THE SPREAD OF COMPUTER USAGE IN THE U.K., 1954-1970

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I

In a recent survey of technical change Kennedy and Thirlwall (1972) suggest that diffusion processes have not been adequately researched, especially with regard to U.K. experience. U.S. studies have been more common(1). As part of a larger project some results on the spread of computer usage in the U.K. have been generated and these are reported in this paper(2) Chow (1967) has performed a similar exercise using U.S. data , but apart from the geographical difference this study extends Chow's work in five directions. First the sample period is extended to include the third generation of computers; second, increasing returns to scale are explicitly recognised; third, technical progress in computers is included explicitly; fourth, cross section as well as time series data is studied; and fifth, order data is included.

This paper proceeds as follows. In the second section the data is discussed. In Section 3 price and quantity series are generated. In section 4 the time series data is analysed and in section 5 the cross section data. In section 6 supply problems are considered and in section 7 the conclusions are drawn.

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(1) For example, E. Mansfield, (1966)

(2) This paper is part of a thesis submitted to the University of Cambridge, Oct. 1973: P. Stoneman, (1973). I wish to thank Dr. R.M. Goodwin for his help with that thesis and thus with this paper.

II

There are two main sets of data used in this paper. The first set refers to the number and type of machines installed and when and in what industries they are installed. The second set concerns the characteristics of the machines in use.

The quantity data is derived from Computer Survey (1962-1970). In the June/July issue, summary tables indicate the number of machines installed at the end of each year 1954-1970 and on order mid year of the date of issue. This means that there is data on installations in December 1954-1970 and orders June 1962-1970. However for the years 1954-1961 the data does not include machines taken out of service prior to 1962. Corrections are made for this by estimating depreciation rates(1).

In the March issues Computer Survey summarises the cross industry distribution of machines installed and on order at the end of the previous year. This data is available for the years 1962-1970. The main problem with this data is that the computer service sector is included explicitly rather than cross industry usage of the sector being given. If some industries use the service sector more than others the data on installations may not adequately indicate cross industry usage.

The industry usage is broken down into twenty-four groups. Table 1 relates these groups to 1968 SIC MLH's(2).

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(1) See P. Stoneman, (1973).

(2) I wish to thank Mr. Peddar, the compiler of Computer Survey for his help in this breakdown.

Table 1:

Computer Survey Industry Groups and SIC (1968) MLH Classification

Group No:	Computer Survey Classification	SIC MLH
1	Aircraft Manufacturers and Guided Weapons	383
2	Armed Services	901(1-5)
3	Atomic Energy	part 876
4	Chemicals Rubber Glass, Plastics Paints, Costmetics	V,463,491,496
5	Computer Manufacturers and Service Bureaux	366 plus
6	Electrical Engineering	361-5,367-9
7	Ferrous and Non Ferrous Metals, Mining and Quarrying	VI,102,103,109(1,2)
8	Financial: Banks, Building Societies etc.	861,862
9	Food, Drink and Tobacco Manufacturers	III
10	Retail, Wholesale, Mail Order, Merchants	810,812-832
11	General and Constructional Engineering	VII,VIII,X,XII,XX
12	Government Departments	901,(6)
13	Government and Other Research Establishments	part 876
14	Insurance and Assurance	860
15	Local Government	906(3)
16	Motor	380-2
17	Oil	104,262,263
18	Public Bodies (mainly Post Office)	N/A
19	Public Utilities (Coal, Electricity, Gas, Water)	101,XXI
20	Transport	701 - 7,709
21	Universities and Other Educational Establishments	872 (3,4,5)
22	Textiles, Clothing, Furniture and Toys	472-3,494,XII,XIV,XV
23	Publishing, Printing, Paper, Bookclubs	XVIII
24	Sports, Leisure, TV, Films, Hotels	881-7
25	Miscellaneous	-
26	Unknown	-

The Computer Survey data is broken down by either computer model or computer family. It is necessary to generate data in terms of models thus the families were reduced to models by the use of Computer Consultants data (1962-1970)

Computer Consultants also provide the data on the characteristics of each model and its price. This data in total, in varying degrees of completeness, covers 312 computers. This data was complemented from Computers and Automation (1961-1969), Shirley (1969) and Smythe(1970). It should be stated however that the data used may be far from perfect, different sources often clashing. This must however be accepted and the best use made of the data available.

III

The main problem with estimating quantity and price series for computers is to remove quality differences. Following Chow with slight variations the hedonic method was used. First the dependent variable was one sum computer price rather than rental. This price was taken as the average of prices quoted by Computer Consultants Ltd. for the average sized installation (over the years the machine was on the market). It has been estimated that the price of a machine is 50.23 times its monthly rental with a standard deviation of 8.16, if no maintenance charge is included in rental. Price was used because of data limitation.

The independent variables were chosen from a data bank comprising data on twenty five different characteristics, but a process of trial and error led to the choice of three independent variables for the construction of a hedonic index. Unfortunately it was not possible to adequately represent the software characteristics of machines. The variables used were (1):

1. Cycle time in microseconds
2. Floor area occupied by the machine in sq. ft.
3. Maximum working store in thousand bits.

The functional form used was linear in logs, the method ordinary least squares and price was regressed on the independent variables for machines in their year of introduction. Years prior to 1960 were grouped (2) but each year 1961-1970 was considered separately. The regressions were also run for grouped periods, 1961-4, 1954-64, 1965-1970 and 1954- 1970, i.e. generations and groups of generations were pooled. The results of the regressions are presented in Table 2.

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(1) An alternative more systematic method is to use factor analysis (as does Wilkinson (1973)) to identify factors as weighted combinations of variables in the data set, and to then regress price on these factors. In an implicit way this is how the study proceeded although each factor was reduced to one variable - a size factor represented by store size, a speed factor represented by cycle time, a time factor represented by the date of introduction, and floor area the function of which is discussed below. The only real advantage that could have been gained by the use of factor analysis would have been to redefine the speed factor over more indicators, but this would have probably produced problems through certain data shortages.

(2) Because of data shortage.

Table 2:

Regressions between Computer Price and Characteristics

Year	Constant	Cycle Time	Floor Area	Maximum Store	N	R^2	$\bar{R}^2$	E^2(1)
To 1960	1.07 (0.76)(2)	-0.04 (-0.27)	0.71 (1.65)	-0.03 (-0.10)	10	.754	.590	3.89
1961	4.71 (1.50)	-0.70 (-1.74)	0.40 (1.48)	-0.09 (-0.27)	13	.774	.674	5.78
1962	1.61 (1.81)	-0.10 (-0.97)	0.41 (3.09)	0.23 (2.43)	16	.802	.736	4.37
1963	1.57 (2.60)	-0.27 (-2.56)	0.44 (4.97)	0.22 (3.10)	21	.835	.796	4.98
1964	-1.94 (-1.82)	-0.18 (-1.42)	1.02 (4.05)	0.13 (1.06)	13	.908	.867	0.964
1965	1.13 (1.36)	-0.07 (-0.57)	0.389 (4.93)	0.22 (2.13)	30	.606	.546	15.3
1966	0.55 (0.79)	-0.12 (-0.82)	0.21 (3.13)	0.44 (4.14)	32	.760	.730	10.4
1967	0.199 (0.28)	-0.37 (3.05)	0.55 (6.56)	0.24 (1.98)	32	.805	.777	16.01
1968	-0.83 (-2.58)	-0.297 (-3.08)	0.57 (13.32)	0.33 (5.56)	27	.970	.965	2.20
1969	-1.31 (-1.59)	-0.34 (-0.91)	0.495 (6.27)	0.484 (4.06)	18	.897	.867	4.81
1970	-0.58 (-0.09)	-0.613 (-1.61)	0.706 (2.37)	0.238 (0.26)	6	.932	.796	0.845

(1) The sum of squares of the errors from the regression equation.

