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INFORMATION, COMPUTERS AND THE STRUCTURE OF INDUSTRY

by

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ABSTRACT

The explosion in use of information on costs, demand, technology, etc., by firms in industrialized countries undoubtedly affected the structure of both the information using industries and those that supply the information or the equipment to process it. In information using industries the heavy cost and large scale of computer equipment several decades ago increased both fixed and sunk costs, tending to enhance concentration and reduce competitiveness. Since then, falling cost and computer size probably reversed this while opening national markets to enhanced foreign competition. Thus, the net effect of the information revolution in the economy overall is probably strongly competitive. The computer industry itself, however, is characterized by a cumulative dynamic which favors the initial leader via the availability of more compatible peripherals and software than are provided to rivals.

The near universal intrusion of computers into the larger business firms of the world's industrialized economies, the startling rise in the share of the labor force engaged in activities devoted to acquisition and dissemination of information and other manifestations of the information explosion will undoubtedly have some effects upon the organization of industry in general, and on the degree of concentration and the effectiveness of competition in particular. The question is whether at least the broad nature of these effects can already be discerned or can be inferred analytically.

Here the issue will be discussed on two levels: the nature of the developments to be expected in the organization of the information industry itself, and the effects of the information explosion on structure of the economy's industries overall. It will be argued that there is a mechanism, at least in the computer portion of the information industry, that makes for a degree of concentration and difficulty of entry greater than one might expect from such attributes as the strength of scale economies and magnitude of sunk costs that characterize firms in the arena. Yet, the source of the propensity toward concentration and of the discouragement of entry is essentially technological, and is not to be attributed to any predisposition toward monopolization on the part of firms in the industry.

In contrast, I will offer reasons for the view that the effects on the economy's industries generally will vary considerably from one case to another, and that while in some industries computerization may exacerbate concentration and weaken competitive pressures, the opposite will be true in others. For this analysis we will recall the critical role of fixed costs in influencing the number of firms in the industry and the significant effect of sunk costs on ease of entry and exit. I will suggest that in some cases expanding information activities have worked to increase either fixed or sunk costs or both, while in other cases the opposite has occurred. Hence, the difficulty of providing any general characterization of the effects of enhancement of information activities upon overall industry structure and competitiveness.

I. Information Technology and Prevailing Firm Sizes

Marx was not alone in drawing the conclusion that technological progress inevitably brings with it ever more gigantic equipment and heavier investment requirements, all tending to lead to enlargement of the typical firm, with smaller enterprises likely to fall by the wayside. History has brought with it less systematic patterns. Often, new techniques have reduced the size of firm, sometimes quite dramatically.

Freight transportation is a notable case in point. At the time when Das Kapital was being written, investment in railroads in Britain, the United States and several countries on the continent of Europe had attained unprecedented levels. The typical railroad was a monster–sized enterprise by comparison with most road or water freight carrying concerns of an earlier period.[1] Yet the invention of the gasoline driven truck brought forth a freight transport mode which has outrivalled railroads in many markets, and the typical trucking firm is, clearly, very small in comparison with the representative railroad. In the same way, recent developments have paved the way for small electronics firms. Other technical changes have made smaller television broadcasting firms possible and so on. The evidence indicates that, presumably as a result, industrial concentration, at least in the United States, has remained virtually unchanged for three–quarters of a century (see, e.g., Adelman (1951), McCracken and Moore (1973) and Duke (1982)).

While a bit of reflection indicates why innovation will sometimes increase the typical size of firm and sometimes reduce it, it is not inappropriate to offer a brief review of the pertinent formal analysis. Here we will deal with two separate but related issues: the determination of the strength of a market's competitive forces, and the determination of the number and size of the firms that populate it.

