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MARYLAND INTERINDUSTRY FORECASTING PROJECT

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# FORECAST OF COMPUTER DEMAND

by

Richard T. Froyen

There are at least three features of the computer industry which make the industry particularly difficult to handle within the framework of an input-output forecasting model. These are:

1. The tables of interindustry flows, upon which input-output models are based, were developed prior to the period of extremely rapid growth of the computer industry. When the BLS table of capital flows, upon which the Maryland model's capital matrix is based, was developed in 1958, the computer industry was one fourteenth of its present size.

2. There is every reason to expect the rapid growth of the industry to continue though probably at a diminishing rate. Such a growth pattern rules out the use of either the fixed coefficient assumption or its alternative, the extrapolation of an exponential time trend.

3. The practice of leasing rather than buying computers results in the peculiarity that shipments of computers are regarded as sales of capital goods, but expenditures of users for computer services are payments on current account.

In this paper I shall explain a way of handling the computer industry which tries to deal with these three problems.

1. Handling of Computer Leasing

In the Maryland model, we have dealt with the difficulties resulting from the practice of computer leasing[1] by including a computer

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1. With reference to the Interindustry Forecasting Model, the problem is that shipments of computers by the Office and Computing Machinery Industry enter into the row control of that sector in the B matrix but not into the column controls of the users which are based on the Annual Survey figures for equipment expenditures.

rental industry as an additional sector in the model. This industry purchases computers from the Office and Computing Machinery industry on capital account, and leases them to computer users, on current account.

All computers except those used by the Federal Government and Educational Services sector are assumed to be leased.[2] This assumption was necessary because we do not have data differentiating between leased and user-owned installations. The Computer Rental industry makes no other purchases or sales. It might, with no sarcasm intended, be referred to as a "dummy" industry.

2. Current Information on Computer Usage

To establish coefficients for the Computer Rental row of the A matrix we need to know the amount of computer rentals paid by each of the other 93 sectors. With the cooperation of General Electric Corporation, we have obtained parts of a census of computer installations compiled by the International Data Corporation. This data file is described in Appendix 1. The specific information we have is a distribution of the installed value of computers by two-digit SIC code as of December 1968. We also have this distribution as of December 1966, but the distributions are not strictly comparable.[3]

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2. The Federal Government and the Educational Services sector purchase computers on current account directly from the Office Machinery Industry.

3. The lack of comparability results both from changes in coverage in the I.D.C. file between 1966 and 1968 and a change in the method used by G.E. to calculate the value of individual installations. The latter is discussed in Appendix 1.

The unit of measurement for the value of a system is the system's average monthly rental. Thus, we have what we need to calculate the coefficients of the Computer Rental row. The yearly rental payments for each of the 93 sectors as of December 1968 are given in Table 1.

The sales of computers from the Office and Computing Machinery industry to the Computer Rental industry are equal to the change in the installed value of leased computer systems plus retirements of computers. We calculate the change in installed value of leased systems directly from the payments of computer rental fees on the assumption of a fixed monthly rental to system value ratio.[4]

Two specifications for retiremtnts were fitted by least squares regression of time series for gross shipments and installed value.[5] These are:

(1) $(V_t - S_t) = aV_{t-1}$  $a = .87$, $R^2 = .993$

(2) $V_t = a(V_{t-1} + S_t)$  $a = .907$, $R^2 = .996$

$S_t = \frac{1}{a}(V_t - aV_{t-1})$

where $V_t$ is installed value in period t and $S_t$ is gross shipments in period t.

The second formulation allows the level of shipments in time t to influence the retirement rate in period t. The logic behind this is that a year where shipments are large will be a year of new develop-

4. Throughout the paper, monthly rental is assumed to be one forty-fifth of installed value.

5. These series were supplied by Mr. Harold Maxon of G.E. and are admittedly rough estimates. They cover the 1956-1968 period. Specification 2 was also suggested to me by Mr. Maxon.