(2) The brackets enclose t statistics.

1961 - 1964:

$$\begin{array}{llllllll} P = & 1.60 & -0.19C & +\ 0.42F & +\ 0.25S & +\ 0.08d_{62} & -\ 0.33d_{63} & -0.49d_{64} \\ & (3.22) & (-3.10) & (6.22) & (5.06) & (0.34) & (-\ 1.6) & (-2.1) \end{array}$$

$$DW = 1.48 \quad R^2 = .790 \quad \bar{R}^2 = .764 \quad N = 63 \quad E^2 = 18.96$$

1954 - 1964:

$$\begin{array}{llllllll} P = & 2.03 & -0.19C & +\ 0.42F & +\ 0.25S & +\ 0.56d_{58} & -\ 1.64d_{59} & -0.37d_{60} \\ & (2.78) & (-3.76) & (6.68 & (5.56) & (0.86) & (-\ 2.04) & (-0.60) \\ & & & & -0.39d_{61} & -0.32d_{62} & -\ 0.72d_{63} & -0.87d_{64} \\ & & & & (-0.66) & (-0.54) & (-\ 1.23) & (-1.48) \end{array}$$

$$DW = 1.65 \quad R^2 = .817 \quad \bar{R}^2 = .784 \quad N = 73 \quad E^2 = 19.3$$

1965 - 1970:

$$\begin{array}{llllllll} P = & 0.12 & -0.19C & +\ 0.45F & +\ 0.345S & -0.180d_{66} & -\ 0.21d_{67} & -0.42d_{68} \\ & (0.34) & (-3.03) & (12.90 & (6.9) & (-1.0) & (-\ 1.2) & (-2.25) \\ & & & & & & -0.165d_{69} & +\ 0.15d_{70} \\ & & & & & & (-0.77) & (\ 0.47) \end{array}$$

$$DW = 1.41 \quad R^2 = .794 \quad \bar{R}^2 = .780 \quad N = 145 \quad E^2 = 64.5$$

1954 - 1970 (1)

$$\begin{array}{llllll} P = & 4.47 & -0.17C & +\ 0.47F & +\ 0.29S & -1.54T \\ & (5.98) & (-4.00) & (15.6) & (8.5) & (-5.80) \end{array}$$

$$DW = 1.8 \quad R^2 = .770 \quad \bar{R}^2 = .763 \quad N = 218 \quad E^2 = 98.5$$

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(1) Where T is simply a time trend. Other formulations to take account of time were tried without any marked change in the results.

In order to produce quality adjusted price and quantity series a base year must be chosen. Chow, using an F test, found that the coefficients on characteristics did not change significantly over time and so the choice of base year did not matter. Using the same technique on the data used here this conclusion was upheld if only data to 1965 was considered. Post 1965 it was found that the conclusion no longer held. Thus the choice of base year will influence the series constructed. 1963 was chosen as the base with coefficients taken from the pooled regression covering 1961 - 1964.

There was however full data on only 218 machines. There were another thirty machines in the quantity data on which full characteristics data were not available. For these machine data were available on the year of introduction, price, and in certain cases on some of the above characteristics. Thus for the 218 machines with full data broken down by year of introduction, the predicted 1963 introduction price was regressed on the actual price, a constant, and all permutations of cycle time, floor area and maximum store. The resulting coefficients were then used to calculate the predicted 1963 introduction price of the thirty machines with less than full data.

If we let $\hat{P}_r$ be the price of computer r, predicted in this way, i.e. as if it had been introduced in 1963, then one can construct a price series for computers by calculating for each year

$$\frac{\Sigma \; P_r W_r}{\Sigma \; \hat{P}_r W_r}$$

where P_r is the actual price of machine r, and W_r is the weight to be applied to that computer in the year in question. In Chow's work $W_r = 1$ for the year of introduction and 0 elsewhere. Here it was decided to weight machine prices by market share in all years in which the machine was on sale. W_r was allowed to equal the change over the previous year in the number of machines of type r installed or on order if it was greater than zero, and zero elsewhere. Fortunately the machines that had inadequate characteristics data also tended to have few installations so this weighting removed some error that the data shortage could have caused. In Figure 1 the resulting price series is shown. An equivalent based on Chow's method is also illustrated for comparison purposes only.

The index resulting is interesting in two ways, by the extent of its fall and by its 'scenic railway' shape.

It is argued that there were four different groups of machines each of which dominated certain time periods. These can be labelled the zeroth generation (up to and including 1956), the first generation (1957-1959), the second generation (1960-1963) and the third generation (1964-1970).

Returning to the price series, the manner in which it has been characterised shows that it falls at exactly the same time that the generations changed from the first to second and second to third. This is to be attributed to technological change.

It is therefore suggested that the major falls in the price series are attributable to the design and production of new machines around the new components that were coming from the components industry, and can thus be attributed to technological progress.

Turn now to the quantity series. To generate the quality adjusted quantity series one just takes the number of each model installed in time t and multiplies by the models associated $\hat{P}$. In Table 3 the aggregate installations, the price series and the industry quantities are presented.

Table 3 (part 1)

Quality adjusted quantity series of the computer stock and orders measured in predicted 1963 introduction prices (£'000)

Year	Installed at end of year	On Order mid year
1954	139.425	-
1955	305.462	-
1956	614.870	-
1957	2253.330	-
1958	4086.162	-
1959	6283.237	-
1960	13027.441	-
1961	23283.770	-
1962	39721.240	-
1963	63050.703	26193.745
1964	92831.480	70022.707
1965	156521.759	121504.629
1966	283821.673	125071.476
1967	427932.118	140552.436
1968	603230.391	152078.397
1969	830642.967	141078.208
1970	990405.300	129116.897

Table 3 (part 2)

Computer Ownership by Industry.

INSTALLED £Th.

