6 INFORMATION TECHNOLOGY AND THE UNITED STATES ECONOMY: MODELING AND MEASUREMENT

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Fritz Machlup published in 1962 a study of the extent to which labor and nonlabor resources were used in the United States for the creation and processing of information as opposed to physical goods. Since then numerous analyses of a similar kind have been carried out—by Peter Drucker (1968), Daniel Bell (1973), Marc Porat (1977), and again Machlup (1980) among others. Although the exact findings depend on how information products or services are defined, the general conclusion emerging is that half of all economic activity in the United States can be attributed to the processing of knowledge or facts rather than physical goods, and that the proportion is increasing with time.

In this chapter we analyze the two major structural changes that have been measured by such studies, and these structural changes are apparent to any casual observer of a modern industrial economy. The first is the increasing demand for information technology as a proportion of demand for all technology. The second is the increasing demand for information or white collar labor as a proportion of demand for total labor.

Even though such structural trends are observed and measured at the macro level, they can properly be modeled and explained only at the

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micro level—in terms of increasing demand by individual producing units (firms) or consuming units (households) for information technology and information labor services. In this chapter we will develop a simple analytic framework that will allow the separate sources of these macroeconomic changes to be identified and measured.

In particular, we will use this framework to ascertain whether the trend towards increased use of information resources (information technology and information labor) is primarily a demand-side or supply-side phenomenon. Is it occurring primarily because consumer demand is shifting in favor of goods and services that are in some sense information intensive—such as entertainment, educational, and professional services? Or is it occurring primarily because the technology and organization of economic supply is requiring greater information resources to manage and coordinate production activities? We will find that it is our second question that provides the right answer. The implications of this finding for future trends in productivity and employment are analyzed in another paper by this author (Jonscher 1983).

THE MODEL

The model is based on two kinds of labor occupation—information labor and production labor—and on two kinds of commodity—information services and production goods. Information and production workers produce information services and production goods, respectively. Broadly speaking, an information worker is one whose primary activity is to handle and process information. In this category we find managers, clerical workers, and accountants. Construction and factory workers are examples of production workers whose primary activity is to handle and process material goods. The distinction is roughly the same as the one between white collar and blue collar occupations.

The task of identifying the pattern of labor expenditures on information activities is made practicable by the very high degree of occupational specialization present in modern societies. We use occupational categories as the primary instrument for distinguishing information processing from production activity. If a person is classified in labor statistics as a billing clerk, we may be reasonably confident that his or her primary functions are to prepare and process bills; these are information handling activities associated with the management, organization, and coordination of economic activity. Consequently, a billing clerk is classified as an information rather than a production worker. Conversely, if a person is classified as a sheet metal worker we assume that his primary function is to work sheet metal and not to process economic information; we categorize him as a producer. Sometimes the billing clerk may help to unload a delivery truck (production, not information handling), and the sheet metal worker may fill out timesheets (information handling, not production); but these activities are the exception rather than the rule.

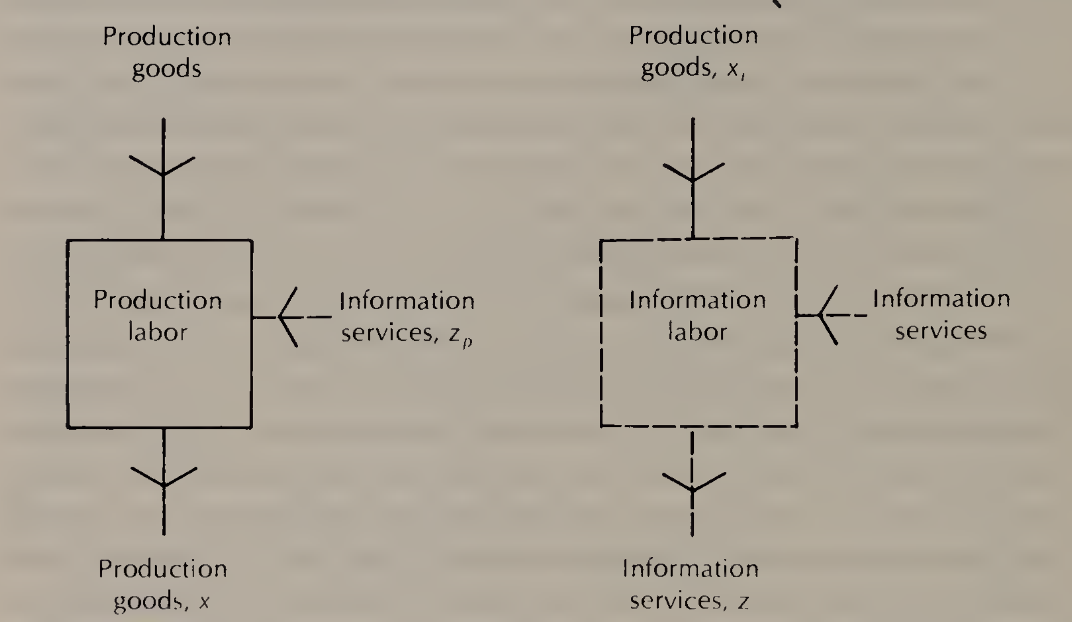
A few worker types are more difficult to classify; in these cases we have to make a (sometimes rather arbitrary) choice. For example, actors and other entertainers do not fit the classification scheme neatly. A foreman is an important instance of an "ambiguous" occupation. While some of a typical foreman's time is spent doing the same job as his subordinates, much of it is spent monitoring, supervising, and keeping time records. Fortunately, for our purposes, the number of occupations for which classification problems of this kind arise is a very small proportion of the total. The great majority, perhaps 95 percent, of the working population can be identified with reasonable confidence as fitting one or the other of our categories. The results of the classification exercise that we have undertaken for this study are presented in the appendix. The first section of the appendix contains a complete list of the occupations we have assigned in the information sector.

