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TECHNOLOGICAL UNEMPLOYMENT

The Case of Computers

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INTRODUCTION

The capacity of computers to perform many types of jobs formerly handled manually has given rise worldwide to an anxious concern that massive unemployment can result unless appropriate policies are implemented. On the other hand, there is the opposite opinion that computers present little or no threat as the increased productivity their introduction entails will help growth and act as a stimulus to new job creation. However, most of the current forecasts and projections[1] are flawed by a neglect of one or another pertinent economic factor or incentive which to a great extent governs the speed by which mere technical possibility becomes a social actuality.

A full study of computers, the job loss and job gain attributable to them, is complicated not only because it embraces many economic adjustments in many sectors of the economy (the direct and indirect employment effects) but also because a multitude of data problems requires attention and even questions of definition have to be settled. For example, what it is that constitutes a 'typical' or 'standard' computer when no two computer models are alike has to be addressed. This question occupies a good deal of the study and an answer is attempted based on the principle of correcting for quality differences between computers of different characteristics and rentals. The method we recommend for obtaining quality adjusted annual computer stocks is the standard hedonic index approach. Unfortunately, the available data for this task is not in the required form and has to be collected afresh, thus adding to the work needed to be done. We suggest a simplier approach which can use data already available as a first step.

But the issue of measuring the computer stock is only half the problem. The second step is to somehow associate new jobs created and jobs displaced with the introduction of a 'standard' computer. The only sure (but still imperfect) way of doing this is to take a full census of personal management in institutions and firms with computers in use, and have them respond to a question of the type, "How many jobs would have become available had computers not been installed"? This information is not available for Canada although there exist two British studies based on this approach. Our suggestion is the second best one utilizing case studies. A few case studies both in the context of the office and in the production process can serve as rough benchmark estimates of job displacement within specific industries attributable to the computer. Very roughly, the number of job losses due to a 'standard' computer for a particular industry can be formulated, and using a forecast of computer growth, a projection of direct job loss can be made.

In parallel with the estimate of job loss would be an estimate of jobs created in occupations directly associated with operating the computer, i.e. programmers, maintanence work, coders, etc. On this score the data is definitely superior.

However, the work suggested thus far only covers the direct effects on employment, those jobs directly replaced or created at the establishment where the computer was introduced, but there are also the equally important secondary or indirect effects which have to be considered, those jobs associated with the 'multiplier' or ripple effect as the impact of changes in capital investment and employment are absorbed by the rest of the economy. This part of the research programme would involve the use of a large-scale econometric model of the national economy for purposes of simulating the 'secondary' effects, and the time profile of the adjustments as they work their way through the entire economic system. These effects must not be neglected as they can be of the same order of magnitude as the initial impact experienced at the industry undergoing the process of computerization.

The extent of computerization within an industry is an evolving process and no industry becomes computer saturated instantly. The economics of automating data handling and production processes varies from establishment to establishment, as also does knowledge concerning the advantages computers offer to management. Put succinctly, for each industry there is a specific diffusion process of computerization which determines the rate at which computers are introduced. Obviously the time profile of computer induced unemployment will in part be governed by this diffusion rate, and so research is required to estimate the rate. A feasible and standard programme is described in the study and is strongly recommended.

This study describe the many elements of a scientific investigation on computers and jobs. The complete work would cover at least 3 years but the hope is that each stage can inform public policy concerning aspects and eventually the order of magnitude of the phenomenon of technological unemployment.

1. EMPLOYMENT IMPACT OF TECHNICAL CHANGE

The introduction of a new technique into the process of production may lead to a saving on labour, on capital, or both. If layoffs are directly the result of the change, a part of the employment impact becomes directly evident, but there are other not so obvious adjustments which on being taken into consideration may tend to offset the job displacement effects. For example, if the unit price of the product falls then extra production may be needed to meet the stronger demand produced thereby, and layoffs averted as a consequence. One may not expect jobs to be threatened by capital saving technical change, but even then jobs in other industries can be on the line. A case in point is the introduction of process control in steel mills that had not much affected employment numbers directly involved in the process of steel production; however, a lot of material waste has been eliminated, energy requirements reduced and accuracy in meeting customer specifications improved.[2] Such cases are instances where the employment level in plants has remained substantially the same in relation to a given production level (although its skill composition has changed through upgrading) but the impacts in the forward and backward linkage in the production chain could lead to job displacement. Less raw ore and less energy are needed from the backward links and less inspection and handling activities needed in the forward links. Thus the economy as a whole, at one stage or another, can experience a slackening in labour demand although paradoxically no layoffs occurred in the sector where the technical change originated.

Other consequences of technical change are transmitted through the price system to the rest of the economy. Steel which has been made cheaper by improved techniques of production obviously benefits the automobile industry, and likewise cheaper telecommunication cost benefits all industries to a lesser or greater degree. These effects reduce average production costs, and result in a downward adjustment in prices. Such changes in relative prices then have the usual consequences for commodity demand and hence production levels. As the demand levels adjust to accommodate the change in prices the level of employment and income distribution (unless the famous "non-substitution theorem" applies) make accommodating changes. In an open economy foreign trade consequences naturally become important. As all these adjustments work themselves out employment in all industries undergo adjustments, forcing us to analyse not only the direct employment effects but to pay due regard to the indirect effects: a full general equilibrium approach to the problem is called for.

To actually capture all the ripple effects technical change can cause throughout the economy and the labour markets, a very detailed econometric model of the economy would be needed for simulation studies of this kind. Ideally, the model should possess good industry detail and a fair estimate of the transmission lags experienced in the real world economy as it responds to a local disturbance. Aggregate demand should interact with particular industry outputs (as in the CANDIDE model and in Informetrica's TIM model) and labour requirements should be specified by industry. Such a model would then permit us to simulate the multifold consequences of the introduction of an improved technique in a very specific sector and enable us to gain a view of the timing of layoffs and job openings flowing from the initial change. This timing is important since the degree of offset new vacancies achieve over job displacement at any point in time will depend on how close or how far the two events are contemporaneous.

Later we will enter into a full discussion of the feasibility of such simulations. We will also later detail how long-run simulations can be performed within the simplier, more transparent framework of a large input-output structure of the economy in which the all-important lags are absent. This latter experiment should offer a rough view of the long run consequences we should expect. Moreover, in both cases we will suggest how possible compensatory fiscal and monetary policy actions might also be examined. But before embarking on such large tasks, to put it plainly, we should know what to do, what to expect and most important of all, to develop some theoretical insight into the processes to take place and their economic meaning. Without this important theoretical understanding there is no way of knowing if the simulation exercise is meaningful or not, or how best to conduct the experiment itself. For this reason an extensive analytical discussion is made prior to the empirical discussion. To this end we examine both a competitive and a monopoly model, the former without demand in view and the latter with demand made explicit. A Leontief structure of production is used throughout with a view to investigating how far the effects of technological change can be studied through pure analysis before resorting to simulations using an input-output structural model of the national economy. The results are not tremendously encouraging because of the over-simplifications, especially regarding fixed capital, that are presupposed in these models for the determination of prices. This suggests that further understanding of the effects of new techniques can come only from careful empirical work.