	YEAR	62	63	64	65	66	67	68	69	70
	1	1793,031	2133,508	3114,802	5262,842	8134,332	11606,862	14237,317	20709,465	19192,895
	2	1210,828	1793,309	2865,613	4705,515	6190,088	9706,314	13236,794	20373,510	26140,776
	3	1770,930	1775,515	3244,552	2620,875	4017,029	6478,271	6757,991	3618,984	7623,257
	4	1836,164	4553,171	6468,213	9919,916	22739,975	31096,136	47740,321	57588,650	70037,665
	5	4819,033	8456,677	13203,037	16123,937	29195,607	46761,911	63276,730	86505,755	131492,918
	6	1874,611	4076,030	4973,676	3716,473	15677,079	25049,907	27419,954	39850,152	49675,876
	7	1159,965	2484,904	4974,117	6365,436	9688,766	16546,057	21169,914	30519,540	36724,972
I	8	1549,677	2719,083	5197,434	9971,511	16433,090	27725,029	43845,078	61324,380	75357,406
N	9	1395,337	4692,626	7893,732	13941,999	22116,756	35938,978	27378,626	46186,132	55096,041
D	10	*	*	*	*	*	*	20479,709	25693,570	30034,909
U	11	1336,677	2577,713	6452,136	13773,075	31740,310	47930,212	66071,543	84680,833	113757,379
S	12	1581,198	3461,133	6460,560	5301,832	7042,536	13742,755	15519,179	15136,010	21753,978
T	13	1654,130	2877,677	4173,137	6469,133	12068,125	11650,933	17458,654	25029,669	34591,814
R	14	1150,633	3135,949	5594,537	10462,504	14337,440	17337,331	23136,919	30362,871	35783,536
Y	15	1079,474	2444,984	4486,479	11361,772	18639,628	33177,613	46379,443	55934,591	69155,933
	16	1112,835	1989,352	2637,514	6514,016	9229,377	11532,220	17459,208	24485,270	21742,525
	17	1450,630	2333,672	3228,150	2505,062	5858,637	10712,507	12151,654	15525,460	15591,726
	18	434,174	465,099	2656,712	2786,711	6731,575	6732,638	17285,588	18217,208	28571,359
	19	1646,149	3536,298	3932,377	7233,377	10389,805	18655,872	23571,755	30650,121	31430,636
	20	671,027	1853,260	4326,564	3280,672	4932,035	9605,199	13682,289	20038,349	24466,333
	21	2083,397	6971,098	11026,530	11707,765	20521,229	28613,717	37494,454	50286,277	57292,972
	22	*	1580,372	2829,934	5519,597	9286,674	15728,937	23379,426	32397,273	35979,929
	23	*	*	1015,813	2194,024	5082,889	10752,034	17627,087	24785,771	32315,934
	24	*	*	*	*	2294,263	4486,753	5155,025	7612,195	10057,395
	25	1328,416	1641,675	2563,065	2887,424	2215,658	10464,329	10258,082	16021,616	28745,504
	26	89,594	1239,982	1809,839	6232,617	2185,658	*	*	*	*
	TOTAL	33827,639	68083,033	115131,223	175848,268	296736,079	461544,018	647860,476	850603,510	1322862,146

ON ORDER £Th.

	YEAR	62	63	64	65	66	67	68	69	70
	1	1440,828	1527,156	1269,690	3617,515	2380,860	1725,296	1527,921	1943,937	*
	2	219,877	371,189	316,137	2525,413	1791,807	7470,134	11512,423	15661,515	*
	3	977,819	2370,248	2472,635	1139,637	901,898	429,607	1490,424	414,486	*
	4	1014,472	1515,361	6436,274	12687,993	11020,052	5940,834	7183,718	6089,153	*
	5	445,875	1807,389	2074,335	6853,077	6417,170	10019,532	7889,385	9627,335	*
	6	549,290	729,519	3501,458	6696,493	6996,464	4696,334	5171,914	4556,310	*
	7	340,112	1479,758	3004,075	4101,830	4461,303	4348,809	3253,145	2343,465	*
I	8	775,016	922,335	7339,771	3444,920	13679,133	11711,526	11670,657	13507,160	*
N	9	2171,727	2332,100	4046,370	11278,591	11876,677	9023,239	5322,810	10272,524	*
D	10	*	*	*	*	*	*	3186,151	4713,311	*
U	11	856,038	1481,285	5739,714	14990,615	17023,851	15356,910	11812,899	17020,471	*
S	12	695,122	2249,401	2755,271	2422,562	6069,236	8954,094	3374,325	9917,055	*
T	13	341,102	1666,216	17[illegible],356	1948,496	1576,289	2034,115	3717,201	861,473	*
R	14	617,860	1965,444	4561,576	3705,966	3697,834	2761,734	2951,588	4279,560	*
Y	15	893,035	1264,427	7635,652	12293,219	15697,200	7796,189	3534,167	5407,671	*
	16	489,735	544,865	2107,733	2983,518	2787,735	1263,030	2041,561	1152,334	*
	17	827,436	777,060	538,472	1013,699	2297,004	2072,237	231,062	173,586	*
	18	124,109	130,795	1933,570	2660,756	5540,613	2326,171	1851,508	5504,422	*
	19	1365,934	1630,644	5017,730	5147,225	1405,660	5463,975	1077,765	2323,639	*
	20	0,030	2119,161	2317,526	2372,027	5299,490	3941,016	2181,748	2356,277	*
	21	3219,930	1327,153	1112,112	6352,703	6724,375	5337,777	1369,608	3972,989	*
	22	*	761,749	2595,121	5271,044	10773,074	3139,231	3364,034	3542,976	*
	23	*	*	626,915	1212,335	4749,185	3417,330	2521,132	3405,160	*
	24	*	*	*	*	1765,342	2421,677	3464,102	870,441	*
	25	989,573	1012,344	1443,610	2491,250	1165,455	4333,650	3649,924	5214,665	*
	26	1244,112	2666,113	12597,177	6203,252	3751,469	*	*	*	*
	TOTAL	15562,030	32042,152	73360,179	127415,056	150708,330	125945,937	133393,251	137519,135	*

IV

The analysis of the aggregate data began by the experimental fitting of three types of diffusion curves to the data - the logistic, Gompertz and Stone and Rowe(1) hypotheses, using the data above and Blue Book data. In each case the curves were relating rates of growth of the computer stock to the relevant variables. As Chow had found, the Gompertz hypothesis performed best in terms of the usual statistical indicators, R^2, t statistics etc. If we let

S_t = stock of computers at time t
Y_t = G.N.P.
p_t^c = price of computers in time t
π^t = general price level
λ = adjustment coefficient

Then the Gompertz hypothesis combined with a multiplicative form for the satiation stock

$$S^x_t = e^a . Y_t^b . \left(\frac{p^c{}_t}{\pi_t} \right)^c$$

implies the fitted equation

$$\text{Log } S_t - \text{Log } S_{t-1} = \lambda a + \lambda b \text{ Log } Y_t + \lambda c \text{Log} \frac{p^c{}_t}{\pi} + \lambda \text{Log } S_{t-1} + u_t$$

where U_t is assumed to have the usual properties.

In Table 4 the results of fitting this form are presented. In equation 1 in that table for the period 1954-1970 only the coefficient on the lagged stock is significant although it is also of the correct sign. Because of this poor result an attempt was made to fit the function to a time period similar to Chow, i.e.

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(1) R. Stone & D. A. Rowe, (1957)

from the first generation peak (1957) to the second generation trough (1964). The performance of the hypothesis improved markedly although in our case the significance of the price and output variables are reversed in comparison with Chow's results.

The results on the straight Gompertz hypothesis are not really very good, thus an attempt was made to improve the fit . The first improvement is to redefine the dependent variable by the inclusion of data on orders. Thus the dependent variable becomes the growth in stock and orders. There are two reasons for the inclusion of orders.

(a) Orders will take up any surplus of demand over supply so that the new variable will reflect the level of demand more closely and

(b) the inclusion of orders by removing the time lag between ordering and delivery will locate the computerisation decision at the moment in time that it is made.

Thus a new variable, Z_t is defined as

$$Z_t \equiv S_t + O_t$$

where O_t is the quality adjusted level of orders in time t. This improvement involves two problems.

