Cost Effectiveness and Competitiveness in the Computer Industry: A New Metric

Suffering from losses close to $5 billion in 1992, International Business Machines seemed to stumble. IBM had grown into a colossus during the age of the mainframe computer, but the company only belatedly and halfheartedly entered the PC market. It consistently underestimated the force of the dynamic change taking place in the industry. Instead, the new microprocessor technology had been pioneered by companies like Apple, Silicon Graphics, Sun Microsystems, and Symbol Technologies. As these representatives of a new computer generation grew by leaps and bounds, established companies like IBM and Digital were fighting for their survival, and companies like Atari and Wang Laboratories were virtually wiped out.

To measure the nature and extent of the high tech revolution in the computer industry, we have been engaged in a research program to assess each company's performance in relation to the advancing cost-effectiveness envelope. The data used for the study reported here are from Standard & Poor's COMPUSTAT data base, which provides a compilation of standard financial data for all corporations quoted on Wall Street during the last 20 years. An extensive data search was carried out to establish the stock "fundamentals" of all computer corporations each year, and to rank the companies in relation to each other.

The envelope or "frontier" to be discussed here is defined by the most cost-effective companies in the industry. The frontier indicates the lowest possible use of inputs while still delivering the same output. Companies located at the frontier have a competitive edge compared to those that are falling behind the frontier. To determine the frontier, and to rank the corporations in relation to the frontier, we have used a new operations research tool called Data Envelopment Analysis or DEA (Charnes, Cooper, and Rhodes 1978). Developed in collaboration with leading researchers at the University of Texas, DEA is designed to rank corporations, public schools, or any decision-making entities in the private or public sector according to their economic performance.[1]

The following simple example introduces the key ideas. Digital Equipment and Hewlett-Packard were widely admired during the 1980s. In the well-known book *In Search of Excellence* by Peters and Waterman, they were listed as possessing "excellent" management. But take a look at the information below for Digital Equipment.

Digital Equipment: Cost of goods sold, in billions of dollars

	1981	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
COGS	$1.67	$2.04	$2.40	$3.13	$3.77	$3.89	$4.07	$4.95	$5.58	$6.03
At envelope	$1.57	$1.86	$2.12	$2.53	$2.92	$3.19	$3.67	$4.34	$5.04	$5.31

Digital Equipment: Employment, in thousands of workers

	1981	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
Employment	63	67	73	86	89	95	111	122	126	124
At envelope	28	34	56	62	39	43	49	61	57	66

The envelope is defined by the most cost-effective companies in the industry. From the information above, though, Digital Equipment, judged from the perspective of what more cost-effective corporations were able to achieve, ran up excessive costs on goods sold. Moreover, given the company's output, employment was twice what should have been sufficient in many years.

The same information is presented below for Hewlett-Packard. Analogous to Digital Equipment, Hewlett-Packard, relative to the most cost-effective firms in the computer industry, generally experienced cost of goods sold and employment that were higher than necessary to achieve its output.

Overall, the envelope calculations suggest that it should have been possible for both of these corporations to reduce their use of inputs such as cost of goods sold and employment while still delivering the same outputs. As such, utilizing standard DEA parlance, both firms were inefficient.

Hewlett-Packard: Cost of goods sold, in billions of dollars

	1981	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
COGS	$1.64	$1.95	$2.10	$2.76	$3.04	$3.03	$3.44	$4.38	$5.67	$6.51
At envelope	$1.60	$1.86	$1.92	$2.38	$2.44	$2.59	$3.02	$3.88	$5.18	$5.90

Hewlett-Packard: Employment, in thousands of workers

	1981	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*
Employment	64	68	72	82	84	92	82	87	95	92
At envelope	36	38	48	58	42	41	43	46	41	83

Empirical results like these will no doubt look suspicious to mainstream economists brought up on the principles of neoclassical economic theory. That theory is based on the premise of cost minimization. Until recently, economists have had no way of being able to check directly whether their standard assumptions of economic rationality and the notion of "economic man" are actually satisfied. Economists have had no tool to *measure* the possible deviations from the textbook hypothesis.