2. ANALYSIS OF THE EFFECTS OF TECHNICAL CHANGE

2.1 The Open Model

From the viewpoint of employment the multifold ramifications of technological change reach jobs in all corners of the economy. Improvements in production techniques in a specific sector or industry can potentially affect all markets and the overall pattern of goods production. A process innovation will immediately be felt in the sector where it is first introduced but its impact will eventually be felt in other sectors and, if strong enough, a feedback of these secondary effects can ultimately reach the original point of the distrubance of equilibrium. The complex picture of price adjustments, job displacement and realinement of sectoral production thus produced is difficult to analyze unless we resort to a simplifying conceptual model, and for this reason the competitive model is utilized here to obtain a rough overview of the important linkages. to further simplify matters let production be characterized by a Leontief linear system, with no joint production, constant returns to scale and indecomposability. The latter assumption simply means all goods are used in production in every sector, a restriction that is inessential to the generality of the final conclusions. Also at this stage there is no durable capital.

The operation of this linear model can be expressed in physical terms as follows. There is one technique used in each sector which are fixed unless modified by the introduction of a new technical development. The model represents the production of a particular flow of output with a given labour force, requiring a particular flow of inputs (intermediate goods and services including the telecommunications, computer rentals, energy, etc.). The system is self-reproducing with inputs being replaced as they are used up and a net output to final demand forthcoming. This is the world of Ricardo and Sraffa where substitution aspects ruling the demand for factor inputs are downplayed and income distributional aspects come into the formation of relative prices.

The introduction of technical change in a particular sector, whether of the labour or capital saving kind and for whatever motive, leads to a fall in the average cost of production. Since the market structure is competitive and production is characterized by linearity, the price of the produced commodity will fall. Furthermore, other produced commodity prices will also fall since the first commodity is used as an input in every sector, and its price reduction induces a lowering of average production costs everywhere, to a greater or lesser degree. Suppose the initial change consisted in the introduction of a labour saving method, so that some workers in this sector are laid off. There are two processes available by which a compensatory employment effect can take place, namely through the extra demand for labour emerging from the capital goods sector or from final demand goods production. Here, we shall consider only the latter potential source of compensatory employment, since the other is in our favour but to an unknown degree.

The phenomenon of economic adjustments made in response to the technical chance must be viewed in general equilibrium terms. A partial equilibrium analysis will not do, as we see from the diagram taken from Blattner (1979) and Heertje (1977). A decline in average cost implies an outward shift in the supply schedule (the same quantity can be produced at a lower price). Whether or not new production is warranted of course depends on demand and its elasticity, and the extent to which new employment offsets the reduction of input requirements per unit of output also depends on the elasticity of demand. But it is important to observe in this context that any substitution effects causing an enhancement of demand for the output produced in the sector under consideration, by the same token also brings about a general reduction in demand for other goods and services.

The cutbacks in production this entails moderate any tendancy for compensatory employment effects. Not only that, for we saw that prices everywhere are affected and further analysis is not possible unless we have some notion as to which price, that of the commodity produced by the new technique or the others, fell relatively the most.

In a competitive general equilibrium where all prices including the wage rate are flexible, and where all markets clear (Say's Law), unemployment is impossible. Thus to make sense of this discussion of labour displacement and compensatory employment it is necessary to make reference to the movement in the wage rate or otherwise have it fixed at the initial equilibrium level by forces lying outside the market system. From our point of view compensatory employment is defined as that which creates sufficient labour demand to effectively restore wages to the initial level. However, an analysis based on rigid wage rates would serve equally well.

The question as to which price falls the most under technical change has troubled both classical and modern economists. Since the time of the classical economist it has generally been claimed that an invention in a specific sector leads in the long run to a lower equilibrium price for that sector. Nordhaus (1969), working with the results obtained by Simon (1965), Samuelson (1961) and Levhari (1965), show that this indeed is the case, and in fact that all prices fall in relation to the wage rate (see also Arrow and Hahn, 1971). More important, however, is the finding that the price for the industry hosting the new invention declines relatively more than any other good. Finally, both assertions remain true in the more general case where alternative techniques are available in each industry. This phenomenon can be illustrated for the two industry cases through a diagram.

Following Nordhaus denote material inputs per unit of output by the matrix

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}$$

where a_{ij} represents the amount of input from sector i required for the production of unit output in the j sector. Let w denote the wage rate and (a_{01}, a_{02}) the labour services required for unit production in sectors 1 and 2 respectively. For sake of algebraic simplicity profits are set to zero and the price equations become

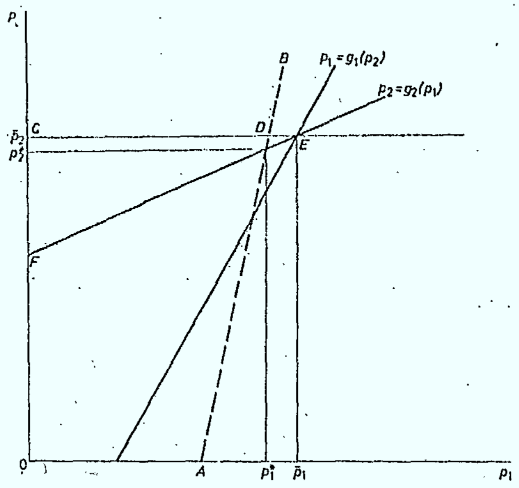


Figure 1 Price determination in the Leontief model

Source: Nordhaus (1969)

$$p_1 = a_{01}\, w + a_{11}\, p_1 + a_{21}\, p_2$$

$$p_2 = a_{02}\, w + a_{12}\, p_1 + a_{22}\, p_2$$

Solving, we obtain the price of the two goods in terms of the technology, the wage rate, and the price of the other good:

$$p_1 = \frac{a_{01}\, w + a_{21}\, p_2}{1 - a_{11}} = g_1(p_2)$$

$$p_2 = \frac{a_{02}\, w + a_{12}\, p_2}{1 - a_{22}} = g_2(p_1)$$

Note that being in the self-reproduction state requires both a_{11}, $a_{22} < 1$. These price equations appear in the graph above. A change in technique which reduces the average cost of industry 1 is illustrated by the dashed line AB. The new equilibrium is shown at $(p_1^*, p_2^*) < (p_1, p_2)$, where both prices have fallen below the original levels. Also, since $g_2(p_1)$ has a positive intercept the change in p_1 will exceed the change in p_2.

This analysis involving a linear economy can be extended to more general technologies where continuous substitutability between inputs are admissible. The reduction in price produced by technical change cheapens the cost of production for the second good, as we saw. But substitution makes available a second mode of cost savings as the cheaper material input partly replaces the more expensive commodity input. Such substitution causes the linear curves $g_1(p_2)$ and $g_2(p_1)$ to be bowed outward, i.e. show diminishing marginal returns to each factor.

To bring the analysis closer to the real world we naturally have to take the presences of fixed capital into serious consideration. Capital goods that last for more than one production period has always presented economic theory with troublesome analytical problems (see J. Robinson, 1953) and Sraffa 1960). The same is true of our tidy results on price determination in the Leontief model. Strictly speaking, an extention of these traditional findings is possible only for those cases where capital aggregation is theoretically feasible (Solow, 1956), both over capital goods within each industry and over time for each capital goods. Unfortunately the conditions which allow for such capital aggregation are pretty severe. For example, goods having different efficiency time profiles in different industries violate these conditions, and consequently further analysis would be needed to demonstrate how far towards realistic economies the simple model can be taken without losing the clarity of the traditional results. However, in those (many) cases where no clear-cut analytical results can be expected a recourse to simulation exercises cannot be avoided.