(i) To include orders may involve some double counting if a machine is being replaced, for the original machine may be included in the stock data and the replacement in the order data. This is accepted but assumed away.

(ii) To included orders some data is required. A series of order data is presented in Table 3 Part 1 for the period 1963-1970.

However that data is mid-year based and the stock data is end-year based. The order data used is therefore taken from the industry data which is end-year based. This data is only available for the period 1962-1969. To complete the series to 1970 it is assumed that 1970 orders have the same machine mix as 1969 orders and thus quality adjusted orders for 1970 can be calculated. This means that full data is available for 1962-1970 and partial data for 1954-61. Thus the new dependent variable is defined as

$\text{Log } S_t - \text{Log } S_{t-1}$ for the period 1954-1962

and $\text{Log } Z_t - \text{Log } Z_{t-1}$ for the period 1963-1970

This series is plotted in Figure 2 and labelled $\Delta \text{ Log } Z_t$. The major differences between the series with and without orders centre around the period 1964-1966. In the original series the second generation growth rate is at its lowest in 1964, and the third generation takes two periods to reach its peak in 1966. The new series has the second generation minimum in 1963 and the third generation peak appearing in 1964, which is the year that the third generation appears. It is this 1964 peak relative to the previous 1964 trough that makes one feel that the new series is an improvement, for if one believes that computer generations are to have any effect on computer usage one would not expect a trough when the new generation appears. Itis significant that during 1964, 346 machines were installed but 474 machines were on order at the end of the year, of which 193 were for the new third generation 360's and 1900's. (1)

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(1) The data is from Computer Survey, op.cit., Summary Tables March and July 1965.

One further change was made before proceeding. The price variable was redefined as the price of computers relative to all input costs, for it was felt that computers were a productive input and thus their price ought to be compared to the price of other productive inputs not the prices of outputs. The new variable is represented by p_t^c / TC_t.(1) The first results achieved are shown as equation 3 in Table 4. Attempts were also made to define computer price relative to wages, but no significant improvement resulted. Different lag structures also made little difference.

These results are not very satisfactory. The failure of the price and output variables would suggest that the equilibrium stock is not affected by either price or output. However, just a visual inspection of the series on Z_t would indicate that something is affecting the equilibrium stock when generations change. It is therefore hypothesised that price will influence the equilibrium stock, but a change in generations by itself also affects the equilibrium stock. We thus define four new variables in line with the generation concept discussed above. This discussion indicates that the generations were available according to a time pattern reflected in the following dummies.

D_0 the zero generation dummy equals 1 for the period 1954-6 and 0 elsewhere.

D_1 the first generation dummy equals 1 for the period 1957-9 and 0 elsewhere.

D_2 the second generation dummy equals 1 for the period 1957-9 and 0 elsewhere.

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(1) TC_t is a series on total costs again from the Blue Book.

D_3 the third generation dummy equals 1 for the period 1964-1970 and 0 elsewhere.

Using these dummies two hypotheses were tested. If one lets

$$Z_t^x = e^a Y_t^b \left(\frac{p_c^t}{TC_t} \right)^c$$

then the dummies may be entered as influences on a or b. Both were tried, the latter suggesting that the scale returns varied with generations. The result of the former approach is shown in equation 4 in Table 4. The DW statistic in this equation implies autocorrelation.

The position now is that the dummies perform reasonably but the price variable does not appear to gain significance at any stage. However, behind these regressions there is one basic difficulty and that is that the correlation between Log Y_t and Log Z_{t-1}, measured by the correlation coefficient, is 0.9827. This would indicate the possibility of multicollinearility. The effect of this would be to generate large variances and covariances for the coefficient estimates, making them very imprecise.(1) If one considers the estimate of the coefficient on Log Y_t it is usually estimated at about 4.7, and combines with a coefficient on Log Z_{t-1} of 0.4. This implies that with

$$Z_t^* = e^a Y_t^b \left(\frac{p^c{}_t}{TC_t} \right)^c$$

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(1) J. Kmenta, (1971) pp. 384-9

Table 4 : The Gompertz Hypothesis

	constant	Log Y_t	Log $\frac{P_t^c}{\pi_t}$	Log S_{t-1}	Log $\frac{P_t^c}{TC_t}$	Log Z_{t-1}	D_0	D_1	D_2	D_3		R^2	$\bar{R}^2$	DW
1. 1954-1970 excluding orders	-1.699 (-0.070)	0.421 (0.172)	-0.400 (-1.477)	-0.208 (-2.19)								0.686	0.573	
2. 1957-1964 excluding orders	-52.39 (-1.55)	5.648 (1.66)	-0.169 (-0.42)	-0.464 (-4.05)								0.882	0.764	
3. 1954-1970 including orders	8.565 (0.377)	0.668 (-0.292)			0.318 (-1.065)	-0.124 (-1.389)						0.656	0.541	2.132
4. 1954-1970 including orders	-45.66 (-2.22)	4.95 (2.37)			+0.027 (0.26	-0.423 (-4.69)	-1.012 (-4.99)	-0.261 (-2.09)		0.229 (1.45)		0.905	0.831	0.901

the coefficient b is being estimated as 4.7/0.4 = 12.0. The coefficient b is equivalent to the degree of scale returns in computer use. This coefficient implies very large decreasing returns to scale. It can be shown however that in terms of computer hardware input there are increasing returns to scale in computer use.(1) It has therefore been decided to introduce b as a parameter into the regressions. To prevent multicollinearity appearing in dummy variables the dummies are introduced as influencing a and not b. The coefficient b was allowed to take values between 0.6 and 1.5 in intervals of 0.1. In Table 5 the results for the the lower values are presented. Three types of equation were fitted, one with a price variable and no dummies, one with dummies and no price variable and one with dummies and prices, i.e. variations on

$$\Delta \text{Log } Z_t = \lambda a_0 + \lambda a_1 D_0 + \lambda a_2 D_1 + \lambda a_3 D_2 + \lambda(b\text{Log } Y_t - \text{Log } Z_{t-1}) + \lambda\ c\text{Log } P_t^c / TC_t + u_t$$

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(1) P. Stoneman, (1973)

Table 5:

Gompertz Modified to show scale returns

			Coefficient Estimates						
b	λa_0	λa_1	λa_2	λa_3	λ	λc	R^2	$\bar{R}^2$	DW
.6	1.880 (6.08)	-1.26 (-2.68)	-0.73 (-1.84)	-0.415 (-1.778)	0.237 (4.313)	-0.040 (-0135)	.847	.756	1.85
	1.887 (6.48)	-1.304 (-3.92)	-0.773 (3.21)	-0.439 (2.955)	0.233 (5.37)		.847	.778	1.88
	1.082 (4.758)				0.144 (2.323)	-0.261 (1.111)	.652	.512	2.05
.7	1.641 (6.03)	-1.262 (-2.692)	-0.730 (-1.842)	-0.415 (-1.778)	0.239 (4.326)	-0.041 (-0.13)	.848	.757	1.85
	1.652 (6.676)	-1.304 (-3.93)	-0.772 (-3.22)	-0.438 (-2.96)	0.234 (5.386)		.847	.778	1.88
	0.144 2.322				0.144 (5.629)	-0.259 (-1.107)	.652	.572	2.05
.8	1.399 (5.79)	-1.263 (-2.69)	-0.729 (-1.84)	-0.414 (-1.779)	0.240 (4.339)	-0.041 (-0.137)	.848	.758	1.84
	1.414 (6.94)	-1.306 (-3.94)	-0.771 (-3.228)	-0.438 (-2.96)	0.236 (5.400)		.848	.780	1.88
	0.789 (7.39)				0.145 (2.32)	-0.258 (-1.104)	.652	.572	2.06
.9	1.155 (5.20)	-1.26 (-2.70)	-0.728 (-1.845)	-0.413 (-1.779)	0.241 (4.352)	-0.041 (-0.137)	.849	.759	1.84
	1.174 (7.315)	-1.306 (-3.952)	-0.771 (-3.235)	-0.437 (-2.97)	0.237 (5.415)		.849	.780	1.88
	0.642 (11.49)				0.145 (2.319)	-0.257 (-1.100)	.652	.572	2.05