II. Sufficient Conditions for Effective Competitive Pressures

Competitive market pressures will, of course, be effective where the number of firms in the market is substantial and none of the enterprises is unusually large in comparison with the average. However, as is now widely recognized, a market may be effectively competitive even in cases where these conditions are not satisfied, so long as entry and exit are cheap and easy -- so that potential competition can discipline incumbents and prevent them from behaving monopolistically, even though they face few actual competitors or even none. Potential competition can be effective if the amount of sunk investment required for operation in the industry is very small. For, by definition, the absence of sunk investment means that firms can exit from a market with very little loss, since investment that is not sunk can readily be transferred to other markets where earnings opportunities are better. In turn, ease of exit is likely to mean that entry is cheap and easy because if exit is relatively costless the firm risks very little by investing in the market in question. It is a tautology to say that entry will then be cheap; because if the act of entry incurred heavy costs that were unrecoverable in some short or intermediate run, those costs would necessarily constitute a sunk investment.

All of this tells us that the growing dependence of business firms upon their flows of information on different subjects such as costs, market conditions and technology will enhance competitiveness if it increases the typical number of firms in a market or if it reduces the magnitude of the sunk investment that an entrant must devote to his enterprise. Similarly, the information explosion can reduce competitiveness if it increases the typical size of firm or increases the sunk investment required for the firm's operation.

III. Determination of Industry Structure

Where competitive pressures are fairly effective the market will tend to force the industry to adopt the structure that can produce its output combination most efficiently. For example, if firms happen, say, to be inefficiently large then smaller enterprises will be able to enter, their superior efficiency will permit them to charge lower prices than the oversized incumbents can, and the small efficient enterprises will then take the market over from the large inefficient companies. Thus, in markets in which competition is effective the number of firms that one finds in reality will tend to be approximately equal to the number that is most efficient.

Now the number of firms required for efficiency in a given market will be determined primarily by two things: the quantities of outputs demanded in equilibrium, and the size of firm that is most efficient ("minimum efficient scale"). If minimum efficient scale is large relative to market demand the optimal number of firms will be small because a large number of firms will each be able to sell only amounts considerably smaller than minimum efficient scale. Similarly, if total equilibrium demand for the industry's products is a large multiple of the minimum efficient scale of firm, competitive pressures will dictate that a large number of firms produce the industry's output bundle.

Minimum efficient scale, in turn, will be determined by the degree to which economies of scale and scope characterize the industry's technology. If both types of economy are substantial and continue over a large range of outputs, the minimum efficient scale of operation of a firm in that industry will be large. Scale economies will mean that with given output proportions large firms can produce more cheaply than small ones. Similarly, economies of scope mean that large multiproduct firms can produce more cheaply than small relatively specialized enterprises supplying only a limited number of products.[2]

Now, as is well known, large fixed or lumpy[3] costs tend to lead to economies of scale and, for parallel reasons, they are also conducive to economies of scope. For suppose the firm must incur a substantial (fixed) outlay in order to operate at all, but, at least over a significant range that fixed outlay is, by definition, not increased by the number of products the firm supplies or the amount of each item it produces. Then the larger the number of different products the company supplies the smaller will be the share of the fixed or lumpy cost that any one of them must bear. That is, a firm that supplies a larger multiplicity of products than another enterprise will be able to spread the fixed or lumpy costs more thinly over those products, and this, of course, is a source of economies of scope.

The implication for our central issue, then, is clear. If the increasing reliance on a multitude of types of computer processed information has enhanced the fixed or lumpy costs of a typical firm it will have served to increase the minimum efficient scale and scope of operation of the representative firm and this will serve to reduce the number of firms in a given market -- it will make for greater concentration. On the other hand, if the increased flow of information has served or will serve to reduce fixed or lumpy costs it will tend to decrease concentration of the pertinent industry.

IV. Information, Fixed Costs and Sunk Costs

So far as I have been able to determine, no empirical evidence is available on the effects of the information revolution upon the magnitudes of sunk costs and fixed costs. My discussion of this point will therefore have to be entirely impressionistic. Even if my conclusions are consequently judged to have little or no basis in fact they will at least serve to identify the pertinent matters upon which future study of the facts should focus.