Table 1

Annual Rate of Computer Rental Payments (Dec. 1968)
(millions of dollars)

| | Sector Names[1] | Computer Rentals |
|---|---|---|
| 1. | Livestock | 1.2 |
| 2. | Crops | 1.1 |
| 3. | Forestry and Fishery Products | .8 |
| 4. | Agricultural Services | 1.3 |
| 5. | Iron Ore Mining | 1.0 |
| 6. | Non-Ferrous Ore Mining | 2.9 |
| 7. | Coal Mining | 1.2 |
| 8. | Petroleum Mining | 35.4 |
| 9. | Minerals Mining | 2.8 |
| 10. | Chemical Mining | .7 |
| 11. | New Construction | 12.6 |
| 12. | Maintenance Construction | 12.1 |
| 13. | Ordnance | 38.3 |
| 14. | Meat Packing | 22.4 |
| 15. | Dairy Products | 10.5 |
| 16. | Canned and Frozen Foods | 8.0 |
| 17. | Grain Mill Products | 8.7 |
| 18. | Bakery Products | 5.9 |
| 19. | Sugar | 1.9 |
| 20. | Candy | 2.2 |
| 21. | Beverages | 11.9 |
| 22. | Misc. Food Products | 8.4 |
| 23. | Tobacco | 4.9 |
| 24. | Fabrics and Yarn | 24.3 |
| 25. | Rugs, Tire Cord, Misc. Tectiles | 4.5 |
| 26. | Apparel | 29.7 |
| 27. | Household Textiles and Upholstery | 3.6 |
| 28. | Lumber & Products, Exc. Containers | 9.3 |
| 29. | Wooden Containers | .5 |
| 30. | Household Furniture | 7.6 |
| 31. | Office Furniture | 4.0 |
| 32. | Paper & Products Except Containers | 24.6 |
| 33. | Paper Containers | 9.7 |
| 34. | Printing and Publishing | 82.5 |
| 35. | Basic Chemicals | 58.7 |
| 36. | Plastics and Synthetics | 23.7 |
| 37. | Drugs, Cleaning & Toilet Items | 33.5 |
| 38. | Paint and Allied Products | 8.0 |
| 39. | Petroleum Refining | 68.7 |
| 40. | Rubber and Plastic Products | 27.5 |
| 41. | Leather Tanning | 2.2 |
| 42. | Shoes and Other Leather Products | 9.2 |

Table 1 (cont.)

| | | |
|---|---|---|
| 43. | Glass and Glass Products | 5.8 |
| 44. | Stone & Clay Products | 15.2 |
| 45. | Iron and Steel | 45.1 |
| 46. | Copper | 11.4 |
| 47. | Aluminum | 9.9 |
| 48. | Other Non-Ferrous Metals | 14.0 |
| 49. | Metal Containers | 5.8 |
| 50. | Heating, Plumbing, Structural Metal | 16.0 |
| 51. | Stampings, Screw Machine Products | 10.9 |
| 52. | Hardware, Plating, Valves, Wire Products | 14.2 |
| 53. | Engines and Turbines | 12.1 |
| 54. | Farm Machinery and Equipment | 15.3 |
| 55. | Construction & Mining Machinery | 18.3 |
| 56. | Material Handling Equipment | 10.3 |
| 57. | Metalworking Machinery & Equipment | 28.6 |
| 58. | Special Industrial Machinery | 17.0 |
| 59. | General Industrial Machinery | 26.3 |
| 60. | Machine Shops & Misc. Machinery | 14.5 |
| 61. | Office and Computing Machines | 22.4 |
| 62. | Service Industry Machines | 18.4 |
| 63. | Electric Motors & Apparatus | 41.5 |
| 64. | Household Appliances | 24.9 |
| 65. | Electric Lighting and Wiring Equipment | 17.8 |
| 66. | Communication Equipment | 64.4 |
| 67. | Electronic Components | 40.4 |
| 68. | Batteries, X-Ray, & Engine Elec Equip. | 13.0 |
| 69. | Motor Vehicles | 118.4 |
| 70. | Aircraft and Parts | 111.2 |
| 71. | Ships, Trains, Trailers & Cycles | 14.5 |
| 72. | Instruments and Clocks | 25.8 |
| 73. | Optical & Photographic Equip. | 19.3 |
| 74. | Misc. Manufactured Products | 18.4 |
| 75. | Transportation | 150.7 |
| 76. | Communication | 101.6 |
| 77. | Radio, TV Broadcasting | 17.0 |
| 78. | Electric Utility | 63.9 |
| 79. | Gas Utility | 28.2 |
| 80. | Water Utility | 8.6 |
| 81. | Wholesale and Retail Trade | 207.4 |
| 82. | Finance and Insurance | 793.3 |
| 83. | Real Estate and Rental | 4.7 |
| 84. | Hotels, Personal & Repair Services | 4.4 |
| 85. | Business Services | 372.8 |
| 86. | Automobile Repair Services | 1.2 |
| 87. | Amusements and Recreation | 5.1 |
| 99. | State and Local Government | 183.2 |
| | Total | 3411.5 |