The envelope calculations provide precisely such a tool. Economic rationality and cost minimization occur at the frontier. But for companies that fall behind the frontier, the postulates of conventional economic theory are not satisfied. It turns out that less than perfect cost effectiveness is very much part of the real world. Applying DEA and computing the cost-effectiveness envelope, we have found that individual "well-run" companies, like Digital Equipment and Hewlett-Packard, have been operating far away from their cost minimization points for years.

DATA ENVELOPMENT ANALYSIS: RATING THE RELATIVE COST EFFECTIVENESS ("EFFICIENCY") OF A CORPORATION

Data envelopment analysis permits a comparison of the actual performance of a corporation with the hypothetical performance at the envelope. The measure of this comparison is the relative cost-effectiveness or the "efficiency rating" of the corporation. As such, this measure is termed the DEA metric. For corporations operating at the industry envelope, the metric is set equal to unity.

Back in the early 1980s, International Business Machines was still a very healthy company, setting the standards in the industry. As illustrated in Figure 1, IBM's efficiency rating was then a comfortable 1.00—the company was 100 percent cost efficient. But by 1984, the giant company began falling behind. By 1986, its rating had fallen to a mere 60 percent. Now IBM was "inefficient" or "subefficient." The company used more inputs than needed at the frontier. The efficiency rating 0.6 means that IBM should have been able to reduce proportionally its use of all inputs to 60 percent of current levels while still producing the same outputs or more. In other words, the efficiency calculations indicate the potential cost savings that would be within reach if the subefficient company were to move up from its current technology practice to the envelope.[2]

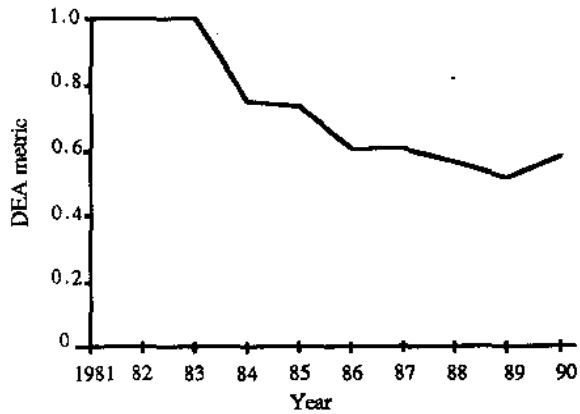

Figure 1. Efficiency rating for IBM.

Newpapers and magazines sometimes rank corporations according to their size (market capitalization) or their rate of growth (of sales revenues). Such rankings are trivial when there is just one ranking criterion. DEA establishes a ranking of corporations in the presence of several ranking criteria. Some of these criteria must be identified as performance indices or "outputs;" others as inputs or costs.

For the outputs and inputs employed in the present study, see Table 1. Note the forward-looking character of several of these variables. Market capitalization (an output) and expenditures on investments and on R&D (inputs) relate as much to the future operations of the company as to present ones. The efficiency frontier or envelope does not refer to current operations alone; it also reflects the resource allocations of the corporation in terms of capital investment and R&D, and the perception of the stock market of the fortunes of the company.

The DEA application is based on data for 44 large computer companies.[3] For a list of these companies, see Table 2.[4] Envelope calculations were carried out for each of the ten years 1981-1990.[5]

Table 1. Outputs and inputs used in envelope calculations

Outputs (Indices of Performance)

(1) Annual sales
(2) Annual net income after depreciation and taxes
(3) Market capitalization on Dec.31 (stock price times number of shares outstanding)

Inputs (Indices of Effort or Cost)

(1) Employment
(2) Plant, property, and equipment, gross, on Jan.1
(3) Expenditure on capital investments
(4) Cost of goods sold
(5) Selling, general, and administrative expenditures
(6) Expenditure on R&D

THE COST-EFFECTIVENESS FRONTIER

From Table 2 it is easy to identify the companies that in any given year define or "span" the cost-effectiveness frontier. For instance, in 1990 the frontier was defined by 18 firms: Amdahl, Apple, AST, Commodore, Compaq, Conner, Cray, Dell, Genicom, Micropolis, National, Quantum, Seagate, Silicon Graphics, Stratus, Tandem, Tandon, and Tandy.

Among these companies, a few happened to stay at the frontier throughout the observed time period. These are the efficiency leaders. Permitting at most one year of subefficiency, they are Apple, Atari, Compaq, Conner, Dell, National, Seagate, and Silicon Graphics.