It seems entirely plausible that some ten or fiteen years ago the growth of computer usage by industry generally tended to enhance minimum efficient scale of firm, sometimes substantially, and may in some cases have expanded sunk costs as well. In the early decades of the computer revolution hardware was large, clumsy and expensive. Even relatively small computers were likely to fill a room of considerable size. In most computer using industries hardware did not constitute a fixed cost -- small enterprises, where any existed, could and often did manage to get along without them. However, for a medium sized firm the decision to go into computers did raise costs discontinuously, and so the investment for many firms was markedly lumpy. This tended, if anything, to raise minimum efficient scale and that, in turn, worked to enhance industrial concentration. To some degree this was undoubtedly offset through time sharing, which enabled a number of small firms to avail themselves of the services of large mainframe computers. Whether the net consequences were sufficient to be observable I do not know. I suspect investigation would confirm that in some industries highly dependent on computers it did increase the average size of firm discernably, but only to a small degree.

But, as we have seen, this possibility by itself cannot be taken to constitute a reduction in competitiveness. Rather, the issue was whether the lumpy costs in question were also largely sunk and consequently constituted a barrier to exit and entry. In fact, the early equipment itself was not predominantly sunk so far as the using firm was concerned. Hardware was generally fungible -- it could be transferred without enormous difficulty from one firm to another (and often even more easily from one of the firm's markets to another without any physical moving of the machines).[4] The very fact that hardware was often rented from the manufacturer meant that while computer investment did constitute a sunk cost to computer manufacturers it was not a sunk cost to computer users.

However, one cannot jump from the observation that hardware outlays were largely not sunk to the conclusion that the computer revolution contributed little additional sunk cost of any variety to industry generally. As a matter of fact, the opposite is probably true. Computerization may well have led to substantial sunk investments of two sorts: in software and in human capital. Specialized software designed for the needs of a particular firm is not generally fungible and so constitutes a sunk outlay. The early machines were also far from being "user friendly" (to indulge in the common jargon). It was not cheap and easy to become skilled in their use and, in particular, to learn how to use them in accord with the needs and customs of a particular enterprise. Thus, the enterprise and/or the individual employee was required to invest in human capital and only part of that investment may have been readily transferable elsewhere. As Williamson (1985) has so effectively emphasized, even human capital costs, if sunk, i.e., if fully usable only in a particular firm, can serve to attenuate the effectiveness of the market mechanism.

From all this, it is my impression that in its early stages the spread of computer technology served both to increase concentration and to weaken the effectiveness of competition. Only empirical evidence can confirm this hypothesis and, if so, only empirical evidence can indicate the magnitude and significance of these effects.

There is, however, reason to believe that more recent developments have substantially weakened such competition reducing effects or even, to some degree, reversed them. The spectacular decline in the cost of hardware and the availability of powerful personal computers have made it possible for the smallest enterprise to share in the benefits. Even small vegetable and grocery stores in the United States use computerized scales and cash registers whose electronic number displays might have been considered the stuff of science fiction only a few decades ago. If computer outlays remain to any degree lumpy, the discontinuities are of the size of pebbles rather than boulders. One is driven to the suspicion, then, that today's smaller sized computers, while they offer advantages to firms of all sizes have, if anything, tended to even matters out, benefitting small firms proportionately more than large. If so, they must, if anything, have worked to reduce the minimum size of firm, and so, to decrease concentration.

Rising user friendliness has also reduced the investment in specialized human capital needed for computer use. "Computer literacy" is hardly a scarce commodity today and probably will grow even more common tomorrow. On this score, then, the competition–impeding consequences of computerization will also have all but disappeared.

Only specialized software, then, remains as a possible source of entry–impeding sunk costs. The significance of that, of course, varies substantially from industry to industry. Only in some industries where highly complex, costly and specialized software continues to be critical is this likely to constitute a problem.

V. Improvement of Competitive Information and Broadening of Markets

So much for the purely internal side of the effects of the information era on industry structure and performance. But the discussion up to this point has left out what may prove to be the main influence of the new technology. If we broaden our conception of information related equipment to include the instruments of communication,[5] a very different view of the entire matter emerges. For what has happened is a broadening of the market, which has dramatically increased the number of competitors, both actual and potential, which face a variety of industries.