All sectors are assumed to rent computers with the exception of the Federal Government and Medical and Educational services including these sectors would bring the total yearly rental value of installed systmes to 4.21 billion dollars.

ments in the industry. This will increase the rate at which existing machines become obsolete. However, for forecasting purposes, this advantage is lost since we have no way of knowing which future years will be years of significant new developments. We therefore used equation (1).

Computers have now been put into the model. In order to treat them realistically, we must allow for changes in the coefficients of the Computer Rental row.

3. Estimating Coefficient Change

a. Chow's Method.

In order to estimate coefficient change, I shall draw on Gregory Chow's work which used, "a Gompertz difference equation, modified by a moving equilibrum due to . . . price change . . ."[6] to explain the growth of computer demand.

The equation for the Gompertz curve is

$$\frac{dy}{dt} = ay\,(\log y^{*}-\log y)$$

or

$$\frac{d\log y}{dt} = a\,(\log y^{*}-\log y) \tag{1}$$

where y is the existing stock of computers and y* is the equilibrium stock. The existing stock has two influences. It has a positive influence on growth in demand which can be viewed as a "demonstration effect." It also exerts a negative influence on growth because the percentage rate of growth is a decreasing function of the distance between the logs of the desired and actual stocks.

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6. Chow, Gregory [1].

To estimate this equation we need to know y*. Chow estimates y* as a function of the price of computer services and the output of the user industry. Assuming this ralationship to be linear in the logarithms of the variables we have:

$$(2) \quad \log y^*_t = B_o - B_1 \log p_t + B_2 \log x_t$$

where $s_t$ is the output variable. Substitution into 1 yields

$$(3) \quad \frac{d \log y}{dt} = aB_o - aB_1 \log p_t + aB_2 \log x_t \quad a \log Y_{t-1}$$

The next step is estimation of the price variable. This must measure price per unit of computer services and reflect the technological change taking place in the industry. To obtain such an index, Chow first tries to explain the rental of a system by three of its significant characteristics; core size, access time and multiplication time. Average monthly rental is regressed on these three variables for all models introduced from 1969 through 1965, again assuming the relationships to be linear in logarithms. A dummy variable is introduced for each year after 1960 in order to allow for the change in the intercept.

Using the 1960 intercept, Chow then computes a hypothetical 1960 rental. A price index is then computed by taking rental value in time t divided by the hypothetical 1960 rental summing over all models introduced in time t and taking the arithmetic mean.

$$\frac{p^t}{p^{60}} = \frac{1}{n} \sum_{i=1}^{n} \frac{r_i^t}{r_i^{60}}$$

where P is the price level and $r_i$ is monthly rental of model i.

Using GNP as the user output variable, Chow then estimates the parameters of the Gompertz equation.

b. Modifications and Applications

With very few changes, the Gompertz curve technique proved useful in estimating coefficient change. Chow, however, was estimating total demand for computers while we need to estimate the growth in each of ninety-three industries. Only if we can assume that all coefficients will grow at the same rate will the two problems be identical.[7] Is this a reasonable assumption?