As to the classification of commodities, an information service is, by definition, the product of the work of an information worker and a good is, by definition, the product of the work of a production worker. This means that the definition of goods in our model includes certain commodities that are generally defined as services but which do not have the character of information services; examples are the output of an automobile repair shop or a trucking company.

The inputs and outputs of an information worker's and a production worker's activity are illustrated diagrammatically in Figure 6–1. The boxes represent labor activity, and the arrows, flow of goods and services. Throughout this paper, boxes and arrows are drawn with solid lines if they represent production labor and goods, and with broken lines if they represent information labor and services.

In the analysis that follows we will be concerned with the *net* output of goods and information services produced respectively by production and information workers—that is, the output net, respectively, of goods and services used as inputs. We will use the following terminology to describe the inputs and outputs associated with a single information worker:

Figure 6–1. The Inputs and Outputs to Production and Information Labor Processes.



x_i: Input of goods used by information worker
z: Net output of information services (net of all inputs except information labor and x_i).

In the case of a production worker inputs and outputs we will use the following terminology:

z_p: Input of information services used by production worker
x: Net output of goods (net of all inputs except production labor and z_p).

We define the following coefficients linking the levels of input and output of each type of worker:

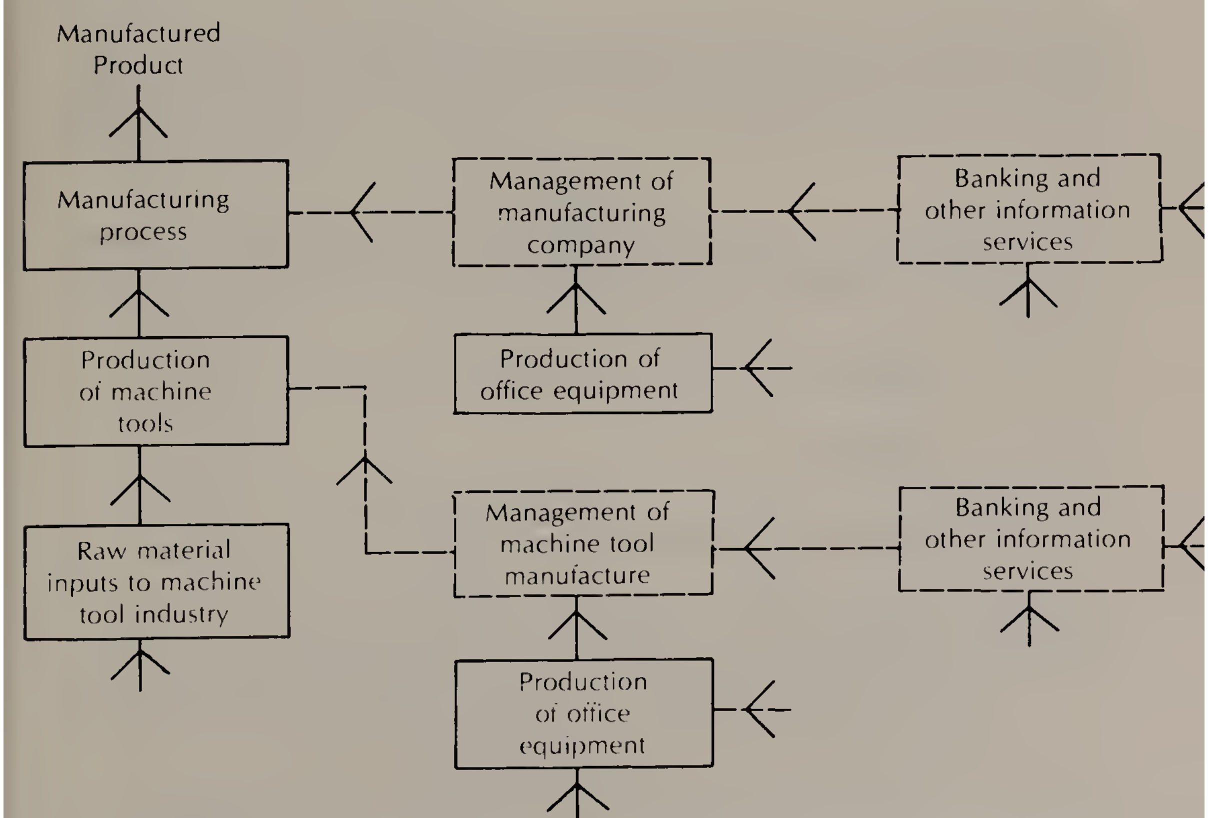
$$a_z = z_p/x$$
$$a_x = x_i/z.$$

A particularly important category of goods used as inputs by information workers is information technology—goods such as computers, telecommunications systems, and office automation equipment. In the empirical analysis that follows we will identify the flow x_i as the use of information technology by information workers. The coefficient a_x

therefore measures the value of information technology used to produce each dollar's worth of output of information services.