Even the simple, partial equilibrium analysis discussed by Blattner (1979) could be inapplicable in cases where the presence of capital goods prevent the formulation of unambiguous conclusions, and to repeat, there is no assurance that these do not include most of the cases to be found in the real world.

Another noteworthy result from the competitive model with labour as the only non-produced input, concerns the distributional impact of a newly introduced invention. The factor price frontier is a downward sloping schedule from which can be read off the maximum value for the other, the profit rate. An invention causes the frontier to move outward, which is another way of saying that the economy is enabled to produce a larger product net of material inputs for dispersement among labour and owners of capital. Analytically, the result arises because all prices fall in relation to the nominal wage rate thus causing the real wage rate to rise for every level of the profit rate.

The foregoing analysis centred about models of the economy where labour is the only binding constraint on production. An implicit assumption is also made concerning the homogeneity of labour, through which the productivity of computer programmers is the same in all industries and is the same as for other skills, such as a taxi driver. Although aggregation of labour types, were it logically permissible, would overcome this particular obstacle, both flexible labour supply and the presence of other contraining factors - land, non-renewable resources - must be explicitly taken into account. To make the point we only have to recall Ricardo's famous example in his chapter on machinery, where labour supply is perfectly elastic and land serves as the binding constraint. Ricardo arrives at the controversial conclusion that the introduction of machinery may well lower prices without benefiting the labouring class. While an invention can increase the return to owners of land and capital, the subsistance wage will stay the same and if final demand for luxuries by the wealthy shifts as a result of the price changes to less labour intensive goods, workers will be laid off. This is an extreme example, made so by the unlimited supply of labour. But it does serve very well to emphasize the need for permitting some degree of elasticity in labour

supply in any analysis of technical change. This forms the discussion of the next section (based on the work of Nikaido (1975)).

2.2 A General Equilibrium Model with Demand

Flexible labour supply and the relative autonomy of demand take the analysis out of the simplified economy characterized by cost of production. In the present analysis, demand is important. Indeed, to further emphasize the role of demand the market structure in this model is altered from the competitive to the monopoly. This change has the added virtue of greater realism since it encompasses monopoly competition, price leadership roles, and market sharing agreements. What the modes does not include, however, is one of the most important of market structures, oligopoly. Although it has not been demonstrated it seems that along with oligopoly's other indeterminacies it is not possible to work out a unique pattern of outcomes - apparently many possibilities abound for technical change under oligopply. The linear Leontief structure is used to model production where fixed capital (and land) is represented by capacity constraints in the short run. While production exhibits constant returns to scale with regard to current input-output relations, increasing returns or decreasing costs occur with respect to the investment of fixed production machinery and equipment. A larger investment in fixed capital goods gives rise to more-than-proportional increase in technological efficiency and plant capacity limits. At the level of the present discussion considerations of investment and growth are put aside and only the static aspects of general equilibrium are explores.

Gross output in this model is sold to intermediate and final demands. For conciseness foreign trade and government expenditures are excluded and final demand is shared between workers and the entrepreneural class. Any demand has to be effectuated by earned income, either through labour earnings or profits, and demand is made equal to supply in each market at the equilibrium point. The existence of this equilibrium and its uniqueness are not as evident as for the previous model but can be demonstrated.

Using this model we wish to examine the change in equilibrium outputs and prices as a consequence of a specific type of technical change. If we suppose for sake of analysis that the material inputs are proportional or otherwise a monotonic function of capital equipment then we can simulate four basic types of technological change in the jth sector: labour saving (using) corresponds to a_{oj}

falling (rising), where a_{oj} is the j-sector labour requirements; capital saving (using) corresponds to a_{ij}, all i = 1, ..., n, falling (rising), where a_{ij} are material input requirements. Specifically, we consider an exogeneous change to have occured on a_{oj} and look at the consequences. Next, we discuss the impact of capacity constraints and the short-run unemployment caused by these constraints. The long-run effects cannot be treated at this stage although clearly they are of vital importance when addressing the employment effects of new technology. It is a worthwhile project, in fact, to explore alternative models as extentions of the present one for investigating the medium term effects with various sectors reacting at differential speeds as intermediate demands adjust and similarly some simple growth models could be examined.

Furthermore, final results are not sought after at the present. The object is to find out if our less simple general equilibrium model has the power to give unambiguous predictions of how the equilibrium of the economy will adjust to a technological parametric change. Only a part of the answer is provided here. Further research along these lines are however suggested since such work will go some way to both better our understanding of the process by which a technological impact in one sector diffuses throughout the rest of the economy, and guide one's approach to simulations based upon economic models of the national economy.

Hopefully, such an analytic investigation will help avoid unnecessary or inefficient simulation studies.

To continue with the model at hand it is to be noted that the formation of profits per unit output originates in the specific market structure that rules in each sector. Various possibilities of market organizations can give rise to a variety of structures accordingly as each sector is subject to immobilities in capital, and/or price or institutionally erected barriers to entry to new firms. An extremely monopolized sector could presumably command a high profit per unit output, while profits would most unlikely be so rich in a relatively competitive sector. These two represent polar cases between which extremes intermediate values of profit per unit of output would be manifested by other market forms. Also included in this formulation is the particular case where profits reflect an equal rate of return on capital across the entire economy. The specifics of market forms do not interest us here, simply their existence, and we take them as predetermined. This allows us to take the profit per unit of output vector (π) as also given and, for small changes in input requirements, constant. Thus, technological change of the kind which affects input requirements in a not too dramatic way will keep the levels of π intact. Actual profits levels can nonetheless be modified through technological change by adjusting the sectors' gross output level, since the profits of the ith sector is given by the product

$$S_i = \pi_i x_i.$$

The output determining equation for the standard n goods and n-sectors Leontief system is as follows:

$$(I-A) x = c$$

where $A = (a_{ij})$ is the input coefficient matrix, c is the final demand vector, x is the output vector and p is the price vector. The dual price equation can be expressed by

$$p' (I-A) = w a_0' + \pi'$$

where w is the uniform wage rate, a_0 the vector of labour requirements and π is the profit per unit of output vector, π_j being the jth sector's profit per unit of output. The prime denotes transpose and here value added is expressed as the sum of wages and profits. By setting $w = 1$, $\pi = 0$ we can define a vector, σ, which represents the amount of labour input directly and indirectly necessary to produce a unit of output;

$$\sigma' (I-A) = a_0'$$

or

$$\sigma' = a_0' (I-A)^{-1} > 0,$$

since $a_0 > 0$ and the system is self-reproducing.

The labour force consists of workers who behave as price takers in supplying labour and demanding goods. Labour supply is represented by the aggregate supply function

$$L (p, w)$$

and labour's aggregate demand function (vector valued) for goods is well defined:

$$F (p, w) = (F_j (p, w)).$$

With no saving, under full employment, we have

$$p'F (p, w) = w L (p, w)$$

Wage is taken as numeraire, $w = 1$.