Table 2 gives, for December 1966 and December 1968, the percent of total installed value of computers held by each two digit industry which held over one percent of the total. In viewing the table; the sources of non comparability between the two series should be remembered.[8] Also the figures are for total usage; they are not coefficients. With this in mind, the table strongly supports the assumption we wish to make. Banking and business services are the only industries to show a really significant rise in the share of computer usage. Other support for the assumption of uniform coefficient growth comes from what seems to be a general view within the industry that most potential users have now become aware of possible applications of computers and

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7. Note that it is the coefficients and not the expenditure on computers which must be constant.

8. See Section 1, footnote 3 and Appendix 1.

Table 2

| Industry | Percent of Installed Value of Computers Dec. 1966 | Dec. 1968 |
|---|---|---|
| Retail Trade | 2.3 | 2.4 |
| Banking and Credit | 8.3 | 12.3 |
| Printing and Publishing | 1.6 | 2.0 |
| Chemicals, Paints and Plastics | 2.9 | 2.9 |
| Petroleum Drilling and Refining | 3.3 | 2.7 |
| Primary Metals | 1.9 | 1.9 |
| Fabricated Metals | 1.3 | 1.1 |
| Electrical Machinery | 4.6 | 4.8 |
| Instrument and Related Products | 1.2 | 1.1 |
| Railroads | 1.3 | 1.4 |
| Air - Transportation | 1.0 | 1.2 |
| Communications | 2.9 | 2.9 |
| Ordnance and Aircraft | 8.9 | 6.7 |
| Utilities | 2.5 | 2.4 |
| Wholesale Trade | 2.1 | 2.9 |
| Securities | 1.0 | 1.1 |
| Insurance | 7.3 | 6.9 |
| Miscellaneous Services | 7.5 | 9.6 |
| Educational Services | 7.3 | 7.6 |
| Federal Government | 12.8 | 9.8 |
| State and Local Government | 3.1 | 3.9 |

37% of equilibrium stock.

Chow found that the logistic curve was inferior to the Gompertz curve as an estimator of growth in computer demand. I have used the logistic curve in regressions on both real rentals and with the Knight price index and in all cases the results were inferior to those using the Gompertz curve.[12]

d. Results

The result of Chow's original regression without an output variable was:

$$\log (y_t/y_{t-1}) = \underset{(.1726)}{-.3637} \log p_t - \underset{(.0739)}{.2526} \log y_{t-1} + 2.950 \quad R^2 = .834$$

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12. a. The criteria of superiority being goodness of fit and abiltiy to identify a consistant price effect.

b. To test the logistic curve hypothesis it is necessary to try various guesses about the price elasticity. From equation (2) we have an expression for log y*. Dropping the output effect, we have

$$y^* = B_o e^{-B_1}$$

where $B_1$ is the price elasticity. We can then substitute this expression for y* in (4), if $B_1$ is known. Following Chow's procedure, I tried estimates of $B_1$ ranging from -.5 to -2.5.

c. Since testing the logistic curve as an explanation of growth in computer demand, I have become aware of a slightly different formulation, which is:

$$\frac{dy}{dt} = \frac{\gamma y}{y^*} (y^* - y)$$

This will, however, generate a curve which is everywhere below the first specification of the logistic. The curve is still symetrical and reaches its maximum at 50% of equilibrium stock. Since growth in the early stages will be even slower than that of the first specification of the logistic this formulation is even less likely to explain the rapid, early growth of computer demand.

For a discussion of this and other formulations of the logistic function, see: Oliver, F.R. [4].

The two price indices are printed in table 3. A description of Knight's measures of computer performance and the calculation of the price index is provided in Appendix 2.

Table 3

Undeflated Price Indices for Computers

| | Chow | Calculated from Knight |
|---|---|---|
| 1954 | 3.2554 | 2.798 |
| 1955 | 2.9610 | 2.255 |
| 1956 | 2.5336 | 1.929 |
| 1957 | 2.3168 | 1.639 |
| 1958 | 2.0342 | 1.426 |
| 1959 | 1.5884 | 1.292 |
| 1960 | 1.0716 | 1.000 |
| 1961 | .9042 | .712 |
| 1962 | .6873 | .494 |
| 1963 | .5712 | .355 |
| 1964 | .4186 | .279 |
| 1965 | .3416 | .181 |
| 1966 | ---- | .141 |

c. An Alternative Estimator

Chow also tested the hypothesis that growth in computer demand follows the path of logistic curve rather than the Gompertz curve.

