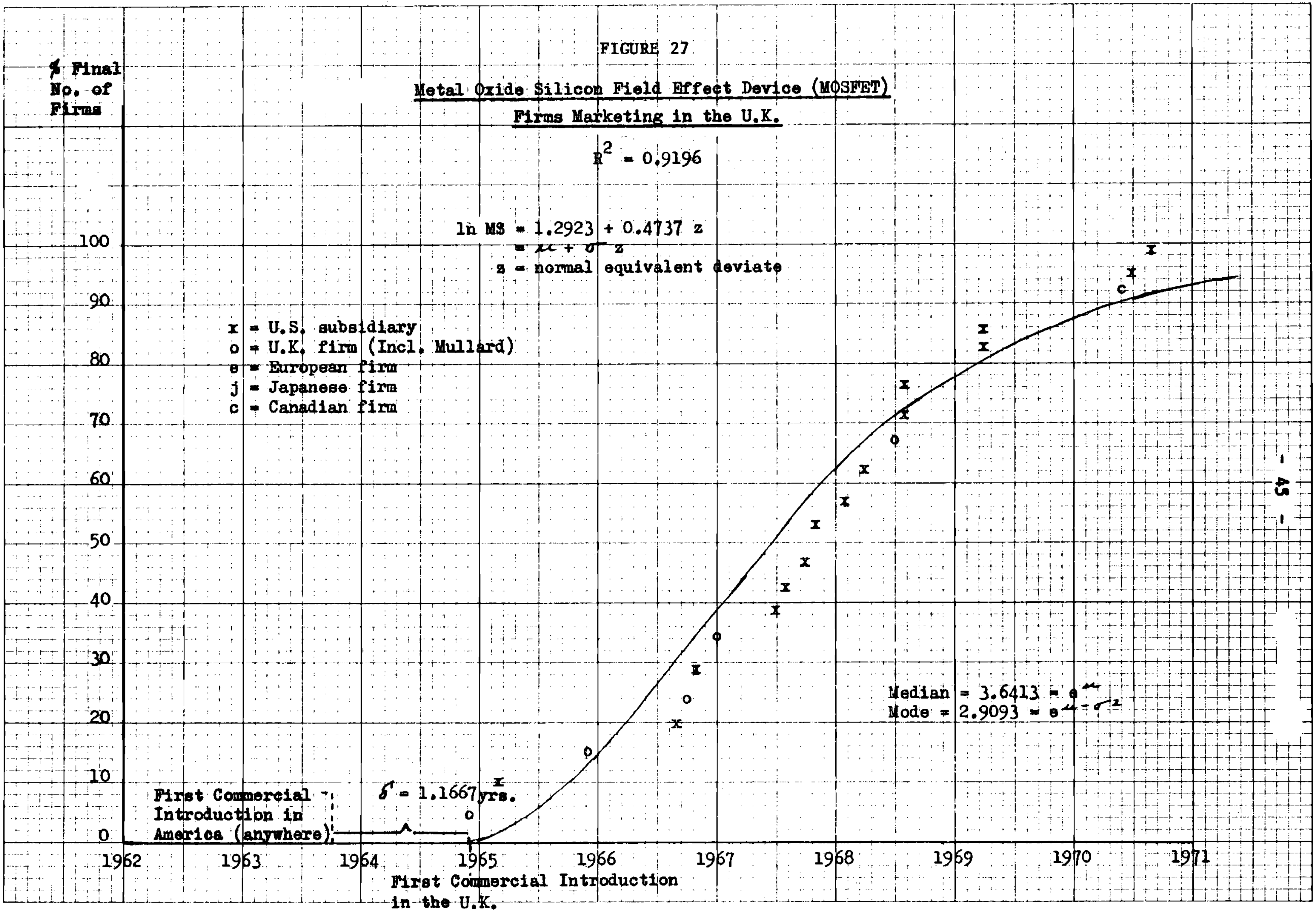


FIGURE 27
Metal Oxide Silicon Field Effect Device (MOSFET)
Firms Marketing in the U.K.
$R^2 = 0.9196$
$\ln MS = 1.2923 + 0.4737\ z$
$= \mu + \sigma\ z$
z = normal equivalent deviate
x = U.S. subsidiary
o = U.K. firm (Incl. Mullard)
e = European firm
j = Japanese firm
c = Canadian firm
% Final No. of Firms
100
90
80
70
60
50
40
30
20
10
0
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
First Commercial Introduction in America (anywhere)
$\delta = 1.1667$ yrs.
First Commercial Introduction in the U.K.
Median = 3.6413 = e^{μ}
Mode = 2.9093 = $e^{\mu - \sigma^2}$

TABLE 10

Semiconductor Discrete Devices

Parameter Estimates for the Lognormal Model

Transistor Devices	N*	$\hat{\delta}$ Yrs.	$\hat{\mu}$ ln yrs.	$\hat{\sigma}$ ln yrs.	$\bar{R}^2$
Point contact transistor (ge)	5	1.2500	0.6456	0.5695	0.8980
Grown junction transistor (ge)	2	4.8333	-	-	-
Alloy Junction transistor (ge)	13	1.1667	1.0653	0.5485	0.9728
Surface barrier transistor (ge/si)	2	3.7500	-	-	-
Grown junction transistor (si)	1	3.8333	-	-	-
Diffused transistor (ge)	2	1.6667	-	-	-
Diffused transistor (si)	6	1.0000	0.5298	0.4756	0.8227
Diffused mesa transistor (ge/si)	17	1.0000	1.1333	0.5209	0.9481
Epitaxial transistors (devices)	25	0.6667	0.8785	0.8258	0.9648
Planar transistors (si)	37	1.2500	1.2700	0.5766	0.9728
JFET	32	..	1.1790	0.6987	0.6243
Other Discrete Devices					
Alloy junction diode (si)	10	3.6667	1.1190	0.6941	0.9758
Power rectifier (ge)	4	1.4167	-	-	-
Power rectifier (si)	16	2.3333	1.4225	0.3469	0.7937
Zener diode (si)	12	2.0833	1.7770	0.6925	0.9776
Thyristor (SCR)	16	1.1667	5.0420	3.3950	0.9292
Tunnel diode (ge/si/ga as)	15	2.2500	1.5040	0.5196	0.9091
Unijunction transistor	5	6.5833	2.2140	0.2331	0.7299
Varactor diode	18	4.5833	1.5320	0.6323	0.9115
Light emitting diode	12	..	0.9411	1.3750	0.7773
Schockly (four_layer) diodes	7	-	-	-	-
Gunn diodes	3	..	-	-	-
Schottky-barrier diodes	9	..	0.1221	1.6980	0.8815
Triacs	4	-	-	-	-