By this specification the labour supply is given flexibility, depending on the nominal wage rate and the price of goods entering consumption. It is customary to use the real wage rate as the determinant of labour supply whereas we allow for a more general functional form. The difference in the two approaches are unimportant and L (p, 1) can simply be thought of in real wage terms with the money wage normalized to unity. Both labour supply and workers' aggregate consumption are determined by commodity prices. Prices in turn are given by technological coefficients and the profit per unit output vector:

$$p' = \sigma' + \pi' \ (I - A)^{-1}$$

i.e. prices are calculated as the sum of embodied labour and profits in commodities. This gives commodity prices the character of linear cost-of-production prices without the intervention of demand considerations. This is true until π became subordinated to demand, or capacity constraints intervene.

Once prices are established, workers' final demand for goods is fixed and what remains after deducting for material or derived demand as well as for workers' demand remains with the capitalist class. Their choice of final demand, c, if made effective by profit income determines output and employment:

$$x = (I - A)^{-1} [F(p, 1) + c]$$

$$a_0' x \leq L(p,1)$$

Profit income constitutes the effective means for purchasing the basket of goods denoted by the vector c. But income depends on the sectoral gross output levels x. To model this interrelationship further, suppose capitalist households behave, like workers, as price takers when spending income; whether the expenditure is on consumption goods or on capital goods. Thus the demand of capitalist households can be written as

$$G(p, \pi_1 x_1 \pi_2 x_2, \ldots, \pi_n x_n)$$

and we write

$$x = (I - A)^{-1} [F(p, 1) + G(p, \pi_1 x_1, \ldots, \pi_n x_n)]$$

In this form the gross output vector is not expressed in terms of an explicit equation since output values appear on the demand side also. This fact complicates the equilibrium analysis involved in finding if there exist at least one nonnegative vector x which satisfied the foregoing equation and which does not require more labour than is available at the ruling commodity prices. Fortunately, this issue of existence has been resolved favourably, and with additional assumptions on demand, uniqueness can be obtained. Since the existence and uniqueness of equilibrium is settled, the way is open to investigate how this equilibrium change under a change in technological parameters. But before going over to this investigation it is useful to indicate how the model with capacity constraints, involving possible unemployment, can be formulated.

Let $m_i > 0$, $i = 1, \ldots, n$, be the capacity limit of the ith sector output x_i and $m = (m_i)$ indicate the capacity limit vector. The economy's production possibility is then constrained by the system of inequalities:

$$a_0' x \leq L(p,1)$$

$$x \leq m$$

If the employment of labour falls short of supply because of capacity limits then the wage bill by commodity breakdown paid out to the employed labour is

$$\frac{a_0' x}{L(p,1)} F(p,11),$$

the capitalist final demand vector $c \geq 0$ and the corresponding gross output vector $x \geq 0$ satisfy

$$x = Ax + [a_0' x/L(p, 1)] F(p, 1) + c,$$

subject to the constraints above. Hence (here x is shown as a function of the choice of c):

$$[I - (A + \frac{F(p,1)}{L(p,1)} a_0')] x(c) = c$$

The matrix shown above is invertible with a nonnegative inverse, preserving the non-negativity of the gross output vector x. It can also be shown (as in preceding case) that

$$\pi' x(c) = p'c$$

holds for any choice of c for which $M(\pi) = L(p, 1) - \sigma' F(p, 1) > 0$, moreover, we have

$$c = G(p, \pi_1 x_1(c), \pi_2 x_2(c), \ldots, \pi_n x_n(c)).$$

This shows that the previous result extends to the underemployment situation induced by capacity limits.

To indicate how technological change can be applied within this model framework consider a change in labour requirements for one sector (sector i), where capacity limits are ignored for sake of clarity. Suppose the change is indicated by

$$a_{0i} - a_{0i}^{0} < 0 \quad ; a_{0j} = a_{0j}^{0} \text{ all } j=i,$$

where the superscript 0 indicate values prior to the change. The input-output matrix A and the profits per unit output π are unaffected. In this case the price vector change is

$$p-p^{0} = \sigma - \sigma^{0} < 0$$

and the relative price decline depends on the relative capital-labour intensities among sectors. This result is a repeat of that established in the two-sector model discussed earlier and needs not be elaborated here.

Let the price and income impacts on final demand by workers and capitalist households be measured by the matrices of first derivatives:

$$F_p \equiv \left(\frac{\partial F_i}{\partial p_j}\right) \equiv \begin{bmatrix} \frac{\partial F_1}{\partial p_1} & \frac{\partial F_1}{\partial p_2} & \cdots & \frac{\partial F_1}{\partial p_n} \\ \frac{\partial F_2}{\partial p_1} & \frac{\partial F_2}{\partial p_2} & \cdots & \frac{\partial F_2}{\partial p_n} \\ \cdot & \cdot & \cdot & \cdot \\ \frac{\partial F_n}{\partial p_1} & \frac{\partial F_n}{\partial p_2} & & \frac{\partial F_n}{\partial p_n} \end{bmatrix}$$

$$G_p \equiv \left(\frac{\partial G_i}{\partial p_j}\right) ; \qquad G_s \equiv \left(\frac{\partial G_i}{\partial s_j}\right) ; \quad S_j = \pi_j x_j$$

The impact of a technological change of the simple kind $a_{0i} - a^0_{0i} < 0$ on gross output can be expressed as:

$$x - x^0 = (I-A)^{-1} \left[(F_p + G_p)(p - p^0) + G_s \begin{pmatrix} \pi_1 & & 0 \\ & \pi_2 & \\ 0 & & \ddots \pi_n \end{pmatrix} (x - x^0) \right]$$

i.e.

$$x - x^0 = \left[1 - A - G_s \begin{pmatrix} \pi_1 & & 0 \\ & \pi_2 & \\ 0 & & \ddots \pi_n \end{pmatrix} \right]^{-1} (F_p + G_p)\ (\sigma - \sigma^0)$$

$G_S \geq 0$

The above two expressions for the adjustment in equilibrium gross output vector show very clearly how the impact of changes in gross output, via profits, feedback as a multiplier effect to heighten the initial impact. Thus in addition to the direct and indirect employment effects we also have to take account of the income effect shown here. This latter effect is not to be written off as no more than an artifact of the model, for it adds to the analysis a new element which is seen to be essential and agrees with our intuition as to what constitutes important factors in economic change.

Observe that the inverted matrix need not any longer be nonnegative showing that some sectors can increase their output and others can lose output.

The case of underemployment creates an added factor in the inverted matrix, involving the ratio of labour demand to supply.

As indicated earlier our intention at this stage is limited to identifying a more suitable model which incorporates non-autonomous components of final demand for studying technological change effects, which also can allow for technological unemployment. The model has the added virtue of bridging the gap between analysis and econometric national economy simulations. The next step to take involves applying the model to see how far we can get less trivial and more realistic predictions of equilibrium change, as well as to challenge our time worn preconceived ideas on technological unemployment.

3. COMPARISON OF COMPUTERS AND MEASURE OF COMPUTER OUTPUT

3.1 Computer Generations

The science-based societies of the 20th century created a tremendous demand for numerical computation and it became manifestly evident that the task was beyond the capability of a skilled workforce, however large it might become. Not only was the sheer burden of innumerable calculations too vast for a trained workforce to process, but many computations of the simplest kind as seen from today's perspective would take more than a lifetime to complete. This growing computational need could only be met by very fast, automated calculating machines with a large memory. Automation in this case means that computational and administrative steps are automatically carried out in sequence. Well-known attempts to automate routine arithmetic computations have been made ever since the brilliantly devised Babbage Machine invented in the 19th century. Subsequently electromagnetic relay machines became prominent but this development was limited by size, slow speed, inaccuracy and power requirements. The limits of this type of computational machine were close to being met in 1939 when Aiken at Harvard designed a machine to find the roots of polynomials. Today such a low level computational task is capable of being performed by $150 handheld calculators.