At this point, a word of caution may be called for. DEA measures input-output efficiency, the proximity of an observed input-output point to the frontier. It measures how efficiently management is able to economize on the use of inputs in order to obtain the given outputs. But there are other dimensions to success, including the timely rejuvenation of the product line, marketing savvy, aggressiveness, growth, and appreciation of the stock price.

So, some care is needed when interpreting the results of the efficiency calculations. A high rating does not guarantee that a corporation is expanding and growing, nor necessarily that it is doing well on Wall Street. Rather, the concept says something about management discipline: the ability of management to keep costs and expenditures under control in relation to outputs. Such discipline can be exercised in good times and bad times alike.

One measure of success is market share (here defined as annual sales of a company divided by industry sales). During the decade, Apple increased its market share about sixfold. Compaq was not far behind. Seagate also did well. Dell and Quantum both grew rapidly in 1988-90. But other efficiency leaders did not improve their market positions. National Computer lost market share in 1987, as did Quantum in 1984-86. The case of Atari is instructive. The last good year for Atari was 1987; from then on, its sales fell in every single year as Nintendo took over the market for computer games. Atari ran up red ink in 1990 and the price of its stock collapsed. Yet, Atari remained efficient. Why? It downsized well, slashing inputs to maintain its perfect input-output ratio.

Turning next to the opposite end of the efficiency spectrum, Table 2 also shows that several companies were consistently or over many years rated as inefficient, that is, they obtained an efficiency rating less than 1.0. Prominent among these are Data General, Digital Equipment, Hewlett-Packard, IBM (since 1984), NCR, Sun Microsystems, Unisys, and Wang Laboratories.

But again, cost effectiveness is only one dimension of the competitiveness of a company. By conventional measures, some of the efficiency laggards did quite well. Digital and Hewlett-Packard were two companies of approximately the same size at the beginning of the decade; each slowly expanded its market share. Unisys lost market share in the early 1980s but blossomed during the difficult years of 1985-87. And then there was the remarkable performance of Sun Microsystems, one of the great stars of the industry. After its introduction on Wall Street in 1985, it saw its sales multiply more than twentyfold during the next five years.

Modern thermodynamics investigates physical dynamic systems that are engaged in disequilibrium paths "far from equilibrium." Low efficiency values for Sun (in the 80-90 percent range) seem to indicate that this corporation, similarly, grew along a trajectory that was located "far" from equilibrium.

Wang Laboratories presents a clearcut case of distress. After founder An Wang retired in 1984, this company ran into serious trouble. The efficiency

Table 2. Computer companies studied, time span during which each company was included in the study, and year(s) when a company was rated as being 100 percent efficient

Corporation	Years present in study	Years at frontier (100 percent efficient)
Altos Computer	1985	1985
Amdahl	1981-90	1984,89-90
Apple Computer	1981-90	1981-88,90
Archive	1990	
AST Research	1985-90	1985,87,90
Atari	1986-90	1986-89
Cherry	1983-89	1983-84
Commodore	1981-90	1981-84,87-88, 90
Compaq Computer	1983-90	1983-88,90
Concurrent Computer	1989-90	
Conner Peripherals	1988-90	1988-90
Control Data	1981-90	1982-84
Cray Research	1981-90	1981,83-87,89-90
Data General	1981-90	1981
Dell Computer	1988-90	1988,90
Digital Equipment	1981-90	
Everex Systems	1987-90	1987
Floating Point Systems	1983-89	1983-85
Genicom	1986-90	1986-87,90
Hewlett-Packard	1981-90	
Intergraph	1982-90	1982-85
IBM	1981-90	1981-83
Iomega	1985	
Key Tronic	1984-85	
Maxtor	1987-90	1987
Micropolis	1986-90	1986,90
National Computer	1984-90	1984-88,90
NBI	1982-87	1982,84
NCR	1981-90	
Printronix	1983-85	1983
Quantel	1981-86	
QMS	1989-90	1989
Quantum	1984-85,87-90	1984-85,88-90
Seagate Technology	1983-90	1983-84,86-90
Silicon Graphics	1989-90	1990
Storage Technology	1980-91	1981,88
Stratus Computer	1987-90	1987,90
Sun Microsystems	1986-90	
Symbol Technologies	1989-90	1989
Tandem Computers	1981-90	1981,83-87,89-90
Tandon	1982-90	1982-84,90
Tandy	1981-90	1981-84,90
Unisys	1981-90	1981
Wang Laboratories	1981-90	

rating dropped to 71 percent in 1985. From 1986 to 1990 the company laid off more than a third of its labor force. Toward the end of the decade, the company suffered large losses. The stock capitalization of this once flourishing company virtually disappeared.