The delivery of a good or service to the final consumer involves a chain of production and information activities, each activity taking as inputs both production goods and information services. Consider, for example, the provision of a production good, such as a manufactured product. The last few steps in the chain leading to that delivery are illustrated in Figure 6–2. Manufacturing is a production activity but uses as inputs both production technology services (e.g., machine tools) and information services (e.g., management and administration of the manufacturing process). The manufacture of machine tools is similarly a production activity using both kinds of input; the provision of management services is an information activity using production good inputs (e.g., office equipment, telephones) and information services (e.g., banking). Throughout the figure a box is drawn with a solid line if it represents production labor; with a broken line, if it represents information labor.

Figure 6–2. Chains of Production and Information Activity: Case 1, A Manufactured Product.



The output of a solid box is always a solid line (production goods); of a broken box, always a broken line (information services).

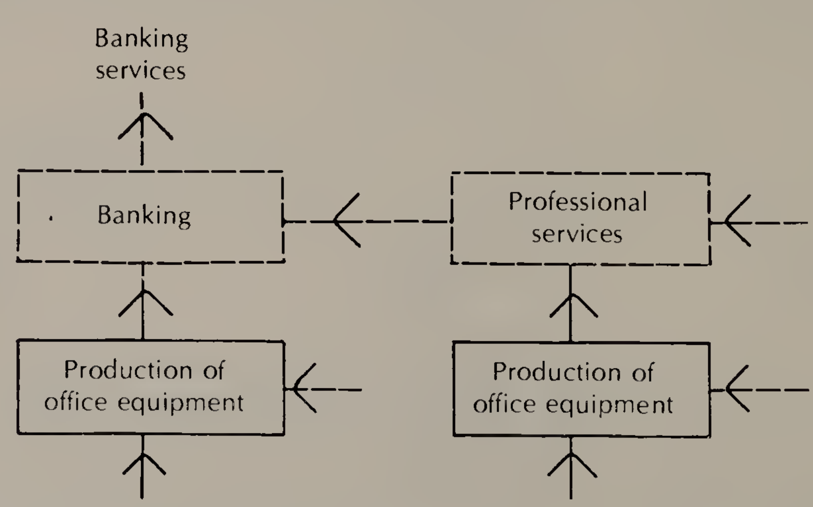
Figure 6–3 shows a corresponding chain for the provision of banking services. While the final output is an information service, successive inputs of both production and information labor are required. We note that in a complete diagram of the input-output structure of the economy, Figures 6–2 and 6–3 would be intermeshed: Banking is an input to the manufacturing industry, and manufactured goods are used in banks.

We wish to model the interrelationships between information and production activities in such a way that the pattern of use of the two kinds of resources can be clearly identified. We do this by taking the two kinds of activity we have defined at the micro level (the activity of information workers and production workers) and defining two sectors of the economy at the aggregate level:

1. *An information sector,* comprising the activity of all information workers
2. *A production sector,* comprising the activity of all production workers.

The effect, in terms of the two diagrams in Figures 6–2 and 6–3, can be described as that of moving all the solid boxes to one side, say the left, and consolidating them into one aggregate box representing the

Figure 6–3. Chains of Production and Information Activity: Case 2, Banking Services.



production sector. All the broken boxes are moved to the other side and consolidated into one representing the information sector. All flows of services between the individual elements in Figures 6–2 and 6–3 are retained but consolidated into aggregate flows between and within the two sectors.