The logistic results from the solution of the differential equation:

$$\frac{dy}{dt} = \gamma \, y \, (y^* - y)$$

or

$$\frac{d \log y}{dt} = \gamma \, (y^* - y). \quad (4)$$

For this formulation the percent increase in computer demand is a linear function of $y^* - y$ rather than of the difference between $\log y^*$ and $\log y$. The logistic curve reaches its maximum rate of growth at 50% of equilibrium stock while the Gompertz curve has its maximum at and the opening up of new markets is unlikely. The demonstration effect has largely played out.[9]

Possibly, I have belabored the justfication of this assumption, but I do so because the relative stability of the distribution of computer usage is, of itself, an important development within the industry.

One modification which was necessary before applying Chow's technique was to change the computer quantity variable from hypothetical 1960 rentals to real rentals. Chow had used 1960 rentals as a quantity variable because he wanted a measure of computer services not of expenditure on computers. Since I wished to estimate expenditures, a quantity variable in current rentals was necessary.[10] In estimating the Gompertz equation, two such series were tried. One was supplied by Gregory Chow and the other by Harold Maxon of General Electric.

Dr. Kenneth Knight has also estimated rates of technological change in computer performance.[11] His work was used to derive an alternate price index to use in place of Chow's. Knight's method of estimating computer performance is much more detailed than the method used by Chow. I also felt that the use of an alternative price index formed a useful additional test of the Gompertz curve hypothesis for computer demand.

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9. As will be seen later, this is true because we are already well above the percentage of equilibrium stock at which the Gompertz curve reaches its maximum rate of growth.

10. It might at first be thought that 1960 rentals could be estimated and then converted into real rentals using the price index. However, since the price index was based only on an arithmetic average of new model prices, this cannot be done. What would be needed is a price index of all models weighted by the number of installations of each type. This would be rather difficult to forecast.

11. Knight, Kenneth [2] [3].

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37% of equilibrium stock.

Chow found that the logistic curve was inferior to the Gompertz curve as an estimator of growth in computer demand. I have used the logistic curve in regressions on both real rentals and with the Knight price index and in all cases the results were inferior to those using the Gompertz curve.[12]

d. Results

The result of Chow's original regression without an output variable was:

$$\log (y_t/y_{t-1}) = \underset{(.1726)}{-.3637} \log p_t - \underset{(.0739)}{.2526} \log y_{t-1} + 2.950 \quad R^2 = .834$$

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12. a. The criteria of superiority being goodness of fit and abiltiy to identify a consistant price effect.

b. To test the logistic curve hypothesis it is necessary to try various guesses about the price elasticity. From equation (2) we have an expression for log y*. Dropping the output effect, we have

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where $B_1$ is the price elasticity. We can then substitute this expression for y* in (4), if $B_1$ is known. Following Chow's procedure, I tried estimates of $B_1$ ranging from -.5 to -2.5.

c. Since testing the logistic curve as an explanation of growth in computer demand, I have become aware of a slightly different formulation, which is:

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This will, however, generate a curve which is everywhere below the first specification of the logistic. The curve is still symetrical and reaches its maximum at 50% of equilibrium stock. Since growth in the early stages will be even slower than that of the first specification of the logistic this formulation is even less likely to explain the rapid, early growth of computer demand.

For a discussion of this and other formulations of the logistic function, see: Oliver, F.R. [4].

where y is the stock variable and p is the price index. The price elasticity at the equilibrium stock is 1.44.[13]

Substitution of the series of real rentals supplied by Chow for 1960 rentals gives a slightly better fit,

$$\log (y_t/y_{t-1}) = \underset{(.0780)}{-.1417} \log p_t - \underset{(.0434)}{.2329} \log y_{t-1} + 2.764 \quad R^2 = .948$$

Here we are estimating not a price elasticity but the elasticity of expenditures on computer services with respect to price. At equilibrium stock this elasticity is .61.