The results for higher values of b were similar in all respects to these results. The conclusions that can be drawn are that a role cannot be found for the price variable in this formulation judging by significance at the 95% probability level. In these equations however, the dummies were always significant at the 95% level. It was therefore decided to concentrate on the version including dummies but no price variable. In all these results the R^2's were reasonable and in each case the DW statistic was in the indecisive area at a 99% significance level. The R^2 varies from 0.847 for b equal to 0.6 to 0.852 for b equal to 1.5, (hardly a difference worth bothering about) which compares with 0.904 in the unrestricted version. The DW statistic has improved relative tothe non-restricted equations.

The main difference between these equations and the unrestricted form is the estimate of the coefficient λ. In the version for b equal 0.6, $\hat{\lambda}$ is estimated as 0.233 with with a standard error 0.043, whereas in the non-restricted form the estimate is 0.424 with a standard error 0.086.

To judge between the estimates achieved for different values of b requires some external information because the results are not significantly improved or worsened when b varies in the region of unity. The study of the industry data below indicates that a coefficient around 0.7 is appropriate. This corresponds sufficiently to what had been expected from ananalysis of scale returns in computer use to (1)

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(1) P. Stoneman, (1973)

justify our proceeding by concentrating on the results for b equal to 0.7.

In Figure 2 the resulting estimate of Z_t^* is plotted and the predictions on $\Delta \text{Log } Z_t$ are also provided to be compared to the actual figures. Consider first the period 1967-1970. Here the predictions are not very good. The problem to answer is whether the actual 1967 growth rate is low or the 1968 and 1969 figures are high. An investigation of the basic data shows that comparing the industry data to the aggregate data, the aggregate data on machines installed exceeded the industry total by £34m in 1966 and only £13m in 1967. A fall in 1967 may therefore be the result of bad data. However there are other factors suggesting that it is the 68 and 69 figures that a relatively high and not the 67 data that is low. For the period 1966 to 1970 computers were singled out for special investment incentives treatment by the government (although there were incentives before this date machines were grouped with all other investment). A grant towards the cost of the machine was available at the rate of 20% in 1966, 1969 and 1970 and 25% in 1967 and 1968. If this was combined with a one year lag it might explain the movement around the period 1966-1970. It was also considered however, that the boost in the 1968-69 period may have been the result of the introduction of the ICL 1900 A series. To test these hypotheses a number of different dummy variables were tried but the results did not improve materially. The grants were also considered by reflecting them in the price series with an overall one year lag on that series but the resulting variable was not significant at the 95% level.

One interesting point that arises out of the results is that the diffusion study would predict a further fall in the growth rate after 1970, a year in which our figures show that the net additions to the stock were in absolute terms less than in the year before. Thus the depression that the industry suffered in 1971 and 1972 could be a natural result of this diffusion process. The analysis would also suggest that to raise the growth rate a new generation would be required. By the beginning of 1973 the industry was picking up again, but the new machines being installed, the 1900 S series, Burrough 1700's and the IBM 370's etc. were only introduced in the previous eighteen months, and may constitute this new generation. The pattern could be said, therefore, to be continuing, but as the exact data has not been analysed these comments should be considered as speculation rather than fact.

Moving back through time the estimated curve does not predict too well for the 1955-63 period. It has not been possible to adequately reflect the peak of 1957, and 1963 has yielded a bad underestimate. The former deficiency may be the result of the fact that with very few machines installed in 1956 a small error in the data for 1957 could reflect in a large error in the growth rate. The 1963 result cannot be explained however, unless it is argued that the functional form is incorrect.

Assuming however that this functional form adequately represents the diffusion process, then one must consider exactly what the results mean. The first question concerns what exactly the calculated Z_t^* represents. It would seem that the best interpretation is that for a given level of output, Z_t^* represents that stock of computers that would have been installed and ordered had all potential users re-evaluated their technology in time t. This does not imply, necessarily, any concept of equilibrium for some machines may be installed mistakenly and others not installed when it might have been better to have installed them. It is in essence the saturation stock however users may evaluate their technology.

The second question is more important; why has it not been possible to relate the saturation stock to price, although the dummies are significant ? The significance of the dummies could be taken to imply two things,

(a) When generations change, the nature of computer applications change e.g. from electronic clerk, to integrated systems to management information systems, and these changes are reflected in increases in the satiation stock.

(b) The dummies could also reflect price changes, either by arguing that the price series, by concentrating on hardware characteristics, does not adequately reflect prices to the user, whereas the dummies, by changing with generations, do reflect such prices which must change most when generations change; or that prices change most when generations change and minor price changes do not matter, so the dummies perform well and the price variable does not.

What then are the a priori arguments for price to influence the satiation stock ? One may argue,

(a) That as price falls more firms may be able to achieve their evaluation targets, and for more firms the machine is a 'feasible'(1) alternative. The problem with relying on price relative to targets is that evaluation procedures also depend on expectations of returns, and minor variations in these returns may swamp minor changes in price. The feasibility argument is again weak with regard to minor changes in price. However, it could be argued that both arguments are realistic for major changes in price, i.e. those reflected in the generation concept.

(b) It may be argued that as price falls the applications of computers to more tasks may pass evaluation and feasibility targets. Once again it would seem more likely with major changes in prices, but in this case there is another element to consider. To apply computers to more tasks more software is needed and it must be stated that the price series does not adequately reflect this (although the generation concept may).

In total therefore it would seem reasonable to assume that prices should affect the satiation stock, but it would require major changes for this influence to be reflected. It is therefore argued thar the importance of the dummy variables is that they reflect different price levels for computers of different generations and also reflect the extensions of the application area as technology has proceeded.

The economic meaning that one can read into the results

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(1) In terms of ability to pay for it.

so far is that the number of machines that it is desired to install during a period is related to the difference between the actual and the saturation stock. The existing stock also exerts influence in fact as a proxy for an information variable. The satiation stock varies with the level of output and has changed as generations have changed. This generation change reflects both increases in the area of computer applications and major changes in the price of computers. This is the only means by which it has been possible to introduce the price variable, and at the same time it has only been possible to generate the scale returns that are apparent in computer use by entering it through a predetermined parameter.

By the use of dummies the above regressions have attributed all peaks in the expansion of computer usage to the expansion of the satiation stock, and this stock has been estimated on the basis that a constant proportion of the difference between it and the actual stock has to be cleared in each period subject only to the level of the previous stock. However, it can be argued that there are specific forces that influence the rate of adjustment. The failure to take account of these may have provided results that are merely contingent relations. In a separate study of the decision to computerise relying on the use of survey data,(1) it was argued that the adjustment coefficient would not necessarily be constant but might vary with other economic variables. All attempts to reflect this in the study of the aggregate data failed although as will be seen, more success was achieved in the industry study.