We also define two categories of final consumption items, consumed by households:

1. *Production goods and services,* consisting of goods (housing, food, clothing, durables, etc.) and of services associated with the supply of these goods (marketing, retailing, delivery, after sales service, etc.)
2. *Information services and technology,* consisting of services directly provided by information workers (newspapers and broadcast programs, education, legal services, etc.) and information technology associated with the delivery or consumption of such services (telecommunications, TV and radio equipment, etc.).

The result is a framework with two sectors and four flows, as illustrated in Figure 6–4. The figure includes examples of the goods and services comprising each of the flows.

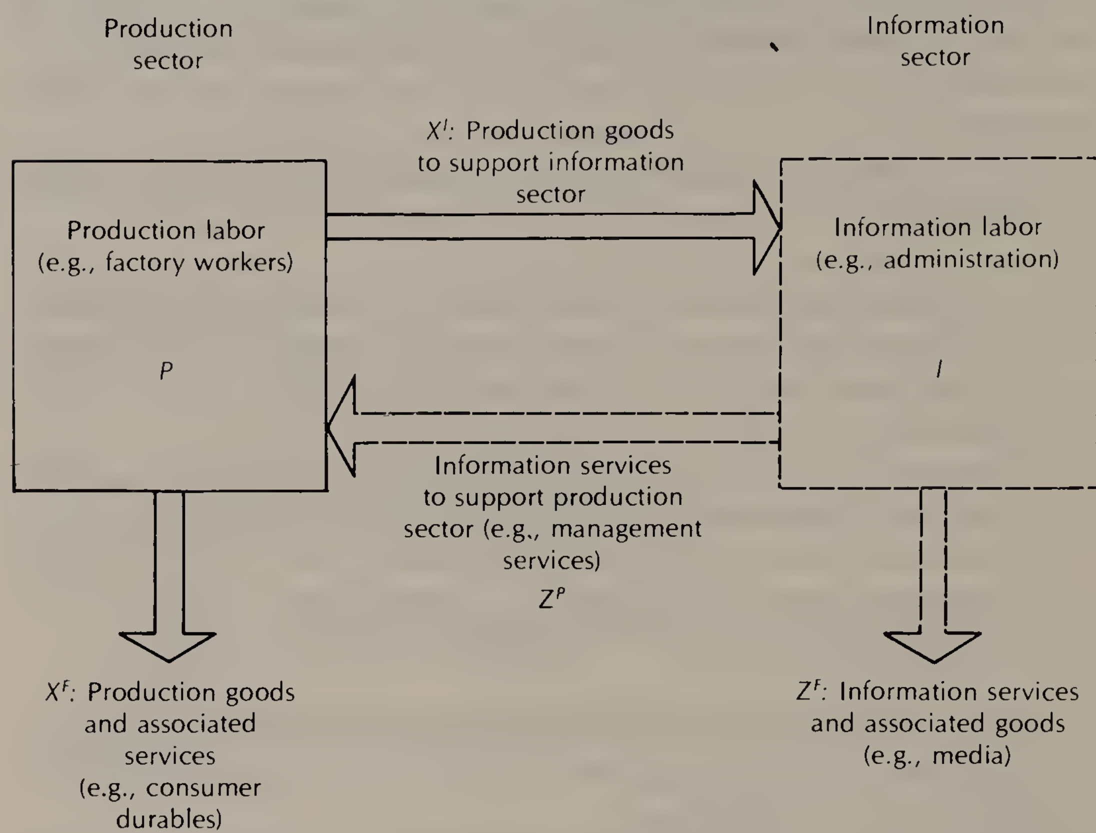
The quantities in the aggregate model illustrated in Figure 6–4 are defined as follows:

I: the total information workforce
P: the total production workforce
Z^F: final (consumer) demand for information services and associated goods
X^F: final (consumer) demand for production goods and associated services
X^I: quantity of information technology provided to the information sector
Z^P: quantity of information services provided to the production sector.

In a closed economy, the relationship between these aggregate or macro quantities and the micro-coefficients a_Z and a_X can be calculated as follows:

1. Define X^T and Z^T as the total output, intermediate and final, of all production and information units respectively.

Figure 6–4. A Two-Sector Model of the Macroeconomy.



Source: Jonscher (1983).