The electronic vacuum tube opened new vistas for developing computing devices since it performed 1000 times faster than the relay. This promise was realized in the ENIAC computer designed by Eckert and Mauchly and applied, needless to say, to military purposes. But it was J. von Neumann's development in 1946 of the "stored programme" which gave the computer its unique versatility, its prized capability as a general purpose machine, which by re-programming could be adapted to other purposes. This software aspect came close to realizing the economist version of the 'Philosopher's Stone' by which capital equipment could be transformed into other machines, since the dedicated and limited functions typical of fixed capital has been removed. However, as can well be imagined this blessing presentsfor us a trial because software can make two machines even of the same model type essentially different. The task of measuring computer output in terms of the economic importance to the user gets even more difficult.

The first notable application of computers came in 1950 when the UNIVAC 1 was used for the U.S. 1951 census. Later, in 1954, the first commercial applications were made with UNIVAC type machines having very limited characteristics by modern standards. They operated with a sluggish drum memory, using paper tape or punched cards as an input medium, possessed a capability of only 1,000 instructions per second and 10 K to 20 K characters of memory. In this first generation of computers, exemplified by UNIVAC I, the IBM 650 and 700 series, and the British LEO, the attempt to promote widespread use and sales met with little success. Sales optimism was so limited in 1954 as to cause General Electric to make the forecast that only 50 computers would be necessary to saturate the U.S. market. Events proved the pessimists to be very wrong indeed.

A qualitative and quantative change overran the computer market in the aftermath of the transistor, invented in 1960. This devise which resulted in faster and smaller machines, and also less energy requirements on two scores, to run the machines and to cool them as less heat had to be dissipated. An equally important benefit of the new transistor technology was the dramatically reduced failure rate experienced in the new generation of machines, leading to a greatly increased capacity for the complete computer system. The transistor and other significant developments warranted the label 'second generation'. This period also saw the introduction of magnetic tape storage which reduced the cost of storage and space requirements and allowed data and instructions to be entered much more quickly than punched cards were capable of.

Typical EDP machines in the second generation were IBM 1401 and 7090 series with a capability for a million instructions per second, 1,000 times faster than the rate for the first generation machines. The utility and appeal to a variety of users, new and old, was greatly enhanced by the developments of time-sharing techniques and of user-oriented languages.

The present 'third generation' was ushered in by the remarkable development of the integrated circuit in the mid-1960s. Typical machines of this period are the IBM system 360 in the late sixties, the IBM system/370 in the 1972-78 period and the current 333X and 43XX series. These electronic devices are more compact, more reliable, faster and less expensive while offering more output in the form of greater versitality, speed and high memory size. Added improvements came with vastly increased disc storage, and high speed magnetic tapes. The whole concept of "data communication" has taken hold, with computers communicating with each other through telecommunication links. Speedier throughput was also achieved by sofeware developments allowing multiprogramming and multi-processing. These important developments were paralled by the development of virtual memory addressing schemes, thus greatly reducing the constraint of memory size on application programmes.

The important trend of miniaturization caused a strong demand for mini-computers and microprocessors. This development of relatively inexpensive machines, representing a small capital outlay, brought a return of EDP machines dedicated to a single task; although the introduction of "firmware" which permits a change of application software by switching to inexpensive modules, may lead to semi-flexible machines.

A general trend which has emerged in the third generation period is a change in the relative cost of machines to human labour in a total computer system. Machine time use to constitute by far the chief cost in the system and extensive programming effort went into conserving machine time. While cheaper processing machines have caused a seemingly exponential fall in CPU time cost, the labour intensive programming costs have been increasing. Programming research and development costs, together with the cost of programmers working on the operating system, now threaten to constitute the chief cost for some systems. It is expected also that this trend will continue and intensify in strength.

The significance of modern developments in computer-communications reach beyond mainframe technology and software innovations. A new and heavy emphasis on peripheral equipment continues to increase throughput, bringing it to a closer match with the speed of the CPU. In addition, there has occured the automation of sensing, recording and converting information which affects both computers and humans. For example, the Universal Product Code system will accelerate the displacement of low-skilled labour, including cashiers. Moreover, these improved methods of collecting information decrease computer systems operating costs substantially, simply by reducing the error rate. In this way new computer capacity is created.

In the future we can see two directions of improvements; a further generational improvement in the internal workings of the machine itself, producing better, cheaper CPUs of both dedicated and general purpose types; improvements in the external workings, including more efficient programmes and compliers that save human resource requirements, terminals, protocols for compatability between different systems, improved telecommunication speeds, and so forth.

In overviewing the history of computer development and applications, we can also see that user's demand has evolved to produce a notable qualitative change at about 1965. Prior to that time the dominant application consisted of substituting machines for humans by having computers do the routine information processing work (e.g. payroll) normally carried out by people. The computers handled tremendous volumes of work at incredible speeds which could not be matched by humans, and in this sense changed the nature of the service provided, but it was not really until after 1965 that we began to witness the application of computers into new areas, such as CAD/CAM (computer-aided design/computer-aided manufacturing) and process control. In the first stage computer efficiency was the chief concern, naturally when computing time was relatively expensive. In contrast, the present stage is characterized by a concern to improve human efficiency due to rising human to machine ratio of costs. CAD/CAM can be expected to involve a human input of a very highly skilled nature and even process control, which during operation uses chiefly sensor based inputs, requires user programming (a Canadian pulp mill got its process control started after using 3 programmer-years). However, the long run trend of low-skill displacement by machines will continue, as for example communicating word processor technology becomes familiar in the office and banks become fully plugged into electronic funds transfer systems.

Thus, the pace and pattern of employment impacts will be different in the future than in the past, making forecasting difficult. A lot will depend on the extent to which the manufacturing of computers stimulated by EDP demand is located in Canada rather than outside. Much also will depend on the rapidity with which new applications are introduced in product design and analysis; production, material and inventory control; automated production; the office and banks. Potentially of course, new computer applications can be profoundly novel; numerical control tools and industrial robots have even the power to change market structures by eroding large scale economies. Such profound changes of this nature could never be made ameable to forecasting techniques. But how likely is the rapid realization are these extreme scenarios? The fact that heavy labour inputs are required for CAD/CAM may well check the rate of adoption of this technology, while the displacement of labour still carrying out routine functions will likely continue at a steady rate. Evidently, the continuity of change is determined by the rate at which new developments and applications diffuse throughout an industry or the total economy.

The rapid foothold mini-computers and micro-processors gained in the computer market well illustrates the importance of costs in determining the speed with which a new technology is commercially adopted. A rapid reduction in cost ushers in revolutionary changes while high, downwardly inflexible costs impede change, as during the first computer generation. Since cost is readily identified as the chief determinant of technological diffusion it seems likely that for the next few years the pace of change will be moderated by the rising cost of software and other human inputs, giving some basis for projecting near future employment developments due to computers. This confidence is further reinforced by the slow-down in aggregate demand the economy will continue to experience for some while. It is during such periods of economic retrenchment that business investment is apt to weaken, not only as it is manifested in orders for new machinery and equipment but also in the research and development which is the source of innovation. At the same time it has to be recognized that several factors can cause this confidence in moderate change to be shaken; perhaps the most telling would be any breakthrough in the ability for machines to programme themselves or other machines and thereby circumvent the high labour costs associated with software development.