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(1) P. Stoneman, (1973)

V

It was originally intended to combine cross section and time series analysis in the study of computer diffusion. However, because of the groupings of the industry data it was only possible to find observations on the independent variables from the Census of Production. This meant that data was only available in 1963 and 1968 and on groups 1,4,6,7,11,17,19,22, and 23.

The data used is presented in Table 6.

Table 6 :

Data on Industries

Industry	Y £m 63	Y 68	Cl Th 63	Cl 68	W £m 63	W 68	C £m 63	C	SA £m 63	SA 68
1	324.7	478.1	107.9	106.9	217.3	280.1	187.0	259.6	550.3	861.9
4	1324.7	1959.4	233.9	269.8	541.8	785.9	1281.7	1982.4	2640.6	3933.4
6	912.7	1357.4	234.0	248.4	522.3	697.6	755.8	1161.2	1681.2	2483.9
7	932.0	1259.4	128.0	142.2	513.0	672.6	1649.6	2379.0	2627.8	3629.3
11	4160.3	6464.5	689.6	809.8	2593.6	2733.7	147.2	4876.6	8204.6	
17	107.8	171.1	10.7	9.8	32.8	38.9	479.8	825.3	592.1	1001.4
19	1636.4	2114.3	178.4	188.8	781.3	834.2	842.2	987.0	2475.5	3116.6
22	1399.3	1953.8	206.0	206.4	790.0	1052.1	1911.1	2353.6	3343.4	4368.6
23	846.5	1252.5	157.0	178.0	457.4	674.1	675.4	965.1	1629.0	2352.6

All prices are current. Y = output, Cl = total clerical, technical and administrative workers, W = total wage bill, C = total costs of fuel and materials, S = sales of goods produced and work done.

The first hypothesis tested was that one could explain inter-industry differences in the demand for computers by means of the Gompertz hypothesis. This hypothesis was fitted to 1968 data but the results were not encouraging. In attempt to improve the performance of the hypothesis a new variable was introduced as a proxy for the equilibrium stock. This variable was based on $Cl_{63}/_{Y_{63}} \cdot Y_{68}$, i.e. the number of clerical workers that an industry would have required in 1968 if the ratio of clerical workers to output was as in 1963. This was rationalised on the grounds that as few industries used computers extensively in 1963 the variable would reflect inter-industry differences in potential applications of computers. However the performance of the hypothesis did not improve markedly. A second approach was made to use the Gompertz hypothesis, this time instead of letting Z_{t-1} be represented by 1967 data it was represented by 1964 data, so the hypothesis is applied to the 1968-1964 stretch. 1964 was chosen for it is the first year in which data is available on computer stock for the whole sample used. The result achieved was

$$\text{Log}\ \frac{Z^i_{68}}{Z^i_{64}} = \underset{(4.147)}{4.013} + \underset{(4.213)}{0.364}\ \text{Log}\ Y^i_{68} - \underset{(-4.417)}{0.586}\ \text{Log}\ Z^i_{64}$$

$$R^2 = .775 \quad \bar{R}^2 = 0.678$$

or when the clerical labour term replaces the output variable,

$$\text{Log}\ \frac{Z^i_{68}}{Z^i_{64}} = \underset{(4.395)}{4.5119} + \underset{(3.929)}{0.313}\ \text{Log}\ \frac{Cl^i_{63}}{Y^i_{63}} \cdot Y^i_{68} - \underset{(-4.016)}{0.537}\ \text{Log}\ Z^i_{64}$$

$$R^2 = .751 \quad \bar{R}^2 = 0.645$$

These results are reasonable but the long time stretch makes one wonder whether it is still a true Gompertz hypothesis in which the lagged term really only appears because of working in discrete time.

The next stage was to attempt to reflect industry differences in computer usage in line with the results of the analysis of survey data mentioned above. The most rewarding approach was as follows. The survey data suggests a behavioural approach to technique choice. Given the difficulty of reflecting a behavioural approach in the analysis of aggregate industry data, it was felt that if one could show that fast growing and more profitable industries diffuse quicker then this may suggest the problem solving bias and feasibility aspects of behavioural theory.

To generate such answers it was decided that the best way was to enter the adjustment coefficient as a multiple of growth and feasibility variables.(1) Three growth variables were used, growth in output, sales and profits. The level of industry profits was used to indicate feasibility. The results in Table 7 were generated.

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(1) This method was proposed by Stone and Rowe, (1957)

Table 7:

Cross Section Gompertz Hypothesis with Variable Adjustment Coefficient

Adjustment Coefficient	Constant	Log Y^i	Log Y^i_{64}	R^2	$\bar{R}^2$
λ	4.013 (4.148)	0.364 (4.213)	-0.586 (-4.417)	0.774	0.678
$\lambda\left(\frac{Y^i_{68}}{Y^i_{63}}\right)$	2.675 (6.803)	0.257 (7.578)	-0.398 (-7.323)	0.918	0.882
$\lambda\left(\frac{SALES^i_{68}}{SALES^i_{63}}\right)$	2.714 (6.438)	0.290 (8.224)	-0.429 (-7.309)	0.907	0.867
$\lambda\left(\frac{PROF^i_{68}}{PROF^i_{63}}\right)$	3.0909 (2.895)	0.257 (3.029)	-0.459 (-2.961)	0.356	0.081
$\lambda\left(\frac{Y^i_{68}}{Y^i_{68}}\right)\left(\frac{SA^i_{68}}{SA^i_{63}}\right)$	1.8401 (6.785)	0.203 (9.241)	-0.295 (7.759)	0.915	0.879
$\lambda\left(\frac{SA^i_{68}}{SA^i_{63}}\right)\left(\frac{PROF^i_{68}}{PROF^i_{63}}\right)$	2.148 (2.562)	0.196 (3.110)	-0.336 (-2.732)	0.152	-0.211

Attempts were made to replace the ratios by growth rates, however the results were definitely worse (lower R^2's and fewer variables significant). The fact that the adjustment coefficient is therefore illustrated as a function of (1 + g) which is entered multiplicatively, tends to indicate the existence of a certain constant element in the adjustment function. Efforts made to enter the level of profits as a 'feasibility' variable led to multicollinearity.

In the results presented it can be seen that either the ratio of output, sales or their multiple, relative to earlier levels, when introduced, can improve the fit of an equation as measured by R^2 or $\bar{R}^2$. In the three formulations where the performance is improved the power to which output is raised in the function for the satiation stock would appear to be estimated at around 0.7, which it is felt justifies the efforts made to introduce increasing returns to scale in the analysis of the aggregate data.

Having found that one can introduce the growth in sales and the growth in output and thereby increase the explanatory power of the hypothesis the next stage is to examine what this implies.

First; the different growth rates in different industries must mean that the pattern of computer ownership is changing. This must present aggregation difficulties for the earlier analysis. We 'look this problem firmly in the eye, and pass on'.