2. Consider initially only one step in the chain of successive intermediate stages of production and information activities required to produce given outputs of X^F and Z^F. We label the intermediate production and information inputs required for producing for *final demand only* $X^{(1)}$ and $Z^{(1)}$ respectively. Then,

$$X^{(1)} = a_x Z^F$$

$$Z^{(1)} = a_z X^F.$$

3. Moving one step further back in the production chain, we can define an input requirement vector for the activities producing $X^{(1)}$ and $Z^{(1)}$ (i.e., units two steps back from final demand):

$$X^{(2)} = a_x X^{(1)}$$

$$Z^{(2)} = a_z X^{(1)}.$$

4. Thus the total required outputs of products and information services, X^T and Z^T, required to product X^F and Z^F of final demand, are then given by:

$$X^T = X^F \sum_{i=0}^{\infty} (a_x a_z)^i + a_x Z^F \sum_{i=0}^{\infty} (a_z a_x)^i = (X^F + a_x Z^F)/(1 - a_x a_z)$$

$$Y^T = Z^F \sum_{i=0}^{\infty} (a_z a_x)^i + a_z X^F \sum_{i=0}^{\infty} (a_x a_z)^i = (Z^F + a_z X^F)/(1 - a_x a_z).$$

APPLICATION TO UNITED STATES DATA

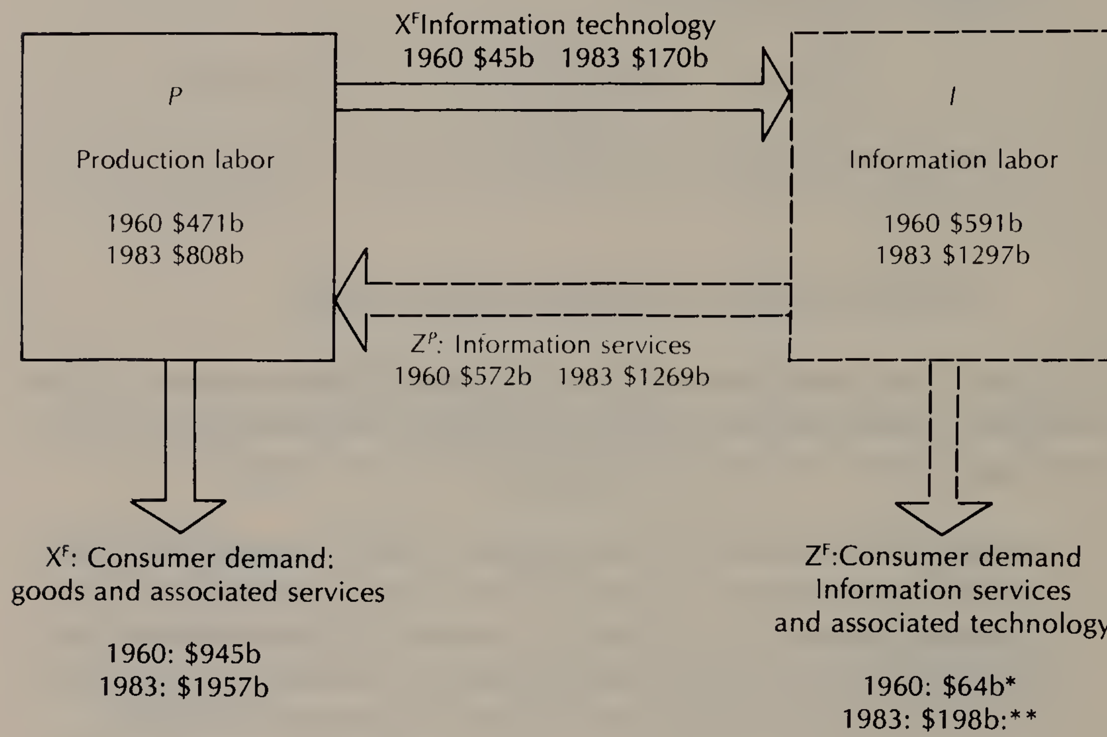
Figure 6–5 indicates the values, for the United States economy, of the variables marked in Figure 6–4. Data have been obtained for two years, 1960 and 1983. The following points should be made:

1. I and P are measures of "labor value added"—employee compensation plus corporate profits and other proprietors' income. Proprietors' income is considered an overhead on the employee compensation of information and production workers; it is allocated to I and P in proportion to the direct compensation costs.
2. Z^F is calculated at purchase prices, using the product classifications in the appendix (sections 2 and 3 respectively).
3. X^F is obtained by subtracting Z^F from total consumer expenditure.
4. Z^P is obtained by subtracting consumer purchases Z^F from the total cost $I^T + X^I$ of providing information technology and labor in the economy.
5. $P + I$ is equal to total compensation of employees plus proprietors' income. In order to arrive at total value added in the economy (GNP), it is necessary to add the following: capital consumption allowances; rental income of persons; corporate profits; net interest; and indirect business tax and nontax liability, *net* of government subsidies.

From this macro data we can obtain, using the equations at the end of the previous subsection, the values of the input coefficients of information and production activity at the microlevel. These values are given in Table 6–1.

On the basis of the data presented in Figure 6–4 and Table 6–1, we can make a few general statements about the changes in information resource allocation that have taken place in the United States between the

Figure 6–5. Information and Production Sector Data: United States, 1960 and 1983 (All data in dollars of 1983 value).