3.2 The Measurement of Computer Quantity Change

There exists no adequate measure of computer stock or its change, for Canada or any other country. The standard informal measures of computer growth take the increase in population size or rental revenues as proxies, in spite of their obvious inaccuracies. As is well-known, a straight computer population count suffers from the age-old problem of mixing apples and oranges; a large, high performance computer is quite a different machine from a computer with only a fraction of the memory size and a slow cycle time. Machines of different vintage or from different generations are not only sharply distinct because of CPU features but also because of the variety of software quality associated with the machines. The second class of measures, by rental values, can overcome some of the more glaring distortions inescapable with a machine population count, but many biases remain. Within one vintage a machine of lower rental is presumably of smaller computer 'quantity' than one commanding a larger rental, but even if we overlook for the moment the issues that this approach has yet to settle such as any disproportionality between rental and quantity there remains the case of between vintage comparisons where all the problems of incomparability we noted with the first method re-emerges. An old vintage will likely have characteristics which are so distinct from new machines as to make rentals a poor measure of their relative quantity.

Most important, then, is the question of measuring change in total quantity over time. Because of the year-to-year movement in the general price level, rental changes over time do not reflect quantity change. While some correction can be made using a standard price index, the procedure itself can introduce serious errors owing to the fact that rapid change in computer technology has generated a price movement for computers different from, and sometimes opposite to, the national account's price indexes series. Clearly computer specific price and quantity indices are called for.

In terms of economic theory, as we mentioned earlier, quantity measures should reflect machine services to the user. Under the important (but unreal) assumption that computer supply shortages are not involved, it is quite reasonable to suppose that rentals reflect the complex of economic services the machine offers, subject to a stochastic error which would subsume a degree of ill-informed shopping by the user, fashion, brand-name loyality and so forth. Seen from this perspective of economic incentives, the computer is introduced by management to strengthen profits, reduce costs or improve services by virtue of its speed, accuracy and information handling capabilities, and it is this perspective which fits well a study on the job displacement effects of computers. In principle the economic considerations can lead to a suitable formulation of price and quantity indices.

To conceptualize this approach further, consider a firm in the private sector which operates a general purpose computer for a variety of functions, which can include scientific (research), administrative and process control. The company's expenditure on computer rental represents the machine's contribution to sales and in this narrow economic sense it can be conceived as one of the firm's productive factors. the computer itself yields economic services to the firm by making available certain data processing characteristics demanded of it. The machine is a 'black-box' which serves to transform these characteristics into service categories - a conceptual device or metaphor very similar to the 'production function' concept. In mathematical symbols, let $c = (c_1, c_2, \ldots, c_n)$ be the vector of n distinct characteristics relevant to the production of m economic services, $q = (q_1, \ldots, q_m)$. Then the transformation can be expressed abstractly as:

$$H(q,c) = 0$$

or, given the minimal assumption concerning separability between outputs and inputs, write

$$Q(q) = F(c),$$

where Q and F are positive, real valued functions having certain convexity properties. For characteristics we take the following six:

1. cycle time
2. access time
3. core memory
4. disc storage
5. tape storage
6. telecommunication links

Note that two extremely important characteristics should be added:

1. Software (system and Applications)
2. Reliability and Maintenance

For category of service we take the following four:

1. batch
2. time sharing
3. process control
4. others

The real valued function Q stands as an aggregate service index over the four service categories. Unfortunately there is no data available on each service category so that for empirical work we are obliged to use the specification:

$$q = F(c),$$

where q denotes a service scalar and c retains its vector form. Rental data is used as a measure of q in the base year, which we take as 1971 since it corresponds with the Statistics Canada base and is located approximately in the mid-point of the time frame of concern. In fact, the actual year taken as base should be one that covers much of the 3rd generation developments in computer design and be fairly stable as an empirical (regression) relationship. It is suggested that two candidate years be tested, 1971 and 1976.

By specifying that the function F be linear in form the foregoing conceptualization converges with the hedonic index method discussed previously. The method employs a sample of computers introduced in the base year and a regression of rentals against characteristics is run. The regression coefficients serve as imputed rentals for each characteristic and these are applied to computers introduced in other years. The quantity obtained in this way (as the sum of the product of imputed rentals and characteristic values) constitutes the computer's quantity index, and its price index can be obtained on dividing the actual rental by the quantity index. If needed, an aggregate computer price index series can be derived (not described here but see Chow (1967)).

To carry out the procedure in practice it is recommended that 50 distinct and dissimilar computer types which have been introduced in 1971 or thereabout be selected as a (random) sample. The required data on individual computers are not readily available, for while the CIPS census publications give date of installation the rental information appears only in aggregative form. One method of obtaining the data would consist of (a) requesting rental information from the sales and service department of suppliers and (b) using the Auerbach EDP Reports as the source for engineering specifications.

Prior to the regressions the data should be subjected to standard statistical tests to determine the extent of deviations from the normal distribution, correlations between pairs of independent variables, etc. In addition the sample should be stratified in various fashions (i.e. by rental class) and the stability of the regression tested as additional subsamples are included. These sets of tests are designed to indicate if further work using the sample is worthwhile, and generally to reveal the data's statistical quality.

In order to infer total computer stock year-by-year two additional steps are required. First, the CIPS census numbers must be adjusted to account for incomplete responses by scaling up the census to population size, and second, based on manufacturer's information, an assumption concerning the rate of machine obsolescence has to be adopted.

The above research procedure will yield time series on (a) the quantity of computer power or stocks (b) a price series for the same. A rough sense of the statistical quality of the series will also emerge. This information can then be employed to the overall task of associating net job loss on a national basis with the introduction of computers, either as an aggregate or by sub-aggregates in terms of service categories, industry of application or rental value class.

However, the quantity series on computer stock will only be as good as the data permits. We have to face up to the fact that the uncertain quality of the data base, however lovingly prepared, can produce such poor results as to not justify the potentially large computer plus clerical expenses involved. Thus the exercise should be approached cautiously. Firstly, it would be advisable to prepare at least one rough series based on rental data from CIPS and various formulations of price series and the rate of obsolescence. A price index which improves upon the standard consumer price index by incorporating modifications for relevant historical events in computer developments (i.e. 'debundling' and generational changes) can be employed to deflate the rental series, thus yielding a first pass at a quantity series. Secondly, the cost of preparing a computer file for 50 computer types containing individual rental and characteristics data is unknown. We can obtain a practical notion about the magnitude of the costs involved by initially preparing a small experimental file on very few computers. This experience will also give the experimenter a 'feel' for the data by which an informed judgement can be made concerning the cost/benefit of improving the 'rough' series suggested above with the refinements promised by the hedonic index method. Obviously if it appears that the refined series on computer quantity is likely to depart significantly from the rough series, and the assembly costs are reasonable, the better series should then be assembled. If on the other hand we have no reason to believe that the two series will show different patterns, the rough and simply prepared series will possibly suffice. Evidently, these decisions involve balanced judgements based on very imperfect information, and there may indeed occur costs which are sunk into a partial file assembly that subsequently is fated to remain unused. Such waste, of course, must be minimized.