COST EFFECTIVENESS AND PRODUCT LIFE CYCLES

Examining the entries in Table 2 again, the reader will note that in every single year inefficiency was the dominant mode of operation in the industry. Cost minimization was the exception rather than the rule. Clearly, efficiency ratings less than 100 percent cannot be seen as just random aberrations. The question then presents itself: *Why* are most U.S. computer companies not cost effective? How can the low ratings be explained?

It would be rash to ascribe these results to weak management, management ineptitude, or even sheer mismanagement. Rather, it may be argued that the low efficiency ratings say something about the pressing need to bring products from the laboratory to the market at an ever-increasing tempo.

High technology products go through characteristic life cycles, starting with product development and subsequent commerciali-zation. If a product is successful, it will experience a phase of growth, quite rapid at first, but decelerating as the product gains market share. Finally there is a phase of falling sales and eventual obsolescence, as competitors introduce new and more sophisticated products embodying more advanced tech-nology. We now discuss the cost effectiveness of a computer company at various stages during the "life cycle" of a product line. Stylized curves in Figure 2 illustrate the notions to be discussed. Only a single technology "vintage" is shown here; at any given point in time a company will hold an entire portfolio of products, some still being under development and others approaching the end of their life cycle.

(i) *Introduction*. In this stage sales are growing approximately exponentially. But unit costs of manufacturing a new unproven product are high. Costs of marketing (advertising the new product, establishing wholesalers and export contacts, etc.) will also typically be considerable. Furthermore, there may be a need for follow-up investments and R&D to consolidate the technological advantage gained. In particular, the new product line may embody major technological advances (such as Apollo and Sun developing the workstation concept in the early 1980s) that require a very considerable development effort. During this stage costs will be substantial and far above the costs of other companies with corresponding market penetration but possessing an established technology. The result is that the relative cost-effectiveness will be low. Examples of this include Sun (with an efficiency rating of 80 percent in 1986) and Silicon Graphics (53 percent in 1989). Notice that the need for investment and R&D varies a lot from one technology to another. For instance, the technology of Dell Computer was essentially one of a new marketing channel (direct mail, with a high level of attention to customers' needs) but with standard engineering. The result was not only lower distribution costs but also lower R&D costs, pushing up the cost effectiveness rating of the company (Dell was 100 percent efficient in 1988 and 1990).

(ii) *Maturation*. As market maturation gradually sets in, sales grow less quickly. At the same time, unit manufacturing and marketing costs are coming down as the computer company travels down its learning curve. Most investment in real capital and R&D directly incident on the initial technological breakthrough may now have been carried out. However, the corporation may be under competitive pressure to pursue new technological and market opportunities as they present themselves. All in all, it is likely that the cost effectiveness rating in this stage, while still less than unity, is slowly rising.

(iii) *Saturation*. Although only a passing state, it deserves special attention. Sales (or market share—sales relative to the total market) are stationary. Minimal costs usually exist. Presumably, the corporation has now travelled to the bottom of its learning curve. R&D costs can be lowered as the entire corporation adjusts from an expanding to a stationary mode. Thus, although prices and margins have declined, profits are nonetheless greatest at this stage. The result is that the cost-effectiveness rating reaches its maximal value, 100 percent.

(iv) *Decline*. If the management of the corporation for one reason or another decides to quit the technological race, and just hang on to the established technology and the established product line, buyers will eventually switch to competitors offering superior products. Sales will fall. In this scenario, management might typically shift its