Sources: The following sources were used to derive this data. *I*, *P* were obtained by multiplying numbers on information and production workers (calculated by applying the occupational classifications in the appendix to data in the *National Industry-Occupation Employment Matrix*, 1971 and 1981) by average wage data obtained from the *Statistical Abstract of the United States*, 1961 and 1984. X^F, Z^P were obtained by applying the industry classifications given in the appendix to data on final demand for the relevant product categories in the *Detailed Input/Output Structure of the United States Economy*, 1962, 1977. In all cases, data for years not directly available in the sources cited were obtained by linear interpolation from available data. For some product categories, data for 1983 were directly from the *United States Industrial Outlook* 1984.

Note: All product and service flows are valued at purchase prices except Z^P, which is not marketed and is valued at the cost of supply.

* of which $48b is spent on information services, $16b on information technology.

** of which $136b is spent on information services, $62b on information technology.

years 1960 and 1983. We observe immediately from the data in Figure 6–5 the increase that has occurred in the ratio of information to production labor costs in the economy; this grew from 1.25 in 1960 to 1.6 in 1980. These numbers justify the description of the present day U.S. economy as one based on information rather than traditional industrial work as its principal resource using component.

Table 6–1. Information and Production Sector Input Coefficients for the U.S. Economy, 1960 and 1983.

Description	*Symbol*	*1960 value*	*1983 value*
Information technology to information labor cost ratio	a_X	0.076	0.13
Information services to production labor cost ratio	a_Z	1.21	1.60

Source: Calculated from data in Figure 6–5; for methodology, see text.

We can see from the diagram and associated table of micro-coefficients that the growth in information resource use is principally driven by changes in production technology rather than consumption patterns. Consumer demand for information services and technology rose from $64 billion in 1960 to $198 billion in 1980, a threefold increase. However, even at the latter date, it accounted for only 14 percent of the total output of information services and technology in the economy. The remaining 86 percent was used as an input to the management and organization of physical production processes taking place in the production sector, or production services delivered to the final consumer (Z^P).

Thus, the demand for information workers has grown in recent years principally as a result of the increased requirement for information services (interpreted in a very general sense, to include management services) by those parts of the economy concerned with physical production. The extent to this increase is indicated by the input micro-coefficient a_z. In 1960 this had the value of 1.21, indicating that the production of each dollar's worth of physical production output in the economy required $1.21 worth of information services to be associated with it; by 1980 cost of information associated with that dollar of final output had risen to $1.60.

The parameter on Figure 6–4 that has increased by the largest proportional amount between 1960 and 1983 is X^I, the production and use of information technology. This grew from $45 billion at the beginning of that period to $170 billion at the end (both figures being quoted in dollars of constant 1983 value). Like the growth in information labor, this increase had two courses, one related to changes in consumer demand and the other to the structure of input coefficients in the supply side of the economy. Consumer demand for information technology increased from $16 billion to $62 billion; this increase is very large in proportional terms but is much smaller in absolute magnitude than the increase in volume of information technology purchases made as an input to the workplace. This latter number grew from $48 billion in 1960 to $136 billion in 1980, and it is largely responsible for the explosive growth in the industries that supply high-technology equipment to the U.S. economy.

APPENDIX
OCCUPATIONAL AND PRODUCT CATEGORIES ALLOCATED TO THE INFORMATION SECTOR FOR THE PURPOSE OF THIS STUDY.

(1) INFORMATION OCCUPATIONS

Engineers, technical
Life and physical scientists
Mathematical specialists
Engineering, science technicians
Computer specialists
Social scientists
Teachers
Writers and artists
Other professional and technical workers
Buyers, sales, loan managers
Administrators, public inspectors
Other managers, officials, proprietors
Advertising agents, sales workers
Stenographers, typists, and secretaries

(2) INFORMATION TECHNOLOGY PRODUCTS

Office, computing, and accounting machinery
Telecommunications equipment (excl. public network equipment)
Telecommunications carrier services
Radio, TV and hi-fi equipment, accessories, and supplies

(3) INFORMATION SERVICES FOR FINAL CONSUMPTION[a]

Banking, insurance, real estate, legal, and brokerage services
Educational services
Postal services
Entertainment services: radio and television broadcasting, cable television, motion pictures
Newspaper, magazine, and book publishing

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[a]Only the value of those services bought by households is assessed.

DISCUSSION OF CHAPTER 6

Dennis A. Yao

Jonscher's dichotomization of the economy into a production sector and an information sector is a useful perspective from which to analyze the impact of information technology on productivity. A time series comparison of the two sectors shows dramatic increases in the share of information workers, expenditure share of information technologies, and relative productivity of the information sector. None of this is particularly surprising, but it does suggest that Jonscher's perspective on the economy is becoming increasingly relevant.