TABLE 11

Semiconductor Integrated Circuit Devices

Parameter Estimates for the Lognormal Model

Bi-polar ICs	N^*	$\hat{\gamma}$ Yrs.	$\hat{\mu}$ ln yrs.	$\hat{\sigma}$ ln yrs.	$\bar{R}^2$
DCTL (Direct-coupled transistor logic) RTL (Resistor transistor logic)	13	0.4167	0.6236	0.9733	0.9197
DTL (Diode transistor logic)	23	1.2500	1.2630	0.6678	0.9407
T^2L (Transistor transistor logic)	24	1.4167	1.2699	0.4919	0.9807
TSL (Tristate TTL)	1	-	-	-	-
Schottky-clamped TTL	2	-	-	-	-
ECL (Emitter coupled logic)	8	1.8333	1.5410	0.3956	0.5968
EFL (Emitter follower logic)	2	-	-	-	-
CDI (Collector diffusion isolation)					
Uni-polar ICs					
p-MOS	22	1.1666	1.2923	0.4737	0.9196
n-MOS	4+	-	-	-	-
Complementary MOS (CMOS)	4	-	-	-	-
Silicon-gate MOS	5		-	-	-
Ion-implanted MOS	2		-	-	-
Silicon nitride MOS (MNOS)	4		-	-	-
Refractory MOS (RMOS)	1		-	-	-
Field shield MOS					
Self-aligned thick oxide MOS (SATO)					
Double-diffused MOS (DMOS)					
Silicon-on-sapphire MOS (SOS)					
Silicon on spinel MOS					
CDI MOS					

20 selected innovations, has the following characteristics: it takes 1.4 years after the innovation in America before the product is first made in the United Kingdom; 50% of the firms imitate after 3.2 years (reflected in the average u of 1.17) and the standard deviation around the mean is 1.9 years (reflected in the average sigma of 0.67).

In the analysis that follows important determinants of the pattern of diffusion associated with N^*, δ, μ, and σ are considered in relation to the changing structure of the U.K. semiconductor industry.

5. Underlying Determinants of the Product Cycle Model

a) The Population of Firms

The semiconductor industry, unlike any other, operates on a very compressed time scale, with some product life cycles evaluated in terms of months rather than years.[33] The scope of application for new products has also been remarkable. However, the composition of end uses in America differs from the composition in Britain and Europe. The segment of new semiconductor and integrated circuit technology applied to military and government end uses is proportionately smaller in Britain and Europe, while the segment applied to consumer electronics has been proportionately larger.[34]

Market size partly determines the number of firms that can operate profitably, depending on other factors such as scale economies. Since the American market developed ahead of the British market, it is reasonable to suppose that expectations concerning the size of the British market would be influenced by

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[33] G. Penisten in Electronics/Management Center (1969).

[34] For example, in 1970 products for consumer end use, i.e. in T.V.'s, appliances, etc., were 20.9% of the total European semiconductor market. This figure can be compared to the U.S. where it was 15%. See annual McGraw-Hill surveys in Electronics.

the experience of the American market. In addition, the number of firms producing in the source country may influence the number of firms which enter the British market, since each foreign firm is a potential transnational producer or licensor.

The number of firms that come to market a new product technology (N*) may depend on the number of firms with previous experience in the host market (Ne), as can be seen in the following regression:

$$N^* = \underset{(-0.68)}{-0.95} + \underset{(13.60)}{1.44\,Ne} \qquad \bar{R}^2 = 0.9 \qquad (3)$$

(Number in parentheses are t-values)

The association is sufficiently strong to accept the importance of previous experience in determining the ultimate number of market participants. But the number of new market entries tends to be in the order of 40 percent of the number of experienced firms entering. Thus, the fact that many experienced firms enter the market does not particularly discourage entries by firms on the fringe or outside the industry.

The effect of market size and prior experience on the pattern of technology introduction in the host country was analyzed by regressing the number of firms marketing in the U.K., N*, against the current (1973, $ mn.) sales in America, S^a, and the number of firms marketing each product in the United States, N^a. The regression was performed for 20 technology products listed except the thyristor.[35]

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[35]Several small adjustments were made in the fitures to account for the fact that market sales of some earlier products are currently nil. This was done using figures from American trade journals and sellers lists. The rank correlation for (N^*, S^a) was +.72, and for (N^*, N^a) was +.59.

The results were better when S^a and N^a were not included in the same estimated equation as follows:

$$N^* = \underset{(-1.67)}{-2.208} + \underset{(+2.51)}{.103}\ N^a + \underset{(+12.41)}{1.313}\ N^e \qquad \bar{R}^2 = 0.93 \qquad (4a)$$

and,

$$N^* = 11.222 + \underset{(4.42)}{0.068}\ S^a. \qquad \bar{R}^2 = 0.68 \qquad (4b)$$

Of the two independent variables, the magnitude of U.S. sales, S^a, appeared more closely associated with total eventual participation in the U.K. market, however, N^a performed better with N^e.

b) The United Kingdom Lag

What has been the record of British-based companies in introducing new semiconductor technology over the period 1950-75? From an analysis of 12 major technology-product innovations associated with transistors and integrated circuits, the following general observations were made:[36]

> 1) The lag between the innovation's introduction in America and the average time of the first three introductions in the United Kingdom by British-based firms has remained roughly the same over the period, and has been about two years.
>
> 2) The speed of response by the first three U.K. firms alone relative to the first three American firms marketing in the U.K. has marginally improved, when compared to late 1950s and early 1960s. This is true regardless of the form of transnational activity undertaken by the American firms.

[35a] Since S^a and N^e were not independent of each other they are not included in the same equation. The simple correlation coefficient (S^a, N^e) was +.78.