Within the lifetime of this author the United States has evolved from an economy whose imports and exports constituted a peripheral concern, transforming them into matters which seem to make the difference between life and death for a number of significant industries. It has been estimated on the basis of Maddison's data (1982) that over the course of a century the share of exports in GDP for the average of 16 leading industrial countries in a sample investigated by Maddison[6] has risen to something between 3 and 4 times its initial value. As a result, even industries which formerly were predominantly domestic affairs and which, in that milieu, were largely immune from competition, have more recently found themselves under constant threat of invasion by foreign rivals and, simultaneously, have grown increasingly dependent on foreign markets where international sources of competition are powerful and unrelenting.

Undoubtedly, improvements in transportation have contributed a good deal to the internationalization of markets. But there is much more to the story. During the course of a century there has been a spectacular convergence in the productivity levels of the world's leading industrialized countries. For Maddison's 16 countries in 1870 the ratio of labor productivity (GDP per labor hour) in the most productive country to the least was approximately eight to one. By 1979 that ratio had fallen to about two to one. In other words, the relative difference in productivity levels fell about 75 percent in the course of a century. This necessarily means that the lagging countries have learned increasingly to understand and adopt the productive techniques employed by the countries ahead of them in terms of productivity. That is, the flow and utilization of information must have played a critical role in permitting the catching up of countries which, like Japan, Sweden, France, Germany and Italy, started off the last quarter of the nineteenth century in positions well behind the leaders. It was only when productivity in those countries began to approximate its levels in the vanguard nations that the former laggards were able to become an effective competitive force in the international market place.

This same set of influences seems to have continued to work with undiminished strength during the forty years of the postwar period. Convergence in productivity and in living standards among the leading industrial countries has continued its dramatic pace and this has undoubtedly rested upon a progressive homogenization of productive techniques whose heart was the acquisition and utilization by each country of information about the industrial techniques in use by all the others. It seems clear to me that this information flow and its acceleration is responsible to a considerable degree for the internationalization of the world's markets, the consequent weakening of monopoly power, and the declining concentration of industry in the relevant markets.

We may note as a postscript that innovation has even internationalized markets previously thought largely impervious to international competition. This has occurred, notably, in a number of services. We are told, for example, that it is no longer extraordinary for engineers in country A to transmit their specifications electronically to country B where the blueprints are quickly drawn and then sent on electronically to country C for use in the manufacturing process. Similarly, television and film have internationalized the performance of drama, which until the twentieth century was exported and imported only as a rare and noteworthy event.

In short, the list of enclaves largely immune from international competition constantly grows shorter as information and its products make it possible for each nation's activities to invade the other's markets and competitive pressures force them to do so.[7]

It follows from all this, despite the discussion of earlier sections of this paper, that the information explosion must have served predominantly, indeed dramatically, as a stimulus to competitiveness. This, then, is its primary consequence for industrial organization in the economy in general.

Matters are rather different and more complex when we turn to the information industries themselves.

VI. The Concentrating Dynamic of Hardware Production

In recent years both AT&T and IBM have made attempts to invade one another's territories. Though, for reasons already suggested, these would appear to be natural moves, given the interdependence of their technology, so far neither step has proved a spectacular success. Yet, in neither case is the invading firm untutored in the other's technology and neither is a diminutive enterprise handicapped by lack of resources in its challenge to a giant incumbent.

No doubt the reasons for the limited success of the invasions are complex and the story has, in any event, not yet reached its conclusion. Yet I believe there are reasons why AT&T is handicapped in its challenge to IBM, not by lack of know how or resources, but by the sheer lateness of its arrival in the computer field. The relationships in question, if valid, have significant implications for the structure of the computer hardware industry and so it is quite appropriate to pursue them here.

The essence of the matter is that consumer demand for the central element (the computer itself) in a system of data processing equipment depends on the availability of a variety of ancillary equipment (e.g., printers) and use facilitating materials (software) which are compatible with the central element in question. But these ancillary items are not produced only by the manufacturer of the central item; indeed the best (most popular) of the ancillaries are apt to be supplied by totally independent firms (e.g., the Lotus corporation).