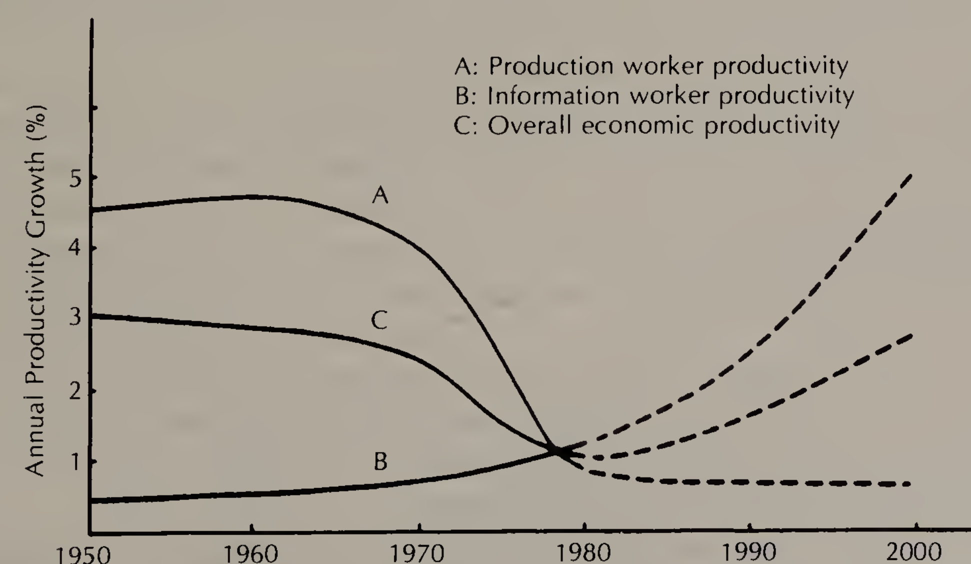
The problems in operationalizing this vision are common to any endeavor that combines theory with measurement: The links between microtheory and macrobehavior are not well developed and the data, at any reasonable level of disaggregation, is uncollected, if it exists at all. Measurement is further complicated by problems such as finding appropriate measures to accommodate learning-by-doing and in-house software development that are important to consider when examining the productivity effects of information technologies. Conquering these problems will be difficult but should prove rewarding.

Jonscher has made headway in this area in his 1983 paper and in the paper included in this volume. Both of the papers use Jonscher's two-sector model of the economy and share a similar basis in some micro-level theory. The 1983 paper is concerned with establishing this theory while the current paper simplifies the micro-level theory in order to introduce chains of production and information activities into the model. In each case Jonscher fits data to his model and discusses what the data imply about the economy.

At the conference Jonscher discussed the primary result from his earlier paper: The 1980s will see "a reversal in the previous decade's slowdown in economic growth, as information worker productivity rises substantially." Figure 6D–1, taken from Johnscher's 1983 paper, shows the historical track of productivity in the economy as well as Jonscher's extrapolations of future productivity.

A casual examination of the curves makes clear the speculative nature of Jonscher's projection. Given the relatively recent rise to prominence of the information sector, it is not surprising that the projections depart from the previous track of the economy. However, the extent of this departure is worrisome. An examination of Jonscher's model (Jonscher 1983) does nothing to allay fears about the accuracy of the model since the model is built from some assumptions that are not innocent, such as a closed economy and fixed coefficients of production and fixed price–productivity relationships. Such assumptions impose considerable structure on the predictions that Jonscher's model can make and raise questions as to the robustness of Jonscher's results to less restrictive assumptions about the workings of the economy.

Figure 6D–1. Size and Productivity of the Information and Production Sectors, 1950–2000.



Source: Jonscher (1983).

In his current paper Jonscher calculates information and production sector input coefficients for the U.S. economy in 1960 and 1983 and suggests that the growth in information resource use is "principally driven by changes in production patterns rather than consumption patterns." The latter conclusion seems hard to deny given the magnitudes of the differences calculated by Jonscher. It is important to note, however, that this growth is that of information technology and information labor together: Substitution of information technology for information labor is not explicitly considered. For example, in banking the effects of information technology have been quite dramatic, but Jonscher's model may treat that activity as one in which the change in the use of information resources may be quite modest since technology was substituted for labor.

Jonscher's paper is basically an exercise in accounting. Given his closed economy assumption and the overall balance of inputs and outputs in the economy, flows between his production and information sector can be calculated indirectly through measures of consumer demand for information, compensation to labor in each sector, and so forth. An incorrect estimate for one of these values will ripple through the accounting relationships and affect other estimates. Thus, if the categorization of information labor and production labor is incorrect or if capital flows are not constant over time (since technology is durable and has value in future years), the flows of information technology and information services will be incorrect as well.