It is reassuring to find that substituting the price index calculated from Knight's work for Chow's price variable produces very little change in the results,

$$\log (y_t/y_{t-1}) = \underset{(.0551)}{-.1223} \log p_t - \underset{(.0341)}{.2284} \log y_{t-1} + 2.765 \quad R^2 = .954$$

At equilibrium stock the elasticity of computer expenditures is .54.

Regressions using the G.E. series of rentals produced less satisfactory results. This was not surprising since the series is a rough estimate.[14] Neither with the Chow nor with the Knight index

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13. Chow [1], p. 1126.

14. The G.E. series is uniformly higher than Chow's and while year-to-year changes are a rough approximation the general level of computer rental is probably more realistic than that implied by Chow's series. Assuming that the I.D.C. file total of 15.8 billion dollars (installed value) in December 1968 is correct, Chow's 1965 total would imply a yearly growth rate of 35 percent for the 1965-68 period. To reach the December 1966 I.D.C. total of 10.8 billion dollars would have required a 60 percent growth during 1965-66. Chow's figures are more in line with I.D.C. totals before correction is made for installations which are missed in the data gathering process.

is the coefficient on the price variable significant.[15] The implied expenditure elasticities at equilibrium stock are .86 and .53 for the Chow and Knight price indices.[16]

Chow attempted to take account of changes in user output which should affect the demand for computers. As a measure of user output he used GNP. In his regression, however, the coefficient had the wrong sign and was very insignificant. When real rentals are the dependent variable, the GNP coefficient has the expected sign but is even more insignificant.[17] This is not surprising since the effect of the large declines in price are likely to obscure the smaller effects of the increases in user output.[18]

We wish to use the Gompertz equation to forecast coefficient change, i.e., change in computer demand per unit of user output, and then use the input-output model to forecast actual demand for computer services on the basis of forecasts of other industry outputs. In order to do

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15. Both coefficients are less than their standard error.

16. The best results using the G.E. series were obtained using the Knight price index. The result of this regression was

$$\log (y_t/y_{t-1}) = \underset{(.1268)}{-.1138} \log p_t - \underset{(.1166)}{.1946} \log y_{t-1} + 2.42 \quad R^2 = .72$$

The expenditure elasticity of .53 is almost exactly the same as when the Chow rental series is used (.54).

17. Its t ratio is less than .05 compared with .5 before.

18. It should be remembered that the growth rate in computer rentals averaged over 40 percent during this period. A unitary elasticity of output would account for only about one-tenth of this.

this, it is necessary to separate the effect of increased user outputs from the effect of coefficient change for the period in which we estimate the equation. Since we do not have a reliable estimate of the output elasticity of computer demand we have assumed that it was unitary throughout the period. With the output elasticity fixed at one, the equation for growth in computer demand becomes

$$\log (y_t/y_{t-1}) = aB_o - aB_1 \log P_t - a \log (y_{t-1}/x_t),$$ [19]

where $x_t$ is an index of user output.

As a measure of user output, a weighted output variable was constructed for each of the eleven years of the period with the 1968 coefficients of the Computer Rental industry used as weights for each of the 93 sectors of the Maryland forecasting model. Ideally, the index of user output would reflect computer usage by each industry in each year, however, the distribution of computers by industry was not available for each year.

Estimation of this form of the Gompertz equation using the Knight price variable yields

$$\log (y_t/y_{t-1}) = \underset{(.0514)}{-.0837} \log p_t \underset{(.0350)}{-.2262} \log (y_{t-1}/x_t) +1.242 \quad R^2 = .952$$

At equilibrium stock, the expenditure elasticity with respect to price is .36. As expected, this is lower than the estimate of .54 obtained when no output variable was included.[20]

19. See equation 3 on page above.

20. Chow also tested to see how seriously the price elasticity might have been biased by failure to isolate on output effect. (see Chow [4], p. 1129). Use of his procedure on the present equation, for estimating real rentals, reduced the estimate of the expenditure elasticity from .54 to .40.