[36] The twelve technology innovations based on major processing or design improvements are: the point contact transistor, alloy (si) transistor, diffused transistor, mesa devices, field effect devices, planar transistors, epitaxial devices, RTL (or DCTL) logic devices, DTL logic devices, ECL logic devices, TTL logic devices, and p-Mos devices.

3) The follow-through by British based firms in terms of the variety of competitive devices using the product-technology has continuously dropped relative to American firms. Although British firms are responding sooner to the American challenge, their competition in terms of relative numbers of products based on the innovations (and in terms of the numbers of firms marketing in the U.K.) has fallen.

The comparisons in terms of imitation lags are given in Table 12. The figures give the average time between the innovation's first commercial appearance in America and its marketing in the United Kingdom by the first three U.K.-based and U.S.-based firms respectively.

c) <u>The State-of-the-Art Introduction</u>

The state-of-the-art introduction to the UK market represents the first entry there whether innovation occurs in America or elsewhere, e.g. Japan in the tunnel diode case or the UK in the case of light emitting diodes. The parameter δ provides a measure of the UK innovation lag for state-of-the-art products. The technical competence required to give this kind of advanced technology is probably contained within a group of firms rather than any single firm. It consists not only in the ability to innovate, but also in the capacity to shorten the lead time from idea to prototype innovation and the lag time between innovation in a foreign market and introduction in the host-country market, such as reflected in the values of the parameter delta, δ.

The competitive factors behind state-of-the-art (STA) introduction of new technology are important to our analysis. Their impact is also described in a discussion falling in section d of competitive pressure and the clustering of introductions. The study of innovating firms shows that the group of firms responsible for state-of-the-art technology may differ from that group of firms responsive to competitive pressure and imitating more than leading. For example, Texas Instruments, a leading semiconductor firm, was responsible for many STA introductions with leading technology in the late 50's and early 60's. When

TABLE 12

Imitation Lags for U.S.-Based and U.S.-Based Firms

Period	U.K. Based Firms Years	U.S. Based Firms Years	Ratio: U.K./U.S.
1950-1958 (4 devices)	2.06	3.56*	0.58
1959-1963 (4 devices)	2.03	1.56	1.30
1964-1968 (4 IC devices)	2.83	2.17	1.30
1969-1975 (1 IC device)	2.08	1.89	1.10

Average of first three firms.

*Participation in the U.K. transistor market by American firms was just beginning, and was hesitant during these years.

its sales became very sizable the company tended more to respond to rather than initiate new technology areas. Another leading firm, Fairchild, pulled out of the UK, relinquishing its STA reputation there. Inevitably, as market size increases, a single firm cannot hope to be STA in all technologies, nor are the motivations of the leader of the previous technology necessarily the same in its participation in successive technologies. With increased competition a large firm may become more defensive than aggressive in its product strategy.

Associated with the state-of-the-art product introduction may be competitive factors, which act to reduce δ. These characteristically tend to push the innovator into a new technology earlier than profit maximization on the superseded technology would demand. Generally this can be expected to entail increased r and d outlays for all firms along the lines described in the earlier discussion of the time-cost trade-offs of market entry (Section 3a), and come to include not only the innovator, but also a large proportion of the whole population of market entrants. As the profitability of deferred or late entry diminishes, the cost of profitable entry increases, since firms, to make a competitive entry, need to step up their individual programmes of product research and market promotion. The STA introduction situation may be in such a way also reflected in an association between δ and the factors that influence the clustering of introductions. As already mentioned, competitive pressure may influence the timing and participation in STA product introductions in a different manner from that in imitational or delayed entries. Firms sometimes prefer not to innovate, but to follow a wait-and-see strategy. A large population of such firms produces a tendency for clustering of introductions. Technology transfer from America increases the pressure on U.K.-based firms, carrying out their own research and development, to enter quickly.

The study of the competitive factors affecting the timing of STA product introductions and the clustering of competitive market entries was based on six variables describing the population of eventual U.K. market entrants whether British, American, or other foreign based. The model tests for association between numbers of entrants and variations in the value of δ over the 20 innovations. It includes the variable N*, the total eventual number of participants, and a variable giving the number of peripheral or new entrants NE. The other variables were defined by the size and location of r and d activity RD, previous host country market experience Ne, the size of market sales either in the source or host country SS, and the licensing of technology through advanced U.S.-based companies LT. In defining the groups of firms a cutoff for r and d in the UK of £200,000 towards the relevant technology was used, i.e. a firm spending more in the U.K. was included in RD, others not. The cut-off of 5% of U.S. or U.K. market sales for SS was applied. Previous market experience meant that firms had marketed products of an earlier major technology in the U.K. The variable for licensing of U.S. technology was numbers of UK based licencees, e.g. of Bell Labs, Fairchild.

Owing to the fact that five of the variables used in the hypothesis testing represented subgroups of the firms in N* it was of interest to see whether any of these variables showed a stronger association with δ. The regression analysis determined that the number of firms carrying out r and d in the UK tended to be more strongly related to reductions in δ than N*:

$$\underset{}{\delta} = \underset{(+3.16)}{+3.35} - \underset{(-.97)}{0.042\,N^*} - \underset{(-1.025)}{.216\,RD} \quad \bar{R}^2 = 0.04 \qquad (5a)$$

The best explanatory combination of variables in terms of independence and significance included RD and NE, the number of new peripheral entrants:

$$\delta = +3.29 - \underset{(-1.28)}{.26}\ RD - \underset{(-1.03)}{.10}\ NE \qquad \bar{R}^2 = 0.05 \qquad (5b)$$

The association between N* and Ne has already been illustrated through equation (3). The number of experienced firms was more closely related to reductions in δ than N*:

$$\delta = \underset{(+3.22)}{+2.66} - \underset{(-1.3)}{.816}\ Ne \qquad \bar{R}^2 = 0.03 \qquad (5c)$$

These results (5a,b,c) tended to confirm the existence of competitive pressure acting to push forward the timing of STA introduction reducing δ. The parameters and correlation coefficients were of the right sign (-). The consistency of the results, as judged by the significance of the t statistic values, suggests that the actual coefficients estimated should be treated with caution. A slightly more consistent pattern of association between parameter values and some competitive factors is found in the case of the clustering of introductions.

d) The Clustering of Introductions

Competive pressure, especially amongst larger established firms, may result in a clustered timing of introductions. Firms that have previously maintained a leading status within the market may seek to hold and extend that lead. At the very least, they may try to keep up with the new technologies. The effect of competitive pressure connected with activities of larger experienced firms can be established by examining the association between numbers of large or advanced firms (or their proportion of the total eventual number of firms) entering the technology markets and the clustering of introductions, as reflected in the parameter sigma star σ*, i.e. e^{σ} transforming σ to its antilog or linear base.