It would seem now that the industry with faster growth in output and sales will adjust faster to its satiation stock (the implication of the absence of sign reversal when these variables are introduced into the function). This result is in line with the results of the existing literature(1), but is not necessarily a justification of the basic behavioural theory. In fact the role of output and sales growth can be rationalised in a number of ways;

(a) A fast expanding industry may require more equipment and as such becomes more aware of the possibilities of computer usage.

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(1) See Kennedy, and Thirlwall, (1972) , and E.Mansfield, (1966)

(b) An industry growing faster may have more contact with a tight labour market and thus be more aware of the need to save labour through computerisation

(c) Fast growth may encourage computerisation through influence on evaluation procedures via expectations.

(d) The faster growth may be the result of better management and this better management may also cause more computer usage.

All these factors can be rationalised in the framework of behavioural theory but the significance of the two variables does not necessarily imply the problem solving basis of that theory and the sales variable would even seem to have the wrong sign to imply problem solving as the motive for computerisation.

Thus attempts to find a role for certain economic variables connected with behavioural theory have been partially successful. However, it cannot be guaranteed that it is the behavioural basis of technique choice that is causing them to be significant so one cannot say that they support or disprove the conclusions of that theory. In fact the results that have been achieved so far can be summarised as

(a) The Gompertz hypothesis best summarises the aggregate data;

(b) A Gompertz hypothesis spread over a four year time period with an adjustment coefficient varying with the growth in output and/or sales can be used successfully to describe the industry data.

IV

The above discussion has been carried on in the absence of any mention of supply difficulties other than to argue that a variable that reflects demand must include orders. In this section the supply of computers will be considered in more detail.

In many econometric studies the approach is to posit a supply and demand curve and to assume that the market is cleared in every time period, which, assuming identification, allows one to estimate the coefficients of the supply and demand curves from one series on the total stock installed. We cannot do this for we are not willing to assume that the market is cleared in every time period.

The approach to take then is to work on more direct information - what the companies tell the world about their output decisions. Unfortunately the computer companies are reluctant to divulge very much about their decision making (IBM suggested that such information was proprietary and worth £½m. to their competitors)(1). It is possible however to build up a picture from Evidence to the Select Committee on Science and Technology and non-attributable industry sources.

A computer takes approximately 18 months to build given the technology. The firm makes an estimate of the demand for its output at the beginning of a time period (ICL state specifically that they use a forecasting model to answer similar questions)(2).

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(1) Private communication from IBM.

(2) Select Committee on Science & Technology, (1970), p. 27.

If at the time that a machine is nine months from completion it has not been ordered, construction work ceases and only those machines with a definite sale are finished. Construction work will restart when it is ordered. Thus if there is an overestimation of demand there will be an increase in inventories and work in progress. If on the other hand there is an underestimation of demand, or the desired supply cannot be produced, there will be an increase in orders and/or a decrease in inventories.

To test this hypothesis rigorously would involve the construction of a supply curve based on some expectations mechanism, combining it with one of the demand curves constructed above, and interposing an equilibriating system based on changes in the order level. The order data is insufficient to allow one to perform such an exercise, and the result moreover would depend crucially on the assumptions about expectations behaviour.

It is possible however to gain some insight by looking at the cross sectional distribution of orders. If the present hypothesis is correct then one would expect to find that the orders of each industry in a given time period are related to the demand of that industry. This demand should be measured by the change in stocks and orders over the previous period and thus the hypothesis would state that

$$O_t^i = a_1 + b_1 (S_t^i + O_t^i - S_{t-1}^i - O_{t-1}^i) + U_1^i \qquad \ldots. (1)$$

An alternative to this is that the industry will work in a contract supply manner i.e. that the industry will only start construction once an order is received. This would imply that orders in time period t would be related to the increase in the stock in the following time period i.e.

$$O_t^i = a_2 + b_2 (S_{t+1}^i - S_t^i) + U_2^i \qquad .... (2)$$

If however the demand variable should not include orders but should only refer to the changes in the stock then the following hypothesis would result,

$$O_t^i = a_3 + b_3 (S_t^i - S_{t-1}^i) + U_3^i \qquad .... (3)$$

Finally one could argue that the industry works in a contract supply manner but is not always able to supply all that is asked of it and then orders will pile up. This would imply the hypothesis that

$$O_t^i = a_4 + b_4 (S_{t+1}^i + O_{t+1}^i - S_t^i - O_t^i) + U_4^i \qquad .... (4)$$

These hypotheses, labelled 1 - 4, were fitted to the whole set of the industry data (combining industries 9 and 10) for the years 1962 to 1970. The results are presented in Table 8.

Of the results for the years 1963 - 1969 the hypothesis that most closely relates to our discussion above, i.e. that orders in this period are related to demand in this period when this demand is measured by changes in stocks and orders, performs best in all but two years (1967 and 1968) in terms of R^2 and is second best in those two years. The contract supply hypothesis does not perform very well. If orders are not to be the base of a contract supply mechanism they must be used to mop up excess demand. However in the results there is a high constant as well as a coefficient on demand significantly different from zero. This means that even if there is no excess demand some orders would exist. This can probably be explained by a production lag.

The results above can be used for yet another purpose. It has been argued that the distribution of computers across industries is in relation to their demands. It has also been argued that if an industry's demand cannot be met it must result in orders. Thus if computers were not being distributed in relation to demand one would expect to find that one industry always had more outstanding orders relative to its level of demand than another industry. Now the fact that the cross sectional relation of orders to demand generates a high R^2 suggests that computers are distributed evenly in relation to demand. However, one can go further. If the relation existed one would expect to find that industries' orders, after the demand effect had been removed, would have completely different rank in each time period i.e. the rank correlationcoefficient of the errors from equation (1) for consecutive years would not differ significantly from zero(1).

The ranks of each industry in these errors for each year were calculated. In cases where the number of industries changed between years the ranks were recalculated. The rank correlation coefficients obtained are presented in Table 9.

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(1) P.G. Hoel, (1966) pp. 255-7

Table 8: Order Hypotheses

Year	1962	1963	1964	1965	1966	1967	1968	1969
a_1		652.5	36.3	1435.8	591.2	2111.0	1248.7	1576.4
t		(2.84)	(0.08)	(2.77)	(0.65)	(2.89)	(1.30)	(1.26)
b_1		0.35	0.79	0.80	0.88	0.54	0.52	0.48
t		(3.65)	(9.03)	(10.50)	(7.89)	(5.91)	(5.72)	(4.36)
R^2		0.43	0.81	0.85	0.76	0.62	0.61	0.48
$\bar{R}^2$		0.36	0.79	0.83	0.73	0.59	0.57	0.42
a_2	284.7	864.1	1421.0	933.6	1311.0	1423.5	2521.0	1629.0
t	(1.10)	(3.19)	(2.76)	(1.14)	1.14	(1.35)	(2.16)	(1.54)
b_2	0.37	0.23	0.63	0.79	0.73	0.48	0.37	0.57
t	(2.72)	(2.06)	(4.34)	(6.85)	(5.33)	(4.41)	(3.42)	(5.33)
R^2	0.29	0.18	0.48	0.70	0.57	0.48	0.36	0.57
$\bar{R}^2$	0.21	0.10	0.43	0.67	0.54	0.43	0.30	0.53
a_3		1079.0	2500.0	2036.0	2365.0	984.9	1504.0	1978.8
t		(4.20)	(2.40)	(2.53)	(1.85)	(1.26)	(1.27)	(1.31)
b_3		0.19	0.30	1.32	0.75	0.62	0.51	0.44
t		(1.43)	(0.74)	(5.77)	(4.11)	(6.72)	(4.25)	(3.16)
R^2		0.10	0.03	0.62	0.46	0.68	0.46	0.32
$\bar{R}^2$		0.00	-0.07	0.59	0.40	0.65	0.41	0.26
a_4	847.0	1192.5	1697.8	775.6	4669.4	2491.0	2585.0	
t	(2.43)	(4.41)	(2.86)	(0.78)	(3.26)	(2.15)	(2.45)	
b_4	0.01	0.04	0.27	0.68	0.28	0.33	0.36	
t	(0.06)	(0.69)	(3.10)	(5.62)	(1.58)	(2.96)	(3.85)	
R^2	0.00	0.02	0.32	0.61	0.11	0.29	0.41	
$\bar{R}^2$	- 0.11	-0.08	0.26	0.57	0.02	0.23	0.36	