## 4. Forecasts of Coefficient Change

The specification of the Gompertz equation which was estimated with output elasticity fixed at unity was used to predict growth in computer demand holding output constant. This is a forecast of coefficient growth. As explained in Section Three, it was assumed that all the coefficients in the Computer Rental row will grow at the same rate so only the growth rate of the total need be calculated. This forecast requires a knowledge of the future behavior of price per unit of computer services.

Forecasting the future behavior of our price index presents some obvious difficulties. When deflated using the implicit GNP deflator the Chow and Knight indices show yearly price declines of 23.2 percent and 27.8 percent for the 1954-65 period. Knight has also shown in a separate analysis of the 1962-66 period that there was no tendency for the rate of price decline to slow down.

To get some idea of very recent price performance, I have tried to extend Chow's price index through 1968.

A regression of the system's monthly rental on add time, access time, and core memory size was run for 84 models introduced from 1964 to 1968. All variables were in logarithms. A dummy variable was included for whether or not the model performed floating point arithmetic. Dummy variables were also included for each year after 1964.

Lack of information on systems rental value or internal characteristics necessitated the exclusion of many other models.

All coefficients with the exception of add time were significant and had the expected signs. The $R^2$ was .54.[21]

Using the coefficients of the dummy variables for 1965-68, a price index was constructed.[22] This index is given in Table 4. The yearly price decline is 29 percent. Other methods I have tried for estimating recent price changes show that the figure for any one year is highly unreliable but the estimate of the average decline over the four years is relatively stable at something over 20 percent.[23]

Table 4

Extention of Price Index for Computers

| | |
|---|---|
| 1964 | 1.0 |
| 1965 | .66 |
| 1966 | .51 |
| 1967 | .46 |
| 1968 | .25 |

There is, however, reason to believe that the industry cannot maintain this rate of technical progress throughout the 1968-1980 period. If the 1965-65 rate of price decline continued through 1980 the price index with 1960 as base would have a value of .005. A dollar would

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21. The source for computer characteristics and rental price was Computers & Automation which prints a buyers' guide each June.

22. As described in Appendix 2.

23. The other methods were first to assume the coefficients Chow estimated were unchanged and use them to evaluate the 1964-68 models this implies a price decline of over 20 percent, although it is slightly below this for the 1966-68 period. An arithmetic price index was calculated using the pooled regression of 1964-68 models. It also indicates a yearly price decline of over 20 percent.

buy more than 200 times the computer power than it would have in 1960.

A less optimistic forecast is that with the opportunities for increased efficiency of mass peripheral storage systems diminishing, the time sharing concept and the small computer becoming fully developed, the rate of technical progress will begin to decline. For the purposes of the present forecast, we will assume that the rate of decline in the price computer services begins at 23.3 percent, which is the exponential rate of decline in the Chow index for the 1954-65 period, but beginning with the 1966-67 year we will assume that this rate itself declines at 1 percent per year. Thus by 1975, the rate of decline is 14.3 percent, by 1980 it is 9.3 percent.

Using the form of the Gompertz curve equation estimated with the Knight price variable and forced unitary output elasticity, we can forecast yearly rates of coefficient change to 1980. These are given in Table 5a.

Table 5

| | 5a<br>Percentage growth rate in coefficient assuming 1% yearly decline in rate of Technological change | 5b<br>Percentage coefficient growth assuming constant price of computer services |
|---|---|---|
| 1969 | 15.6 | 15.5 |
| 1970 | 13.8 | 11.9 |
| 1971 | 12.5 | 9.3 |
| 1972 | 11.3 | 7.2 |
| 1973 | 10.3 | 5.5 |
| 1974 | 9.4 | 4.3 |
| 1975 | 8.7 | 3.3 |
| 1976 | 8.0 | 2.6 |
| 1977 | 7.4 | 2.0 |
| 1978 | 6.8 | 1.5 |
| 1979 | 6.2 | 1.2 |
| 1980 | 5.7 | .9 |

We can also separate the coefficient growth resulting from continued movement of the equilibrium stock as the result of price decline from the influence of the growth parameter in the Gompertz equation. Table 5b gives the yearly rate of coefficient change estimated on the assumption that prices remain constant at their 1969 level. The fast decline in the growth lends support to the view that the "demonstration effect" on computer demand has pretty much been realized. Futute industry growth will depend, to a larger extent than in the post, on improved computer performance and on growth of user industries.