The greater the competitive pressure between firms, as may occur within specific groups of rival companies, the smaller would we expect to find the value of σ*. As evidence of intense competition, a negative association between σ^* and the group size is important. On the other hand, a positive association between the numbers of eventual market entrants and σ^* is evidence of the absence of competitive pressure. An interpretation of competitive pressure is slightly different when the make-up of the eventual population of entering firms is examined. Then the intensity of competitive pressure is proposed to be associated with the proportional representation of companies, within the total participant group, that have specific characteristics. An eventual population with a higher proportion of a particular type of firm may be examined for evidence of more intense competitive entry activity. In the case of peripheral entry the absence of competition may be an important inducement. We may expect to find a positive association between pheripheral entry and clustering of introductions. The fact of pheripheral entry of itself probably means a lengthening of the time-spread of initial participation.

One result of the analysis was that the variable representing numbers of firms entering with large market sales, SS, tended to be fractionally more significant than the variables N* and Ne. Also while RD had reflected a stronger association in the case of δ it was less important in determining values of σ^*. A similar picture emerged for N* and Ne, which although contributing marginally to increases in the intensity of competition, i.e. negative association with σ^*, tended to spread out entry more than SS and LT. Variations in the number of UK licencees of American technology had greatest effect in reducing σ^* and was significant at 5%:

$$\delta^* = 2.838 - \underset{(-.134)}{.0033\,N^*} - \underset{(-2.17)}{.1613\,LT} \qquad \bar{R}^2 = 0.14 \qquad (6a)$$

Peripheral entry measured by NE/N* was positively associated with σ^* with the following result:

$$\sigma^* = 2.833 - \underset{(-.45)}{.068\,SS} - \underset{(-1.72)}{.141\,LT} + \underset{(+.61)}{.99\,NE/N^*} \qquad \bar{R}^2 = 0.12 \qquad (6b)$$

The licencing of American technology by British firms tended to bring about a greater clustering of introductions while pheripheral entry was greatest where competitive pressure of this type had less effect.

e) The Peak-Entry Time

Use of the lognormal modal means that we can calculate the peak-entry or modal times for each imitation cycle. This is done using the two parameters μ and σ which are part of the formulation giving modal time:

$$\text{Mode} = e^{\mu - \sigma^2} \tag{7}$$

In our analysis up to this point little mention has been made of the parameter μ, the coefficient average of natural log times of market entry, ln MS, of equation (2). By transforming μ from ln years to years we create we create a parameter μ^* which is suitable for linear regression.[37] The parameter μ^* tells us when one half the eventual number of firms have participated in the market. The mode gives us the point at which market entry is most rapid. Both variables describe important aspects of the imitation cycle.

The eventual number of market entrants N* was found to have very little association with μ^* and even Ne performed poorly:

$$\underset{(4.09)}{\mu^* = 4.03} - \underset{(-.46)}{0.034\ \text{Ne}} \qquad \bar{R}^2 = 0.01 \tag{8a}$$

[37]The variable μ^* is simply e^{μ}. This transformation creates a variable that when used in regression analysis gives a linear relationship based on years rather than ln years. It is also the median of our lognormal distribution showing the point where 50% of entries have taken place.

However, some of the experienced firms may have greater relevance than others. Can an association be found if only the very active leaders are included? To obtain such a group those firms that have five or more product introductions in the first five places, as indicated in Table 5, are selected. The number of such firms in the market prior to the innovation is represented by Ne*. Regressing Ne* on μ* we find:

$$\mu^* = \underset{(4.616)}{+5.87} - \underset{(-1.876)}{0.47}\ Ne^* \qquad \bar{R}^2 = 0.12 \qquad (8b)$$

While the association is not very consistent, the coefficient of the independent variable is larger and more significant than for Ne. This suggests that the number of highly innovative firms entering may have some marginal effect in reducing μ*. A similar result is obtained by taking as independent variable the proportion of firms carrying out r and d in the UK:

$$\mu^* = \underset{(6.47)}{+4.62} - \underset{(-1.675)}{2.85}\ RD/N^* \qquad \bar{R}^2 = 0.09 \qquad (8c)$$

Again the presence of such firms acts to reduce the median time.

The determination of peak-entry time is only partial given the six independent variables of the analysis. The following result was derived:

$$\text{Mode} = \underset{(+3.52)}{+4.322} - \underset{(-1.34)}{.322}\ RD - \underset{(-.55)}{0.066}\ NE \qquad \bar{R}^2 = 0.01 \qquad (9)$$

The contribution towards a reduction in the modal time varied most consistently with RD. New entrants had relatively small association with peak-entry times.

Combining the results of the study of the STA introduction, the clustering of innovations and peak entry timing, it has been observed that competitive pressure has had the effect of hastening the commercialization of a new commodity. All four factors mentioned, licencing, r and d, sales size, and previous experience, have a marginal influence on the speed at which market entry takes place. The timing determined by the four factors differs, owing to the different circumstances and motivations that characterize the groups of firms to which the four factors apply, or which make up the final composition of market entries.

The licensing of new technology hastens market entry, but its principal effect is in the clustering of introductions. The lead time of product innovation and the lag time between introduction in an American market and then the UK are not necessarily reduced by licensing which may have had an extending effect. Potential licensees perhaps have waited for the technology and when they have received it there has been considerable competition within the licensee group.

The size of sales has had a similar effect on product introductions as licensing. Firms with vested interests in existing large markets and defraying related investment have perhaps tended not to race into state-of-the-art technology. Rivalry amongst such firms when it comes, however, has been fierce.

The effect of location and size of r and d facilities has been to bring about state-of-the-art introduction in the UK earlier than it would otherwise have been. Nevertheless, the competition amongst such firms has not meant a strong clustering of introductions. A similar story is associated with previous market experience. It would appear that some prior knowledge of the market has helped firms to be state-of-the-art if they so wished. They could also delay introduction since size of r and d and market knowledge have been important factors in a deliberately delayed market entry, i.e. the effect of competitive pressure being not nearly as great on these groups of firms, e.g. of Mullard and Texas Instruments, that they could not recover some lost ground.