Table 9:

Rank Correlation Coefficients

Period	Coefficient
1963-1964	0.355
1964-1965	0.360
1965-1966	0.487
1966-1967	0.305
1967-1968	0.347
1968-1969	0.455

The null hypothesis can then be accepted at the 99% level for all years and at the 95% level for all years except 1965/66 and 1968/69.

These results indicate that in fact computers were distributed in relation to demand. It was felt, however, that it was possible to go one stage further. The most important question of distribution is whether the computer supply industry will always meet its own demands before its customers. As this industry (number 5) always seemed to have a low rank, and thus low orders relative to its level of demand, it was felt it was important to test whether its rank was always the lowest. Thus the rank correlation coefficient was calculated between its actual rank and what it would have been if it always had the lowest orders. The coefficient calculated was 0.506 with sample size 7. The tabulated value at the 95% level is 0.714. Thus the null hypothesis cannot be rejected and it is accepted that computers are distributed in relation to the demand of all industries.

VII

In this paper is has been suggested that the supply of computers is based on expected demand and if that demand does not appear there is an increase in inventories or work in progress. If the actual level of demand is greater than supply then orders take up the excess. This implies that the actual measure of the level of demand for computers should be the change in the sum of stocks and orders. It has also been shown that computers are distributed between industries in relation to their demands, there being no favouritism.

Using the change in stocks and orders as the demand variable(1) it was shown that a Gompertz hypothesis could be used to summarise the diffusion process at the aggregate level. In this study however scale returns must be included as a parameter and price can only be shown to affect the selected stock if it is assumed to be included in the generation concept. Attempts to show a behaviourally varying adjustment coefficient could be introduced but the results were not conclusive. Moreover, at the industry level the time spread of the Gompertz hypothesis applied is suspect. In fact the contradictions between this study of data on computer usage and an analysis of survey data leads one to wonder whether the diffusion hypotheses applied here are little more than statistical summaries

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(1) This inclusion of orders also prevents any simultaneous bias being introduced by the use of non-simultaneous estimation methods.

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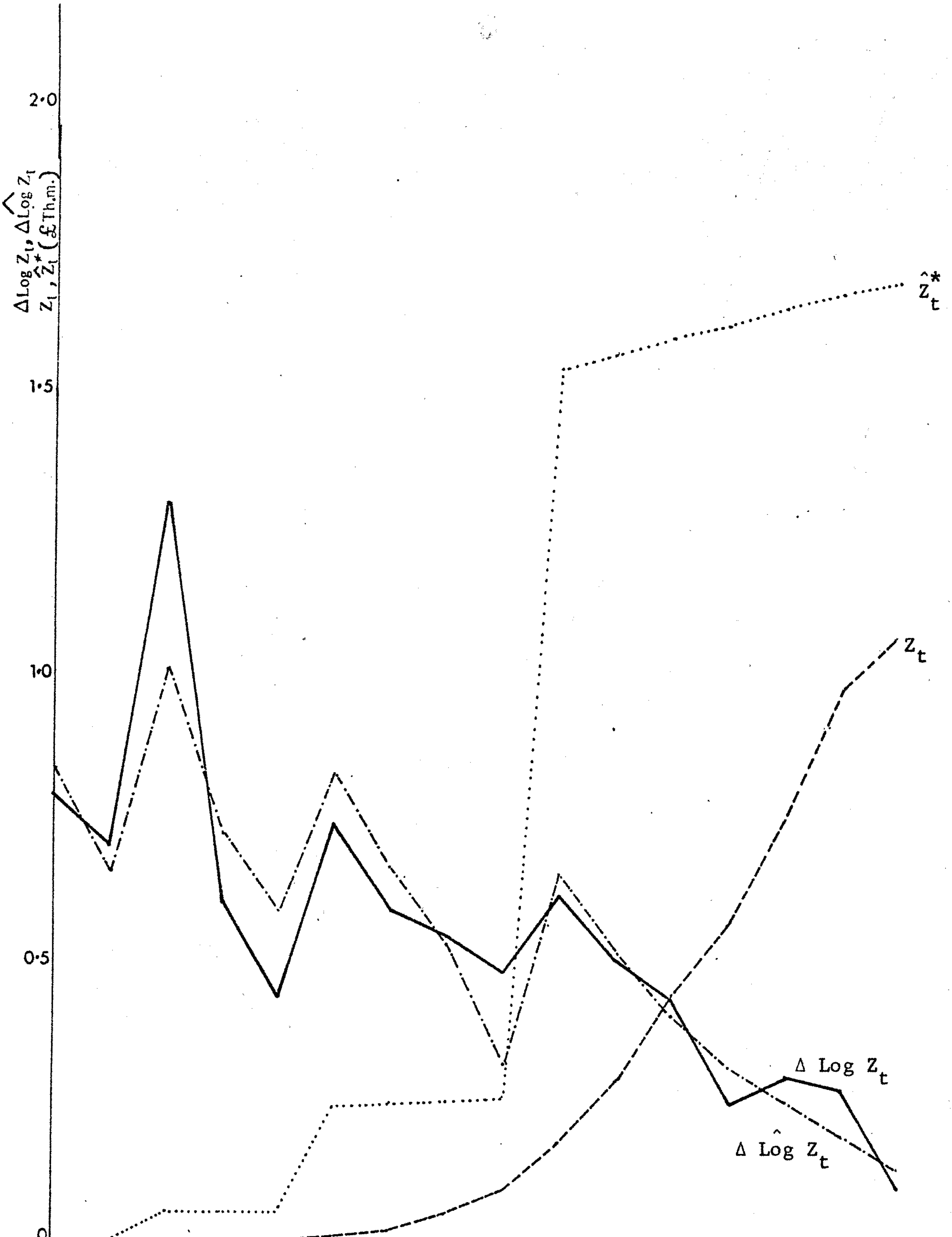
Figure 1 Quality Adjusted Price Series for Computers.

Figure 2 Quality Adjusted Quantity Series for Computers.

Figure 1


200
150
100
50
Index
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
Year
Comparison series
Price series

Figure 2



$\Delta \log Z_t$, $\widehat{\Delta \log Z_t}$
Z_t, $\hat{Z}^*_t$ (£Th.m.)
2·0
1·5
1·0
0·5
0
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
$\hat{Z}^*_t$
Z_t
Δ Log Z_t
Δ $\hat{\text{Log}}$ Z_t