5. Growth of the Computer Rental Industry.

Once the coefficients and their growth rates have been estimated, the Interindustry Forecasting Model is then used to forecast the output of the Computer Rental Industry which is dependent on all other industry outputs and various final demand categories.

The forecasts of the output of the Computer Rental Industry for selected years in the 1968-1980 period as well as the implied industry growth rates are given in tables six and seven.

Table 6
Computer Rentals (millions of dollars)

| | |
|---|---|
| 1968 | 3129.7 |
| 1970 | 4370.4 |
| 1972 | 6010.7 |
| 1975 | 8984.5 |
| 1980 | 15227.3 |

Table 7
Annual Growth Rates of Computer Rental Industry

| | |
|---|---|
| 1968-70 | 16.7% |
| 1968-72 | 16.3% |
| 1968-75 | 15.1% |
| 1968-80 | 13.2% |
| 1970-75 | 14.4% |
| 1975-80 | 10.6% |

## REFERENCES


1. Chow, Gregory, "Technological Progress and the Demand for Computers," American Economic Review, December 1967, 57, pp. 1117-31.

2. Knight, Kenneth, "Changes in Computer Performance," Datamation, January 1966, pp. 40-54.

3. Knight, Kenneth, "Evolving Computer Performance 1963-1967," Datamation, January 1968, pp. 31-35.

4. Oliver, F.R., "Another Generalization of the Logistic Growth Function," Econometrica, January 1969, 37, pp. 144-47.

5. "Computers and Automation," various issues 1964-69.

## Appendix 1

### Description of Data Source

The source of our data on computer installations is the data base compiled by International Data Corporation.[1] Presently, this file includes 27,000 computer systems. One of the details available for each installation is the SIC code of the user industry.

General Electric established a rental value for each system based on the individual characteristics of the installation rather than rely on an average value for all systems of a particular model. This was done only for the data in the 1968 version of the file, which is one source of the lack of comparability between the end of 1966 and the end of 1968 figures.

General Electric also made a correction for what they felt were installations missing from the I.D.C. base. They developed correction factors for each of seven size classes. The largest correction factor was for the smallest size class which includes the installations most likely to be missed. Overall, the corrected number of installations is 40,000 compared to 27,000 total before applying the correction factors.

Both of the above modifications should have substantially improved an already very useful data base.

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1. I am grateful to Mr. Robert Mathieson, formerly of General Electric Corporation, Mr. Harold Maxon of General Electric, and Mr. Max Eveleth, Jr., of the International Data Corporation, for making it possible to obtain.

Appendix 2

An Alternative Measure of Technological Change in the Computer Industry

Two articles by Kenneth Knight provided the basis for an alternative price index to use in estimating computer demand.[1] Knight constructs a performance variable for each computer model for both commercial and scientific computations. In the construction of this variable he takes account of memory size, calculation time (each type of calculation entering the variable with a weight proportional to the frequency with which it is used in representative programs), and the time which the central processor is idle waiting for information.

He then regresses cost, measured in seconds per dollar, on performance. Dummy variables are included for all years other than the base:

$$\log (C) = a_0 - a_1 \log (P) + d_i, \ldots, d_n,$$

where C is seconds per dollar and P is the performance variable. For each year this produces what Knight calls "technology curves" and the dummy variables estimate the yearly shift in these curves.[2]

From the coefficients of the dummy variable, a price index can be calculated. If b is the base year and t is the year in question, then:

$$\log C_t = \log C_b + a_t$$

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1. Knight, Kenneth. [2] [3]

2. There are separate regressions for scientific and commercial computations. For a price index I have used the average of the price indices calculated for each type of calculation.

where a is the coefficient of the dummy variable for year t, so,

$$\frac{C_T}{C_B} = e^{a_t}$$

C is measured in seconds per dollar, the reciprocal of price so:

$$\frac{P_T}{P_B} = \frac{1}{e^{a_t}}.$$ [3]

3. Chow suggests this interpretation for the dummy variables in his pooled regression [1], p. 1124