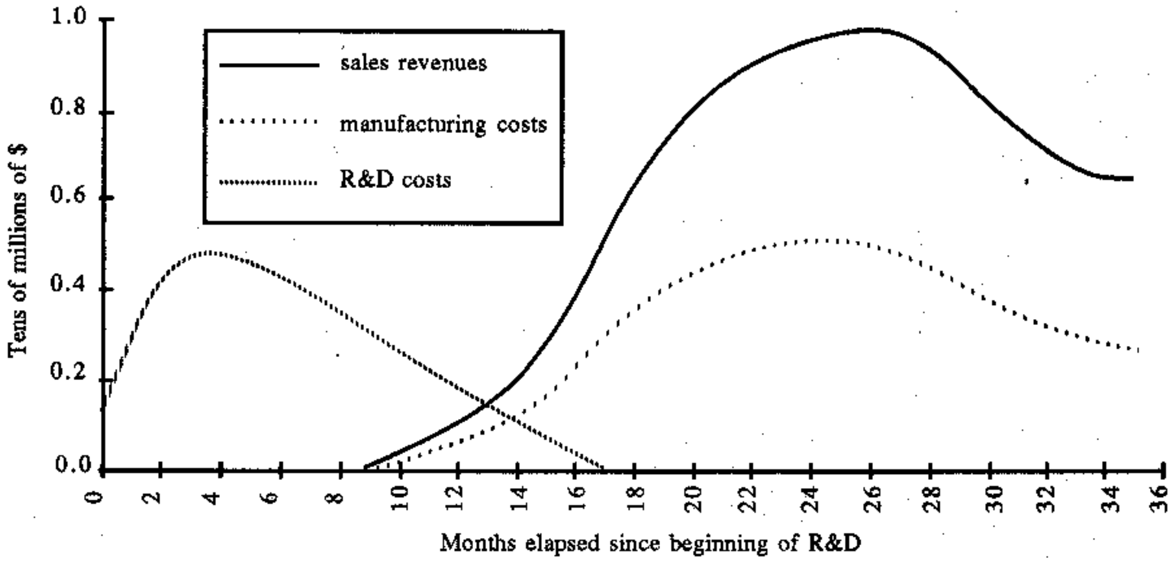

Figure 2. Illustrative sales revenues and costs during life cycle of a new product

attention from product development and the technology race to cost-effectiveness. Eventually this may mean laying off employees and downsizing in order to pare costs. If done aggressively, the cost-effectiveness rating may then stay close to 100 percent. A good example of this is Atari.

Another possibility is that the company *tries* to continue the further development of its product line, investing in R&D and even in machinery, but that it *fails* to generate the advanced product that is required to stay ahead of competition. Failure may take the form of unlucky technological bets or organizational disarray. Examples include IBM and Wang. In any case, falling sales will coexist with maintained costs and the cost effectiveness rating will fall.

To conclude, just as an individual product goes through a life cycle, the efficiency ratings of producers also go through a cycle. Products that are still located in the early stages of their life cycles require heavy expenditures on R&D and on capital investment but these expenditures will decline during later stages of the cycle. In addition, direct manufacturing costs also fall over the cycle (as a result of the so-called "learning curve"). Therefore, the envelopment calculations will yield low efficiency ratings for companies with many recent market introductions, such as Sun Microsystems spending heavily on developing the Sun workstation series that includes the Sparcstation. But companies selling mature products with superior market staying power will be treated as being efficient. A case in point is Apple, which with its Macintosh series commanded a secure technological lead with an early "windows-like" operating system, pull-down menus, and the mouse.

MANAGEMENT COMPETENCE AND INVESTMENT STRATEGIES

As is well known, standard financial theory states that it is impossible to make money on Wall Street because current prices already discount all available information. An investment analyst can certainly compare costs, sales, earnings, and prices of a couple of stocks. But when it comes to processing huge amounts of data for all stocks in an entire industry, the analyst is no match for the computer. The results of the envelopment calculations do not constitute generally available information on the stock market. They cannot have been discounted by current prices.

The efficiency calculations reported in this article may be seen as a fundamental measure of the *management competence* of a corporation. The efficiency calculations eliminate any difference between two corporations due to different mixes of inputs and outputs. Any remaining difference in efficiency rankings must therefore be ascribed to deeper, structural factors. One of the crucial dimensions of management competence in a high tech corporation is the ability to provide for the timely upgrading of the product line. As one product reaches market saturation and then enters the downhill stage of its life cycle, a company needs to phase in a successor product embodying a later generation of technology. Such accomplishment takes superior coordination of R&D, financial control, and marketing.

The rationale of the investment strategies now to be presented is the simple proposition that corporations at the efficiency envelope also tend to possess outstanding abilities of product life cycle management. Presumably, stock of such corporations will outperform a stock index of the industry at large.