Conclusions drawn from Jonscher's results for 1960 and 1983 should be made cautiously for a number of reasons. First, since Jonscher's input coefficients are each based on essentially one data point, the true input coefficients a_x and a_z for the early 1960s and the mid-1980s may be substantially different than those calculated by Jonscher for 1960 and 1983. Second, the criticisms associated with the 1983 model are also applicable here. In particular, the degree to which the economy is closed changes in important ways over the period of comparison. Finally, Jonscher's model does not hold constant the mix of industries in the U.S. economy. Thus, while gross estimates of the change in information resources can be made, an arguably more interesting question, the extent to which existing industries have changed their use of information resources, is not addressed.

One could always say more about the various problems that afflict all attempts to understand complex interactions. However, I will go on to discuss how contributions from the theory of organizations may be useful for understanding the effect of information changes on productivity. In so doing, I will address some of the problems of administrative coordination and point out some issues that are important for an understanding of the impact of information technology on the service sector.

A change in information technology affects productivity in at least two different ways. First, the technology offers a new means for carrying out tasks (e.g., billing or expert systems). Second, it can change the nature of organizational relationships through its effect on the control of decision processes. The first effect is self-explanatory. The second is more woolly, and therefore more difficult to explain; but it is potentially the most important.

I will briefly describe two different views of organization theory and the implications of these views for assessing of the impacts of information technology. The "rational" school of organization theory descends from Max Weber. It offers a view of organization structure as something that is designed to increase an organization's efficiency in meeting its goals. In this view, structure is designed to break complex tasks into subtasks, which are further broken down into smaller tasks, until the task becomes manageable by a single worker. Working backwards, the lowest level individual's output becomes a higher level worker's input, until the overall task is completed (Simon 1976). These relationships are orchestrated through the formal organizational structure and its rules. Thus, in this view, the basic problem of organizational design is to coordinate activities and manage information flows among the units of the organization.

Given the premise that organization design is an instrument of rational management, it is clear that advances in information technology that widen the set of possibilities for coordination and information exchange should lead to changes in organization structure. For example, headquarters can have more control over its regional offices if telecommunications are improved. If communications technologies are adopted, it might be possible to reduce the autonomy of regional offices, assuming such a change is desirable.

The premise that organizations are designed and managed to accomplish the relevant task most efficiently is arguable. For example, an implication of such a premise is that an organization faced with significant environmental change will adapt its structure to the changed environment. However, "population ecology" theorists suggest that individual organizations rarely change in substantive ways, even in the face of considerable environmental change (Hannan and Freeman 1977).

Organizational inertia may result from power and politics within organizations, systematic misperceptions by organizational members, previous investments in plant and equipment, legal and financial barriers constraints on action, or considerations of legitimacy. I will describe the first two factors in more detail since they seem the most compelling and widely applicable explanations for organizational inertia.

Organizational structure determines the power and influence structure within the organization as well as the structure used to achieve organizational goals (Pfeffer 1981). The relationship works in the opposite direction as well: Players with power can determine structure. Thus, managers in power are likely to resist change since it puts their current situations at risk. Those who might benefit most from change are, on average, not in a position to affect decisions about structure. These forces act to bias organizational decisionmaking in favor of the status quo.

A second explanation for organizational inertia is that organization members may misperceive problems and potential solutions to those problems. Organization design and culture affects the way information is transmitted and processed within an organization, which, in turn, affects how people within the organization perceive the internal and external environment. For example, a firm that has spent the last two decades protecting its profits from the regulatory clutches of the federal government may see most of its problems stemming from regulation even when regulation ceases to be a primary factor in the firm's profitability. This occurs because sensitivity to regulatory issues has been institutionalized into the firm's culture and its structure, to the neglect of other factors that affect profitability. Similarly, when a person has learned to perceive a particular problem in a particular way, a tremendous amount of contrary information is required to cause a shift in the person's perceptual paradigm (see Jervis 1976). The same holds true for organizations.

Of course, organizations that do not change in the face of environmental shifts may not survive. The implication of the population ecology argument is that organizational change within an industry comes not as much from adaptation by dominant organizations as through the growth of less dominant organizations or the genesis of organizations that are a better match to the demands of the environment. Thus, new technologies, rather than causing changes within existing organizations as is predicted by the rational organization school, could lead to the growth of less established organizations at the expense of more established organizations.

Advances in information technology are likely to result in changes that improve productivity in organization structure; however, our earlier discussion indicates that it is unclear from the theory whether these changes will occur rapidly within existing organizations or will come about as new organizations displace the inertia-bound older organizations. Such uncertainties have troubling consequences for researchers who attempt to measure the impact of information technology on the economy. The effect of information technology involves both the simple use of the technology and the rearrangements of organizational structure that such a new technology may allow. To incorporte the organizational effect in measurements of productivity, researchers will need to learn how to identify changes in organizational form and how to link these changes back to the more conventional measures such as investment and labor force size.

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