Design and launching of peripheral equipment and software packages is expensive and their minimum efficient scale is likely to be relatively large; in the case of software, indeed, the bulk of the cost is characteristically both fixed and sunk. Hence, if these ancillary items are to be designed in a manner that makes them compatible with use in conjunction with one particular type of computer rather than another the supplier (designer) of the peripheral item will be attracted to a brand of computer, call it X, the demand for which is large and can be expected to continue to be so.

However, demand for computer X itself will depend on the range of compatible peripheral equipment now available for it and likely to be available in the future. In other words, the two variables, quantity of brand X computers demanded and range (number) of peripheral items compatible with X that are available, will stimulate one another. The larger the value one of these variables attains the larger, ceteris paribus, the value of the other will be.

There is, however, at least one offsetting influence. The more crowded the field of peripheral supply for computer X already is, the less attractive supply of an additional competing item is apt to be. In other words, growth in supply of items compatible with computer X is apt to vary inversely with the number of such items already being supplied.

The relationships just described constitute the elements of a dynamic behavioral model of developments in the structure of the industry (see appendix). The workings of the model are not too difficult to describe intuitively. In essence, the computer manufacturer who is able earliest to establish a sizable niche in the market will achieve a self cumulating advantage over all smaller incumbent rivals as well as over entrants of the future. Brand X, having achieved a sizable market share will, by virtue of that achievement, become an attractive target for the designers of peripheral equipment and software. But the more such X compatible items there are available, the more consumer demand will grow relative to that for competing brands.

In practice, supplementary influences may work in the same direction. For example, buyers may be concerned about the possibility of bankruptcy of a computer supplier and the consequent unavailability of replacement parts, let alone of upgrading equipment which successful manufacturers may provide in the future. This, too, will constitute an advantage to a manufacturing firm which obtains a substantial market share early.

The story, then, is that in this industry technological and vertical relationships are such as to make success tend to breed further success. The firm that succeeds in getting a major market share thereby becomes attractive to the producers of software and peripherals. New computer buyers, in turn, find that brand even more attractive as the variety of ancillary products compatible with it expands. That, in its turn, further stimulates the available range of compatible ancillaries, and so on ad infinitum.

Such a set of relationships can make it rather difficult for a newcomer to break into the field. Dominance is achieved and retained by the leading incumbent, not necessarily because of any monopolizing goal or course of action, but rather, it is thrust upon that firm by the very nature of the industry's dynamic.

This does not mean that the successful incumbent will inevitably and necessarily become the sole occupant of the field. Product differentiation may provide viable niches for smaller rivals that undertake to supply products catering to special needs and desires. Moreover, as suppliers of ancillary equipment flock increasingly into the provision of items compatible with the leading computer, that portion of the market may grow overcrowded, and supply of ancillary items for less successful computer brands may grow more attractive. All this may finally place an upper bound on the market share of the early leader in computer manufacturing.

Yet its position will remain powerful and resistant to attack. Only revolutionary innovation by an entrant or critical mistakes by the management of the successful computer manufacturer may be able to produce a significant change in industry leadership and to offer a substantial and enduring share to firms other than the current leader. This, then, seems a plausible scenario for the structure and competitive performance of an industry with the technological attributes of computer manufacturing.

However, another entry strategy may be available to entrants in competing with the successful incumbent. The entrant may undertake to produce what may be referred to as superclones to the successful firm's equipment. The entrant's machines can be designed to be compatible with every peripheral and every major software package designed for the incumbent. By doing this and offering a few additional attractive features as well, the entrant may be able to mount a successful attack upon the incumbent's position. There are signs that this strategic approach is already being employed and that it is already working, at least to some degree.[8]