6. The Place of Individual Firms in the Product Cycle

a) Introduction Lags and Market Participation

What factors determine the speed with which individual firms respond to new technology products? In the following analysis the lags and places of individual firms are examined. Not all firms pursue the same technology or product-market strategy.[38] Nevertheless, it is possible to assess the placing and lags of broad groups and individual companies in response to new technological opportunities. We begin with British-based companies and compare them with American competitors. The latter are then considered and the lags of various forms of foreign ownership compared. The analysis is primarily based on the results of 41 companies marketing the 20 product innovations in the United Kingdom over the 1950-75 period.[39]

A common assumption is that highly innovative (or imitative) firms that are familiar with the local market will tend to have shorter imitation lags. The firm's average lag time for all products, T (in years measured from the date of first world appearance of the product) was therefore used as the dependent variable against which was regressed F, the frequency of imitative activity, measured by the number of the 20 technology products listed that have been marketed in the host country by the firm from its own production, and A, the length of time that the firm has been selling in the United Kingdom. The results show that a firm's active participation in new technology products and the length of time that it has operated in the host country are associated with a reduction in its average lag time.

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[38] "Corporate Strategy in the Electronics Industry," (Paper presented at the WESCON Conference), Vol. 12 (2) 1966.

[39] The 20 innovations are listed in footnote 12. The thyrister and the Schottky-barrier diode are excluded from the present analysis.

$$T \text{ (in years)} = 5.26 \underset{(-2.87)}{-\ .13\,F} \underset{(-0.69)}{-\ .03\,A} \qquad \bar{R}^2 = 0.27 \qquad (11)$$

While the coefficient of A is not significant at the 5% level, it has the correct sign. The reduction in lag time, partially determined by these two factors, is consistent with the "learning by doing" hypothesis.

An analysis of the fifteen firms with largest sales in the UK semiconductor industry in 1972 suggests that large sales are associated with individual company performance in introducing new technology products. The sales of the companies in the host-country market, S_h, are regressed against an index W, that represents an aggregated record of each company's relative timing of product introductions over the twenty semiconductor technologies. The index W, as illustrated in Table 5, is compiled by giving state-of-the-art introductions a value of 12, and subsequent positions values declining from 11 to 1, with the 12th and following positions all having the value, 1, aggregated as follows for the ith company:

$$W_i = w_{1i} + \dots + w_{20i} \qquad (12)$$

The results of the regression are given below:

$$S_h = -0.95 + \underset{(5.88)}{0.0863\,W} \qquad \bar{R}^2 = 0.54 \qquad (13)$$

Evidently higher sales are associated with the early introduction of new product or process technology.

b) The Experience of American and British Firms

All British firms have been dependent, in greater or smaller degree, on the exchange of know-how from American sources through licensing agreements. More recently several have attempted to pursue an independent approach to technology development, but as already explained, this entails high costs, and longer lead times. An argument in favor of home-grown technology is based on the long-term considerations of individual firms in their expectations concerning world markets. Some technology is more easily developed given the expectations for market size of companies based in Britain.[40] Individual companies have had to make trade-offs between volume (off-the-shelf) or custom designed production, as well as scale of integration,[41] all the time aware of what potential competition could mean to their future operations.

How do the lag times of British based companies compare with American? In analyzing the timing of technology introduction by British based companies,[42] the lag times of these companies for the twenty innovations were gathered and the averages computed for individual companies. The average lag time of all 41 firms (British and American) marketing in the United Kingdom has been 4.07 years. The average lag time for British firms alone has generally been lower. The firm averaging the lowest lag time of British based firms is Ferranti with 2.65 years. The lag time figures for individual U.K. based firms were as follows:

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[40] Plessey, Ferranti, and S.T.C. have tried to explore various areas of semiconductors, independent of American technology: Plessey in consumer electronics, Ferranti in computers, and STC in microwave ICs. The other British companies, GEC-Marconi-Elliot, and Associated Semiconductor Manufacturers (through GEC and Philips'-Mullard connection) have depended more on American and foreign technology.

[41] At least one firm, Plessey, has specialized in custom designed circuits in the hope of developing a long-term market. STC has utilized a sophisticated computer-aided design method for large scale interconnection problems.

[42] For the purposes of this analysis, both Mullard and STC of IT&T are assumed to be British based. A good proportion of the sales of Mullard come from Associated Semiconductor Manufacturers, which is British based. Although IT&T has had an American company manufacturing its semiconductors, the company is primarily based in Europe.

Company	T (years)
Ferranti	2.65
Plessey	2.94
General Electric Co.	3.25
Associated Electric Ind.	3.48
Mullard (A.S.M.)	3.56
GEC Marconi-Elliot	3.62
Brush	3.90
Standard Telephone & Cable	3.22
Lucas*	5.00
Westinghouse Brake*	5.75
Brimar*	6.83
Average	3.33

*Peripheral manufacturers excluded from average

In comparison American firms marketing in the United Kingdom have averaged 4.2 years. The difference between British and American firms in mean lag times is nearly one year.

The implications of these figures for British based firms are not really so encouraging since many American entries arrive later but with a more sophisticated version. The difficulties tend to run as follows. Firstly, when a product innovation is introduced into the United Kingdom, those American firms that license the basic process or product technology may also sell to the British market and have shorter lag times. The American firms, Texas Instruments, Fairchild, and R.C.A., are very competitive in their lag times. This is shown in the following table that gives the lags they have averaged over the twenty technology products that we have considered:

Company	T (Years)
Fairchild (S.G.S.)	2.23
Texas Instruments	2.45
Westinghouse (USA)	2.85
R.C.A.	2.87
General Electric (USA)	3.41
General Instruments	3.75
Philco (-Ford)	4.25
Average	3.15

Secondly, the leading American firms have advantages of greater product variety in the technology products they introduce derived from serving a larger home market. Thirdly, when the leading American firms have extracted the best from British based companies, their imitators in America arrive with either bargain basement prices, or sophisticated models, higher priced, but sufficiently differentiated to be very competitive.