Somewhat paradoxically, it is frequently said that the key to success in the high tech industry is to sell products that at all times are at the brink of obsolescence. Since the unit profit of a product reaches its maximum at the stage of saturation (stage (iii) above), a company that at all times manages to offer a product line where each product has reached saturation will also at all times realize its maximal profit potential. Its stock price, the discounted present value of the time stream of all expected profits, is then also maximal. This leads to the obvious conclusion that superior product line management leads to a maximal appreciation of the stock value.

A cursory examination of the efficiency leaders listed in Table 2 seems to confirm this assertion. An initial $1 invested in Apple stock at the end of 1981 grew to $4.11 at the end of 1990. The star performer of all computer stocks during the decade was Compaq, with an initial $1 invested at the end of 1983 (when Compaq entered the study) growing to $15.30 at the end of 1990. An investment of $1 in Conner grew to $4.97.

But half of the 44 stocks included in the study actually decreased in value over the decade. Some extreme cases: an initial $1 invested in Atari would have been worth only $0.24 at the end of 1990; an initial $1 invested in Genicom ended up being worth $0.14.

These figures should be compared with the industry index. Assuming that all invested funds at all times are distributed between all 44 stocks in proportion to the relative capitalization of the stocks—a standard assumption in index calculations—an initial dollar invested at the end of 1981 would have grown to $2.26 at the end of 1990. This corresponds to an annualized return of 8.5 percent.

Thus, several of the efficiency leaders beat the industry index quite handily. Is it possible to translate this observation into a workable investment strategy? Let us first test the following simple strategy (strategy I): *buy* a stock (or *hold* a stock if it is already in the portfolio) if its efficiency rating calculated for the immediately preceding year equalled 1.0; *sell* the stock if its rating fell below 1.0. Total available funds at the beginning of each year are split equally between the stocks qualifying for inclusion in the portfolio. Under strategy I, an initial $1 invested at the end of 1981 (it takes one year to get the strategy started!) would have grown over the decade to $4.49 at the end of 1990. The annualized return would have been 16.2 percent—nearly twice the industry rate.

A more sophisticated strategy (strategy II) is to buy a stock (or hold a stock) if its efficiency rating as calculated for the immediately preceding *two years* equalled 1.0; sell if the rating fell below .95. This strategy lays more stringent conditions for the inclusion of a stock in the portfolio, but once a stock has been purchased it will also be more difficult to sell.

Strategy II generated the portfolio listed below (cf. Table 2). Note that this strategy takes two years to get started.

1983: Apple, Commodore, IBM, Tandy
1984: Apple, Commodore, Intergraph, IBM, Tandon, Tandy
1985: Apple, Cherry, Commodore, Compaq, Cray, Floating Point, Intergraph, Seagate, Tandon, Tandy
1986: Apple, Compaq, Cray, Floating Point, Intergraph, National, Quantum, Seagate
1987: Apple, Compaq, Cray, National, Seagate
1988: Apple, AST, Atari, Compaq, Cray, Genicom, Micropolis, National, Seagate, Tandem
1989: Apple, Atari, Commodore, Compaq, Cray, Everex, National, Seagate, Tandem
1990: Atari, Compaq, Conner, Cray, National, Quantum, Seagate, Tandem

An initial $1 invested at the end of 1982 (and reinvested at the end of each year by equal amounts among the candidate stocks) would have grown over the decade to $5.18. The annualized rate of growth of the portfolio would have been 22.8 percent.

To put these numerical results in perspective, it is helpful to compare them with the results of a randomly chosen portfolio (a "dart board"). This can easily be done with the computer, using a random number generator. One thousand portfolios were generated. Each of these was reinvested each year in a random selection of stocks. Only stocks participating in the original DEA calculations qualified for selection. Furthermore, the probability of selecting any one candidate stock in any given year was set equal to the observed relative frequency of participation.

The random drawings were organized as follows. There were 24 qualifying stocks in 1983 (see Table 2). Strategy II had selected four of them (Apple, Commodore, IBM, and Tandy). The probability of selecting any participating stock in 1983 was then set equal to 4:24. All funds available for investment in 1983 are split equally between the stocks drawn. A new random drawing is done for 1984. And so on.