After all, if imitation is inexpensive and legal, then others will follow the industry leader with the same design, and production cost and marketing ability will determine the winners, who need not necessarily be the first of the pacesetters. For example, the designers of the typewriter keyboard layout set the industry standard (even if it has many drawbacks), but doing that first gave them no permanent market–share advantage. Although IBM set the standard for personal computers it now faces stiff competition for market share from the clone producers, who can legally make a very close copy and sell it for substantially less. A dissertation being written by Robert Levinson at New York University analyzes the microcomputer purchase decisions of consumers as a function of purchase price, the expected cost of service and peripherals, reputation of the manufacturer (and its likelihood of being in business five years in the future), degree of compatibility (not only for present software and peripherals, but also for those yet to be introduced), availability of software and hardware peripherals (and ease of connecting them) and the existing installed base (which lowers the cost and ease of service, the significant time–cost of learning, and the ease of getting assistance from friends familiar with the same unit). Many of these factors, of course, work in the direction of the model described here. Preliminary results derived from a fairly extensive data set show the importance of near–perfect compatibility of the competitor's product offerings with IBM associated products, since semi compatibility has proved to be an ineffective basis on which to compete.

VII. Summary Remarks

To summarize, our investigation has suggested that the information explosion has affected industry structure and competitiveness in a number of ways: a) In earlier decades in industry generally it seems likely to have worked to enhance both the minimum efficient size of firm and the typical magnitude of sunk cost, thereby contributing to concentration and serving to weaken competitiveness; b) with the subsequent phenomenal decline in hardware costs, in equipment size, and the growing ease of computer usage ("user friendliness") the contribution to concentration and to reduced competitiveness may have been reversed and more; (c) at the same time, by accelerating the internationalization of the world's markets, the information revolution has probably stimulated competitiveness dramatically; d) the noteworthy exception seems to be the market for computer hardware itself which appears to be subject to a dynamic that makes entry difficult and serves to stimulate a substantial degree of concentration. In short, the new information technology may well have augmented competitiveness everywhere except in its own headquarters. But even here, the game has not yet been played to completion.

APPENDIX

A Simple Model of The Dynamics of Hardware Markets

It is not difficult to construct a formal model with the characteristics attributed in the text to the computer equipment markets.

The following vastly oversimplified model is intended only to illustrate the logic of the relationships. It will help for this purpose to assume that the industry contains exactly two firms. For either of these firms, i, let

r_{it} = the proportion of the available peripheral (software) items compatible with firm i's equipment in period t, $0 < r_t < 1$

s_{it} = firm i's share of the market in period t, $0 < s_{it} < 1$, where these variables satisfy

(1) $r_{it+1} - r_{it} = f^i(r_{it}, s_{it}) \quad f^i_r < 0,\ f^i_s > 0$

(2) $s_{it} = g^i(r_{it}) + s^*_i \quad g^i_r > 0.$

Then, direct substitution yields the first order difference equation

(3) $r_{it+1} = r_{it} + f^i[r_{it}, g^i(r_{it}) + s^*_i]$

with $dr_{it+1}/dr_{it} = 1 + f^i_r + f^i_s\, g^i_r$

which will be explosive in the neighborhood of an equilibrium point if $-f^i_r < f^i_s\, g^I_r$. If f_r increases in absolute value with the size of r the non-linear relationship (3) is apt to have several equilibrium points. It is, for example, plausible that its graph will have the shape of curve RR in Figure 1, intersecting the 45 degree ray at three points, A, B and C. Treating the figure as a phase diagram, it is clear that points A and C constitute stable equilibria, while B, which lies, so to speak, toward the center of the figure, is unstable.

Thus, with just two firms, I and II, in the market, suppose that B is, indeed, the midpoint of the diagonal. If firm I's initial position, r(1,0) is to the right of B, firm II's initial position, r(2,0) will necessarily lie to its left, since r_t is defined in terms of shares. Then firm I will be driven inexorably toward upper equilibrium point C while firm II will be pushed toward lower equilibrium point A, and once there, only exogenous developments can dislodge them from their positions.