A serious problem for British companies is that the competition is continuously growing and changing. The American industry has undergone many structural alterations that have been largely absent in the U.K. except through American activity, e.g. large-scale entry by big companies at the periphery of the industry such as Westinghouse, Corning Glass, Union Carbide. The correlation between introduction performance, i.e., the index, W, in equation (12), within a group of the seventeen most active American firms in the U.K. for 6 planar (early 1960's) devices and 7 integrated circuit (mid- and late 1960's) devices was found to be only 0.19. The correlation between the same planar devices and 7 discrete devices of the previous period was found to be 0.68. This is a clear indication that entry strategies and company and company composition of the industry have changed. Within the potentially profitable and growing U.S. markets there is constant peripheral entry, and entry by small breakaway groups of the larger companies. British-based firms have to adapt to this competition.

Licensing is a way for British-based firms to compete. To be on a par with American companies they may need to source more of their technology in America, and sell to the European and world markets. They inevitably require a larger market if they are to create in time new technology needed to be competitive.

c) Imitation Lags, Transnational Activity, and Patterns of Foreign Ownership

What association is there between imitation lags (selling in the host country) and forms or patterns of transnational activity? There are at least five methods for American firms to exploit their technology in foreign markets: (1) exports; (2) licensing of manufacturing and sales rights; (3) joint ventures with foreign partners; (4) outright sale of technology; (5) subsidiary manufacture and distribution. In the last the firm may either go in for full production or point-of-sale assembly.[43]

To ascertain what imitation lags are associated with the various forms of transnational activity the data of forty-one companies are used over the same twenty technology products of the previous section. A firm may first export to the UK and then produce in the UK. For a given innovation only the first route employed is included in the averages. The results were as follows:

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[43] Finan [1975] also considers these forms of activity in relation to the semiconductor industry.

Initial Form of Participation*	Average Imitation Lags T (years)
1) Wholly owned manufacturing subsidiary	3.679
2) Wholly-owned POS assembly subsidiary	3.712
3) Wholly-owned sales subsidiary	3.544
4) Joint venture	4.039
5) Exports	4.631
6) Licensee (British based)	3.329

*Includes the first route used by individual firms per innovation.

Obviously licensees have been successful in reaching the market earlier, but the crucial relationships are between the licensor and licensee, and the frequency of imitation (and number of firms taking part that are British based). The average for the major licensors has already been shown to be less than 3.2 years, which is ahead of the licensees.[44]

Imitation lags are one measure of imitative activity, but some firms are more active in developing and imitating technology products. What is the relationship between the weighted index of performance in introducing new products, W, and the form and pattern of transnational activity? The following figures for W were calculated:

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[44] One method of relating lag times to the form of transnational activity is through regression analysis using dummy variables. The dummy variable X_1 has the value 1 if the observation is for a British based licensee and 0 if not; similarly X_2 has the value 1 if the firm has a manufacturing subsidiary or POS assembly, and 0 if not. The regression is as follows:

$$T \text{ (years)} = \underset{(21.9)}{4.84} - \underset{(-3.65)}{1.51}\, X_1 - \underset{(-3.2)}{1.12}\, X_2 \qquad R^2 = 0.28$$

Compare these results with those in the table.

Form	W
1) Wholly-owned manufacturing subsidiary	64.75
2) Wholly-owned POS assembly subsidiary	51.00
3) Wholly-owned sales subsidiary	45.83
4) Joint venture	29.00
5) Exports	11.47
6) Licensee (British based)	77.88

The weighted index W shows the important roles played by licensees and wholly owned subsidiaries in the exploitation of technology products in the host country. The licensing of new technology is a means whereby American firms both exploit their technology advantages and assist British based firms to compete more effectively internationally as well as in the host country.

d) <u>Company Size and the Rate of Imitation</u>. What effect does company size have on the rate at which individual U.S. companies imitate technology products in the host country? This question may be answered by examining the experience of 17 U.S. companies that have sales in the U.K. For each of these an index of its record, W, in introducing twenty semiconductor technology products has been calculated as given in Table 5. It is hypothesized that the index value of the company in the host country is determined by its size, S, and the length of time it has been selling in the host-country market, A. For a variable reflecting company size, the figures for total worldwide sales of the companies in 1973, $ mn., were used. The results are as follows:

$$W = \underset{(2.316)}{-41.90} + \underset{(4.536)}{0.19\ S} + \underset{(4.906)}{5.3\ A} \qquad \bar{R}^2 = 0.75 \qquad (10)$$

Size and length of time in the host country market clearly influence the product-technology activity of American firms in the United Kingdom.

Summary

This paper has examined the factors that affect the pattern of introduction of semiconductor innovations into the United Kingdom, studying both differences among products and differences among firms.

Taking 20 individual innovations as units of observation we found that the spread of a technology in the U.K., in terms of the number of firms eventually marketing a product, to be greater in those products for which more producers had previous experience marketing in the U.K., more companies marketed in the U.S., and sales were large in the U.S.

The lag between the first introduction of a product anywhere and the introduction into the U.K. has declined between the 1950's and the 1960's. The earliest U.S.-based firms in the U.K. in terms of new product introductions have tended to be somewhat ahead of the earliest U.K.-based firms, since the beginning of the 1960's, although not before that.

We were not very successful in explaining differences among products in the delay between first introduction anywhere and introduction in the U.K. There were some signs that the degree of competitive pressure had some influence on this delay because the number of firms eventually participating, the number of firms with previous marketing experience in the U.K., and the amount of R. & D. conducted on the product by U.K. firms all were negatively, although weakly, related to the delay. Once a product was introduced into the U.K. its rate of diffusion among U.K. producing firms was increased by the presence of more U.K. licensees of U.S. technology in the product and by the presence of large firms among the producers. Another measure of the speed of diffusion is the time required for half of the eventual participants to enter the market. The larger the number of firms experienced in the U.S. market and active in new product introductions, and the larger the proportion of firms doing research in the U.K., the more rapid was the entrance of firms into the market. Thus, more R. & D., more firms with experience in the U.K., more licensees of U.S. technology, and larger size of firms all tended to speed the introduction and diffusion of a product in the U.K. market.