3.3 The Hedonic Index Measure

The hedonic index analysis has been applied to the measure of computer stocks in two important studies, one by G. Chow (1967) and the other by Stoneman (1975). In the following we examine the hedonic index methodology and indicate its limitations in the context of the changes which have occured in modern computer technology. A fuller report on Chow's seminal work is given in Chapter 4 and Stoneman's analysis reappears in Chapter 5, but only in regard to employment effects.

The economic performance of a computer is manifestly affected by its technical and physical specifications or attributes. For Chow, three characteristics were uppermost, namely cycle time, memory size and access time. He assumed "that all general purpose computers can be grouped into one commodity. The quantity of a computer is measured by an estimate of what its monthly rental would have been had it been introduced in 1960". This method of measurement requires firstly to establish a relationship between monthly rentals and the individual computer's basic characteristics for 1960 models, and then applying the relationship to estimate what each computer of every vintage would have cost if it first appeared in that year. This procedure operates under the central assumption that the model's rentals are linearly related to basic characteristics. In effect the base year monthly rental acts as a measure of computer quantity (price equal to unity in base year) and a linear regression involving all models for the year provide estimates of coefficients, one for each characteristic, which weights the importance of each basic attribute for the total quantity. Each coefficient then, is an estimate of a shadow price for the corresponding characteristic. The sum of the product of the characteristics' shadow price and quantity provides the quantity measure for any particular model in base year prices, a measure which corrects for inflation and differences in major technical attributes.

The later work of Stoneman is in this regard very similar, although used for a different purpose, and takes into account only computers used in administrative work, by far the major application over the period of his data set. Stoneman identifies the basic characteristics to be cycle time, memory size and floor space.

The hedonic index method represents an important application to the measurement of computing power, but nevertheless it is not free of criticism of a theoretical nature. The index can be explicitly related to behavioural postulates which condition the actions of economic agents as suppliers and consumers of computer characteristics, but this connection can be made only for a competitive market in a divisible commodity. If anything is noteworthy of the market for computers, it is the dominance of IBM as the major, virtually monopoly supplier, and the, until recently, large size of the machines. With a single supplier and a spectrum of machine having many large gaps, the presumptions underlying the economics of the index show it to apply to real world situations only imperfectly. The monthly revenues reflect more than solely the demand by users for computing services; they obviously include some degree of monopoly markup, the amount of which will vary as between suppliers, between the models of one supplier, and between years.

Even for competitive markets, monthly rentals will reflect both demand and supply conditions and all the difficulties associated with the 'identification problem' in econometrics becomes important. It has been suggested (Rosen, 1974) that regressions of rentals against characteristics should incorporate variables which help to identify the demand relation.

The indivisible nature of computers brings to the forefront both the issue of capacity limits and excess capacity. The former situation can only be overcome by a purchase or rental of a new machine, a solution which inevitably will lead to the other situation of excess capacity owing to the discrete sizes of machines. When the machine is too small, and two would be too large for the user's purposes, then some of the rental can represent a premium or quasi-rent in the first case, and in the other case of doubled capacity some rent represents idle capacity. Of course, renting allows a greater freedom to switch models than does outright purchase as information processing usage and requirements change, but there still likely remain frequent instances of a mismatch between capacity and needs. As the number of model types grow, however, this problem will likely decrease.

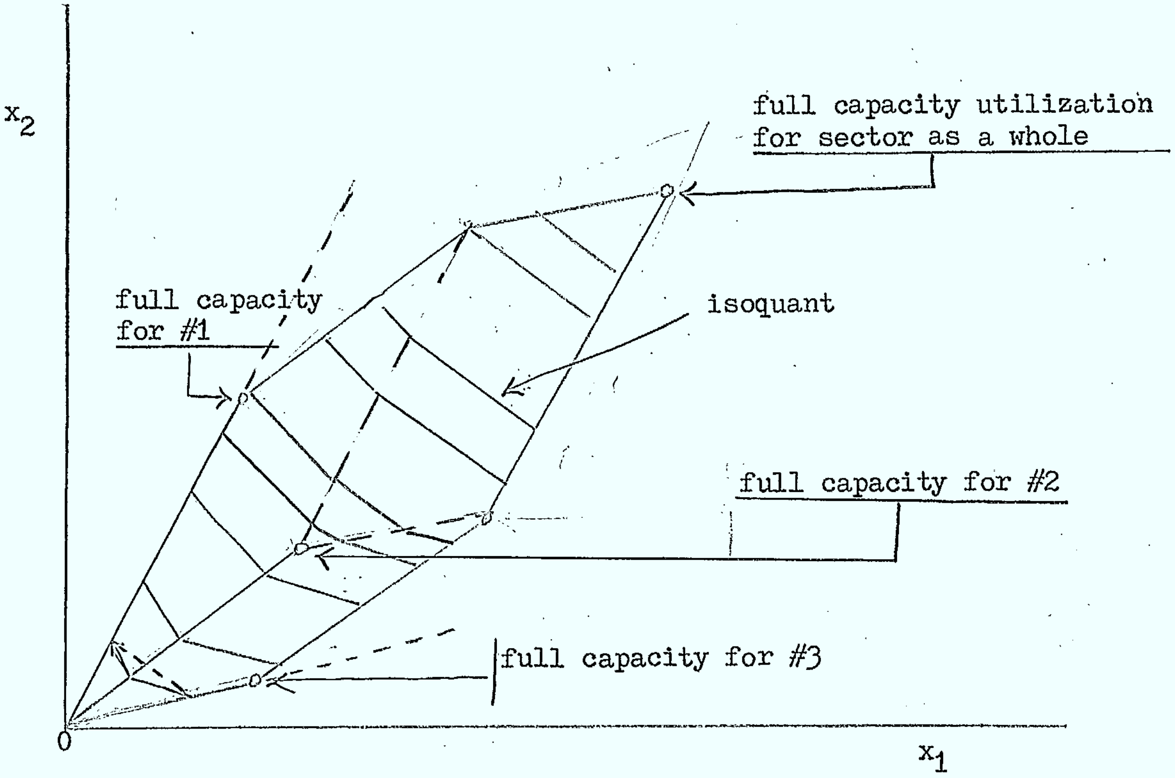
A further difficulty which afflicts rental data on computer models is the wider application to which computers are being put to use. Whereas in the past the administrative data processing function of computers dominated any other use, this is less true today. The dominance is still there and continues to be commanding but other uses are gaining a foothold. In Britain over 2,000 machines were used for administrative purposes in 1969 while process control took 150 machines. In the United States in 1970, 65% of revenue came from sales of general purpose computers, while dedicated application machines had 5% of sales. The modern trend shows up in the 1976 Canadian CIPS Census of computers in which we see that 72% of computers are assigned to bach processing and 15% to process control. These numbers do not of course reflect units of computing power, and they would have to be revised in order to do so. A further complication of a similar nature also occurs because of a tendency to apply machines to multiple uses, as the CIPS survey shows. The issue of different computer applications is important because, to repeat a point made earlier, in different applications computers threaten (and promote) different jobs and skill types. It follows that any pronounced differences of these kinds would call for several studies, one each for separate applications and perhaps even for separate industries.