Of all 1000 simulations, precisely 69 simulations reached an annualized return of 22.8 percent or more. That is, there is a 0.069 probability that a randomly drawn investment portfolio would perform at least as well as strategy II.

It does not follow, of course, that the same strategy will remain equally advantageous if pursued in the future. A simulation based on historical data cannot guarantee future performance on Wall Street. There is only one way to test the real power of any investment strategy: real-life investments in the face of an uncertain future, rather than retroactive simulation.

NOTES

1. The pioneering paper of DEA is Charnes, Cooper, and Rhodes (1978). A current overview of DEA can be found in Cooper (1994). For additional introductory material, some simple numerical examples, and computer software see Thompson and Thore (1992), Chapter 6. An early application of DEA to rank U.S. and Japanese electronics companies is Yue (1991). Results presented in the main text are developed more fully in Thore, Kozmetsky, and Phillips (1994).

2. The mathematics of the envelopment calculations can briefly be explained as follows. To gauge the performance of an individual company in a given year, one needs to calculate the hypothetical performance at the efficiency frontier, also called "best practice." Best practice is formed as a weighted average of all companies. The weights are unknown, to be determined. Shrink equiproportionally the inputs of the company currently being rated. Determine the largest radial contraction of all inputs possible, while still delivering the same output as best practice, or more. The contracted inputs must not fall short of best practice inputs (the calculations are an instance of linear programming). There is one linear program for each corporation rated. The practical computer work thus takes the form of a sequence of linear programs.

3. The input variable "cost of goods sold" was not used when ranking IBM. For the rationale, see Thore, Kozmetsky, and Phillips (1994).

4. To be included in the study, a company had to satisfy three criteria: (i) be in SIC codes 3570-72 or 3577, (ii) be a domestic company, and (iii) meet the following minimum sales volumes: 1981-85: 100 million dollars; 1986-87: 150 million dollars; 1988-89: 200 million dollars; 1990: 250 million dollars.

5. To obtain some smoothing over time, the observations for any two consecutive years were pooled into a two-year "window." In other words, best practice was defined as optimal practice in the light of the experience during the two last years. As a consequence, two different efficiency values can be computed in each year for each company, one calculation for the first year in the two-year window, and one calculation for the second year in the window. Only the latter results are reported here.

BIBLIOGRAPHY

Charnes, A., W. W. Cooper, and E. Rhodes, "Measuring the Efficiency of Decision Making Units," *European Journal of Operational Research*, 2 (1978), pp. 429-444.

Cooper, W. W., "Data Envelopment Analysis," in *Encyclopedia of Operations Research and Management Science*, S.I. Gass and C.M. Harris (Eds.), New York: Kluwer Academic Publishers. forthcoming, 1994.

Thompson, G. L. and S. Thore, *Computational Economics: Economic Modeling with*

Optimization Software, South San Francisco, CA: The Scientific Press, 1992.

Thore, S., G. Kozmetsky, and F. Phillips, "DEA of Financial Statements Data: The U.S. Computer Industry," *Journal of Productivity Analysis,* forthcoming, 1994.

Yue, P. *Competition Between U.S. and Japanese Electronics Companies*, Austin, TX: IC^2 Institute, the University of Texas, 1991, p.133.

Recent Publications by IC^2 Researchers

Creative and Innovative Approaches to the Science of Management, Yuji Ijiri (Ed.), Westport, CT: Quorum Books (1993).

Generating Creativity and Innovation in Large Bureaucracies, Robert L. Kuhn (Ed.), Westport, CT: Quorum Books (1993).

Political Economy: Institutions, Competition, and Representation, William A. Barnett, Melvin J. Hinich, and Norman J. Schofield (Eds.), Cambridge, UK: Cambridge University Press (1993).

Thinkwork: Working, Learning, and Managing in a Computer Interactive Society, Fred Y. Phillips (Ed.), New York, NY: Praeger (1992).

Science, Technology, and Society: A Japanese Perspective, Kunio Goto, Austin, TX: IC^2 Monograph Series (1993). (512) 478-4081

Teaching Factories: A Strategy for World Class Manufacturing: Regional Deployment of Manufacturing Application and Education Networks, Mary Ann Roe, Barbara Fossum, Helen Baca Dorsey (Eds.), Austin, TX: IC^2 Monograph Series (1993).