Looking at differences among firms, we found that larger firms, those that had been in the U.K. market a long time, and those that marketed many new products in the U.K., tended to introduce new products earlier. U.K.-based firms as a group introduced new products into the U.K. somewhat earlier than the average U.S.-based firm, but those U.S. firms that were licensors preceded most U.K. firms. Two U.S.-based firms, Texas Instruments and Fairchild, had shorter introduction delays than any British-based firm. Even the late imitators from the U.S. were not uncompetitive because they often entered the market selling at very low prices or with sophisticated, differentiated products, different enough to provide competition for earlier producers but not different enough to be listed as major innovations.

When we examined the type of transnational activity involved in product introductions by each of the 41 companies we found that the shortest lags were for introductions by U.S. licensors and then those by U.K.-based licensees, followed by wholly-owned sales subsidiaries of U.S.-based firms and by wholly-owned manufacturing or assembly subsidiaries. In terms of activity in introducing new products, which takes account of the number of new products and the rank in introducing them, rather than only the average lag for those products that are introduced, British-based licensees were the most active, followed by U.S.-based manufacturing subsidiaries and then by U.S.-based POS assembly subsidiaries. By both measures, exporting without U.K. sales subsidiaries was the slowest method.

Product innovation in semiconductors in the U.K. is clearly heavily dependent on ties with U.S. firms, whether through licensing or through U.S. ownership of British firms. Licensing does not seem to be a substitute for direct sales by

U.S. companies since the U.S. licensors were themselves active in new product introductions. While foreign firms--mainly U.S.-based--have generally had an important role in stimulating the British industry, the ability to respond quickly and competitively varies among products and firms with the extent of U.S. licensing, the size of individual companies, and the amount of earlier marketing experience in the U.K.

Bibliography

Aitchison, John and J.A.C. Brown, The Lognormal Distribution, Cambridge, The University Press, 1957.

Bain, Andrew D., The Growth of Television Ownership in the U.K. Since the War, Cambridge, The University Press, 1964.

Bradshaw, C. J., "Alternatives to Export Sales: License, Joint Venture, and Subsidiary," Paper 14/4, 1972 WESCON Conference.

Bryant, Edward C., Statistical Analysis, McGraw-Hill, New York, 1966.

Business Week, New York, April 20, 1974.

Camenzind, Hans R., "An Industry of Copycats," Electronic Products, January 1969."

__________, "Automated vs. Foreign Assembly--Can Highly Automated Assembly Machines Compete with Cheap Labour Overseas," Electronic Products, Nov. 15, 1971.

__________, Electronic Integrated Systems Design, Van Nostrand Reinhold, N.Y., 1972.

Chow, Gregory C., "Technological Change and the Demand for Computers," American Economic Review, Vol. 57, 1967.

Drummer, G.W.A., "Micro-Electronics--A Special Survey," Electronic Components, London, August 1965.

Electronics/Management Center, LSI: The Changing Interface, McGraw-Hill, 1969.

Farina, Donald, "Controversies and Future Trends in LSI," in Electronics/ Management Center, LSI: The Changing Interface, McGraw-Hill, N.Y., 1969.

Finan, William, "The International Transfer of Semiconductor Technology through U.S.-Based Firms," NBER Working Paper 118, Dec. 1975.

Fleet, J. J., "Types of Transistor--A Classification According to Methods of Construction," Electronic Components, London, September, October, and November 1965.

"Forum on MSI/LSI," Electronic Products, December 1969.

Foss, R. C., "Economic Considerations in LSI Design" in NATO, Large Scale Integration in Microelectronics, 1970.

Globerman, S., "Technological Diffusion in the Canadian Tool and Die Industry," York University, Toronto, processed, 1973.

__________, "Technological Diffusion in the Canadian Paper Industry," York University, Toronto, processed, 1973.

Golding, A., "The Semiconductor Industry in Britain and the U.S.: A Case Study in Innovation, Growth, and the Diffusion of Technology," Unpublished Ph.D. Thesis, Sussex University, 1971.

Gruber, William H., D. Mehta, and Raymond Vernon, "The R. & D. Factor in International Trade and International Investment of U.S. Manufacturing Industries," Journal of Political Economy, Feb. 1967.

Gruber, William H. and Donald G. Marquis, Eds., Factors in the Transfer of Technology, MIT Press, 1969.

Hamer, Donald W. and J. V. Biggers, Thick Film Hybrid Micro-circuit Technology, Wiley-Interscience, New York, 1972.

Hirsch, Seev, Location of Industry and International Competitiveness, Clarendon Press, Oxford, 1967.

Hnatek, Eugene R., A User's Handbook of Integrated Circuits, Wiley Interscience, N.Y., 1973.

Hufbauer, Gary C., Synthetic Materials and the Theory of International Trade, Harvard University Press, Cambridge, 1966.

Integrated Circuit Engineering Corp., Integrated Circuit Engineering: Basic Technology, Boston Technical Publishers, Cambridge, Mass., 1966.

__________, Status of Integrated Circuits, 1970.

Lathrop, J. W., "Evolution in LSI," in Large Scale Integration in Microelectronics NATO, Advisory Group for Aerospace Research and Development, 1970.

Mansfield, Edwin., Industrial Research and Technical Innovation: An Econometric Analysis, Longmans, London, 1968.

__________, "Intrafirm Rates of Diffusion of an Innovation," Review of Economics and Statistics, 1963.

__________ et al., Research and Innovation in the Modern Corporation, Macmillan, London, 1971.

NATO, Advisory Group for Aerospace Research and Development, Large Scale Integration in Microelectronics, 1970.

Payne, M., "The American Challenge on a Chip," Electronics, Jan. 20, 1969.

Penisten, Glenn E., "Implications of LSI for the Electronics Market, LSI: The Changing Interface, McGraw-Hill, N.Y., Electronics/Management Center, 1969.

Posner, M., "International Trade and Technical Change, Oxford Economic Papers, Vol. 13, October 1961.

Quantum Industry, Quantum Industry Report, Electronic Watches, 1974.

Rapoport, J., "The Time-Cost Trade-Off Function," in Mansfield et al. [1971].

Tilton, John E., International Diffusion of Technology: The Case of Semiconductors, Brookings, Washington, D.C., 1971.

United Kingdom, Monopolies and Restrictive Practices Commission, Report on the Supply of Electronic Valves and Cathodes Ray Tubes, HMSO, London, 1956.