FOOTNOTES

* AUTHOR'S MAILING ADDRESS(s)

1. Of course, the construction of canals also incurred sunk costs which were hardly insignificant.

2. Indeed, efficiency in industry structure requires that each firm, j, produce an output vector y^j at which costs are subadditive. That is, it must not be possible to save money by breaking firm j up into smaller enterprises, with smaller firm i producing output vector y^i and with $\Sigma y^i = y^j$. That is, for any such subdivision we must have $\sum_i C(y^i) > C(y^j)$ where $C(\cdot)$ is the total cost function. This must be so because if y^j violates this subadditivity inequality it would be more efficient to divide j's output, y^j, among some number of smaller firms, thus contradicting the hypothesis that y^j is the output bundle of firm j in an efficient industry structure.

   The pertinence of all this is that subadditivity is directly related to economies of scale and scope. Thus, (1) if $C(y)$ is subadditive at $y = y^j$ then it must display declining average cost on average between y^j/r and y^j for r any integer greater than unity, i.e., for proportionate increases in all outputs (economies of scale along the ray $0y^j$) since otherwise smaller firms could produce y^j more cheaply; (2) if y^j involves more than one product, its efficiency requires economies of scope, since otherwise several smaller and more specialized firms could produce y^j more cheaply than firm j can do it by itself and (3) strictly declining ray average costs and a somewhat (stronger) economies of scope condition called "trans ray convexity" are, together, sufficient to guarantee the subadditivity of C(y) at $y = y^j$. For details on these results see Baumol, Panzar and Willig (1982), chapters 3–5.

3. By a fixed cost I mean a cost which a firm must incur in order to produce anything at all, and which over some range does not increase with output. If the cost function is $C(y) = F + G(y)$, $G(0) = 0$; F is the fixed cost, which may or may not be sunk and need not become variable in the long run. A lumpy cost is like a fixed cost except that it is efficient to incur it only after output exceeds some magnitude, y^*.

4. Another example of a step that facilitated transfer of capacity was rental of computer time by one firm to another. Consulting firms, for example, leased time on manufacturers' equipment. My impression is that this happened frequently in the 1960's.

5. Technological change has already blurred the boundary between the computer and telecommunications industries and threatens to erase it altogether. Computers, of course, communicate by telephone and telephone systems are run by computers. The heart of telephone network operation is the "smart switch", an amalgam of computer hardware and software capable of making complex routing calculations, storing information, etc.

6. Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, Switzerland, U.K. and U.S.A.

7. Electronics have obviously also internationalized capital markets and have sped up and otherwise facilitated the transfer of investment resources.

8. See, e.g., the report in the New York Times, April 22, 1986, p. C6,

   In a comprehensive test of performance among I.B.M.

compatible computers, a company other than I.B.M. won.

Software Digest, an independent organization long known for its exhaustive testing and methodical comparisons of software programs for personal computers, has branched out into the hardware arena. In this month's issue of the Software Digest Ratings Newsletter, seven computers were tested against the standards set by International Business Machines for performance and software compatibility.

The final tally put Compaq's top-of-the-line Deskpro 286 at the top of the field, ahead of I.B.M.'s flagship personal computer, the PC-AT.

I.B.M. compatibility is obviously not a problem for the I.B.M., so the triumph of the Deskpro 286 is all the more impressive. It ran 19 of the 20 software programs used in the compatibility tests without a hitch, and the 20th ran after minor tinkering. The Deskpro 286's edge came in raw speed; its microprocessor runs rings around that of the AT.

REFERENCES

Adelman, M.A., "The Measurement of Industrial Concentration," Review of Economics and Statistics, , November 1951, 33, pp. 295–96.

Baumol, W.J., Panzar, J.C., and Willig, R.D., Contestable Markets and the Theory of Industry Structure, San Diego: Harcourt, Brace, Jovanovich, 1982.

Duke, D., "Trends in Aggregate Concentration," Working Paper No. 61, Washington, D.C., Federal Trade Commission, June 1982.

Maddison, Angus, Phases of Capitalist Development, New York: Oxford University Press, 1982.

McCracken, P.W. and Moore, T.G., "Competition and Market Concentration in the American Economy," Subcommittee on Antitrust and Monopoly, U.S. Senate, March 29, 1973.

Williamson, Oliver, The Economic Institutions of Capitalism, New York: The Free Press, 1985.