Vernon, Raymond, "International Investment and International Trade in the Product Cycle," Quarterly Journal of Economics, Vol. 80 (May 1966).

APPENDIX TABLE 1A

LEADING SEMICONDUCTOR MANUFACTURERS

Companies	UK Sales 1972 £ mn.	UK Assets 1972 Plant & Equipment £ mn.	UK Research and Development[2] 1968 New Products/ New Processes £'000	UK Research and Development[2] 1968 Production/ Product Adaption £'000	Licensing 1968
1. Mullard (Philips)[1]	75.1	*	350 (1–3)	800 (1–3)	Yes
2. Associated SCM (Philips, GEC(25%))	9.6	12.9			
3. Newmarket (Philips)	0.9	0.2			
4. Texas Instruments	23.9	7.2	-	100	Parent
5. STC[1]	161.4	*	350	100	Yes
6. RCA[1]	12.5	*	-	-	-
7. Motorola	5.2	0.4	-	-	-
8. Ferranti[1]	63.7	21.4	300	*	-
9. Plessey[1]	283.0	111.0	600	100	-
10. AEI Semiconductors (GEC)	1.8	0.9	-	-	-
11. General Electric Company, USA	1.8	*	-	-	-
12. Transitron	1.7	0.3	-	-	-
13. Emihus	1.3	1.1	-	-	*
14. SGS (1971)	2.8	1.0	*	*	*
15. Fairchild (1971)	1.0	0.0	-	-	-
16. Marconi-Elliot (GEC)	*	*	550	500	Yes
17. GEC Semiconductors	1.1	1.6	-	-	-
18. IRC	1.7	0.5	*	50	*
19. Siliconix	0.6	0.1	-	-	-
20. General Instruments	1.0	0.7	-	-	-

[1] Sales and assets figures for company as a whole.

[2] Towards integrated circuit technology.

* Not available

- Nil

Sources: Anthony Golding (1971); NEDO,"Company Financial Performance in the Electronics Industry 1968/69 - 1971/72;" Companies.

APPENDIX TABLE 1B

Market Entry Data for Thirty Semiconductor Firms

Companies (see App. Table 2B) — Month/year — Innovations (see App. Table 2A)

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.
1.	4/53	5/54	5/60					8/56	6/58	2/60			2/71							
2.	10/52	9/54	3/61	8/61	10/61	8/61		2/57	10/57	2/57	3/60		9/65	3/63		1/63	8/66	6/68		
3.	7/53	9/53	7/61	8/59	12/61	8/61	9/67	9/53			3/61		4/71	9/67		3/62	1/67	1/67	2/67	7/67
4.	1/54	2/54	2/61	3/61	8/63	12/63	12/67	7/59	7/59		12/61		5/64	10/71	11/68	6/64	6/64	5/67	1/67	11/64
5.	12/56	12/56	10/60	10/60	6/63	1/63				3/61					12/70					
6.	11/54							11/56	11/56	11/56										
7.	8/55	5/59	3/61	2/62	2/62			4/56	6/57	2/57	3/61			2/65		2/62	1/64	5/67	12/67	
8.		10/55																		
9.		10/55			11/67					3/61										
10.			6/59	6/60	6/62	6/61	2/66	10/67	5/61	11/57	12/60	10/66		5/67	10/66	8/61	7/64	11/64		7/68
11.				3/62				5/59												
12.				3/62	6/62	5/65		4/60		4/60	7/61									6/68
13.				3/61	6/63	3/66		6/60		8/59	10/60							12/65	7/67	12/69
14.						9/63		4/60	5/60											
15.				8/61	11/62	10/64	10/66		2/63	2/60		5/67	8/65		5/67	6/64	4/64	4/67	4/64	10/66
16.				12/61	1/62	5/62					12/60	4/63		1/64			10/68	10/68		
17.					2/62	3/63				3/60			3/64			3/62	7/64	4/65		
18.					1/64								7/64			1/64	1/64	11/67	6/68	1/67
19.										4/60										
20.							8/65						8/70					1/66		6/67
21.				2/62	11/64	7/61											8/66			7/68
22.		12/59		11/64	6/63	6/63									5/67			10/65		
23.					5/63	1/64	11/65			1/59				3/66	5/67	7/62	1/67		10/68	11/65
24.					3/63	3/63	5/66							7/64	12/65	12/65				3/69
25.					11/66	2/67	2/67													
26.					5/65		5/65													
27.					11/64													5/66		8/66
28.					3/65	3/65														
29.																9/67				9/67
30.																	8/65	8/65		

Sources: Companies and trade journals of the electronics industry.

APPENDIX TABLE 2A

List of innovations
(See App. Table 1A)

1. Point contact trnasistor (ge)
2. Alloy junction transistor (ge)
3. Diffused transistor (ge)
4. Diffused 'mesa' transistor (si)
5. Planar transistor
6. Epitaxial transistor or devices
7. Field-effect transistor or devices
8. Alloy junction diode (si)
9. Zener diode (si)
10. Power rectifier (si)
11. Tunnel diode (ge/si/ga as)
12. Unijuction transistor
13. Varactor diode
14. Light emitting diode
15. Schottky-barrier diode
16. DCTL,RTL logic system
17. DTL logic system
18. TTL logic system
19. ECL logic system
20. pMOS logic system

APPENDIX TABLE 2B

A List of Selected Firms[1]

1. GEC
2. Mullard
3. Texas Instruments *
4. Pye - Newmarket Transistors
5. Marconi
6. Siliconix *
7. International Rectifier Company *
8. Ferranti
9. AEI - Edison Swan
10. Plessey
11. Amelco *
12. Signetics *
13. Brush Clevite *
14. Hughes or Emihus *
15. Transitron *
16. AEI - British Thompson-Houston
17. Standard Telephones and Cables
18. International General Electric (USA) *
19. Sylvania - Thorn or Sylvania *
20. National Semiconductor *
21. Raytheon; Micro State *
22. Teledyne; Crystalonics *
23. Elliot Automation
24. Hewlett Packard *
25. General Instruments *
26. English Electric
27. RCA *
28. SGS - Fairchild*
29. Motorola *
30. Westinghouse Brake

* Foreign company

[1] The numbering system of these companies does not correspond to that in App. Table 1B. The list of firms given is only a partial list.