A further critical remark concerning the hedonic index for computers requires our attention. From the economic point of view, the computer which possess less amount of each characteristic than some other computer, or other computers in combination, and rents for more or an equal amount to the computers which dominate it, is simply a bad buy. At the same price or rental, the inferior computer under conditions of perfect information will not become the object of exchange, for the conditions of economic efficiency will be violated by such an exchange since it will result in the purchase of wanted characteristics at higher than minimum cost. Consequently the presence of dominated computers signify one of two things, either imperfect information or, more likely, an additional characteristic has been overlooked. This difficulty of economic logic arises most likely in the case where the number of characteristics are small, and is bound to occur in studies where only three attributes serve to distinguish between computers.

Finally we arrive at the difficult question of software. A new application software can give a mainframe a new lease of life and enhance its accessibility to different users less skilled in programming. There has been a proliferation of application software over the past decade and while the earlier estimates of computer quantity could overlook or skate around this aspect of computer systems, it is a problematic concern that cannot be avoided when using modern data.

We return now to the subject of relating a hedonic index to economic efficiency at an analytical level as a way of illustrating the remarks and criticisms made above. Let points in the Enclidean m- dimensional space represent a bundle of characteristics, where $x' = (x_1, x_2, \ldots x_m)$ has as its entries the amount of characteristic j, j=1, 2, ..., m. Thus a computer can be represented uniquely by such a point. In the standard way we can then portray the capacity of computers by vectors in characteristics space, as in the following example.

Suppose there are three types of computers in a particular sector of interest and at a specific point in time their numbers are given by the diagram on the following page.



This shows the sector's capacity of characteristics for information processing. The full cone bounded by the outer lines is unattainable owing to limits on capacity and further investment would be required to expand further into the cone. These capacity limitations give rise to shadow prices standing for the quasi-rent attributable to this scarcity (whenever the constraint is binding). The angle of the cone can be widened only by introducing new models of computers with a bundle of characteristics lying outside the existing cone. Within the cone "isoquants" or indifferen~~t~~ce curves are drawn on the absurd but convenient assumption that different computers can be combined for use in any proportion.

Without this assumption, employed for conceptual purposes only, our analysis would have to be conducted in terms of integer programming. Each isoquant represents units of computing quantity or power.

Suppose there are n computers and let y_i stand for the quantity of output that can be delivered by computer i, i = 1, 2, ..., n. Regard the characteristics as inputs with certain fixed amounts required to produce unit output, these fixed amounts differing as between computers. Thus the input requirements of characteristic j for computer i is related to units of output via the input-output coefficient a_{ij} as follows:

$$y_i \, a_{ij} = x_j \qquad i = 1, \ldots, n_i \qquad j = 1, \ldots, m.$$

To produce the output levels represented by $y = (y_1, \ldots, y_n)$ a minimal level of total input requirement are needed:

$$x_j \geq \sum_{i=1}^{n} a_{ij} \, y_i \qquad j = 1, \ldots, m$$

In matrix form this can be expressed by the inequality

$$x' \geq y'A$$

where $A = (a_{ij})$ is a rectangular matrix, and the prime indicates transposition.

Let $r = (r_1, \ldots, r_n)$ stand for the rental rate vector where r_i is the monthly rental for computer i. Then the concern of economic efficiency can be expressed in terms of maximizing revenues from computer rentals, where rental rates are given, and choice is subject to constraints on inputs (characteristics) and on capacity:

$$\max_y r'y$$

subject to

$$A'y \leq x, \quad x \geq 0,$$

and

$$y \leq \bar{y} \text{ (} \bar{y} \text{ is vector of capacity limits)}$$

It is the assumption that r is fixed which brings forth the assumption of a competitive market structure.

This linear programme has its dual form expressed in terms of shadow prices. Let $W = (w_1, \ldots, w_m)$ stand for rental rates imputed to the m characteristics, and let $s = (s_1, \ldots, s_n)$ be the vector of quasi-rents attributable to the capacity constraints. The dual programme is

$$\min_{x,y} [w'x + s'y]$$

subject to

$$s + Aw \geq r \qquad r \geq 0$$

These programmes represent the simultaneous action of maximizing total revenue and of minimizing total costs; they parallel the tension between supply and demand. It is to be observed that $s_j = 0$ whenever $y_j - \bar{y} < 0$, and $s_j > 0$ whenever $y_j - \bar{y} = 0$, $j = 1, \ldots, m$. Likewise $w_i = 0$ whenever x_j is in excess supply, i.e. $A'y-x < 0$, and $w_i > 0$ for $A'y-x = 0$.

More information can be gleaned from these programmes but the object at this point is to relate the efficiency programme to the regression analysis used to estimate the hedonic index. Basically the regression of the type

$$r_i \, y_i = \sum_{j=1}^{m} \beta_j \, (a_{ij} \, y_i)$$

$i = 1, \ldots, n$ are n observations taken over the computer sample and $(a_{ij} \, y_i)$ is the quantity of the jth characteristic possessed by machine i; the data is normalized at the sample mean. The estimated β_j are estimates of the rentals w_j, j = 1, ..., m, and we may write for sake of comparison:

$$r_i = \sum_{j=1}^{m} w_j \, a_{ij}$$

Thus $A = (a_{ij})$ is the data matrix in the regression, and the least square fit gives as estimates for w:

$$w = (A'A)^{-1} A' \, r$$

Now consider the programming situation where the capacity constraints are binding and there is no excess supply of inputs. Then

$$A \, w = r$$

Since A is retangular, to solve for w write

$$w = (A'A)^{-1} A' \, r,$$

which corresponds exactly to the least square fit for the rental rates attributed to the m characteristics. Thus the hedonic index, estimated by the regression, yields the same shadow prices as are uncovered by the efficiency programme under competition.

4. TECHNOLOGICAL DIFFUSION

An invention or innovation which is not applied to the economic process is otiose as far as employment implications are concerned. As a new production or information processing technique spreads then its impact on jobs grows. It is the rate at which adoption or diffusion takes place, and the determining elements behind this diffusion, which concerns us here.

The general factors which accelerate or retards the pace of a process innovation's spread to other firms in the industry include business secrecy and patents, poor communications, management attitudes, labour relations and fears of job loss and longlived fixed capital equipment (Parker, 1978; Nordhaus, 1969; Mansfield, 1968). "More specific influences affecting the rate of adoption of innovations will include the intensity of competition, the elasticity of substitution of new for old capital and capital for labour, relative price movements and the expected value of the proposed change" (Parker, 1978). One should also not overlook the state of aggregate demand as expressed by underutilized capacity as an important influence, and finally international competition has its very significant role to play, as for example in the upgrading of processes in the textile industry, albeit slowed down by protectionist policies.

In their studies of growth in computer output both Chow and Stoneman endeviour to capture most of these influences for the economy as a whole. Basically the influences are broken down into two movements; the process of information contagion and secondly, economic factors. The former movement is expressed solely in terms of an empirical curve that indicates the rate at which the economy's computer stock approaches the target stock. The rate is not constant and is very like the contagion of disease; the introduction of innovation is slowly initiated, accelerates and then slows as the entire population (industry, economy) is affected. This process accounts for the general factors listed above.

The specific economic factors relate to the target stock or the desired (optimal) level of computer output wanted from the economy, given factor prices, level of overall production in the economy, etc. Movements in factor prices and GNP causes a shift in target computer stock (or "population" as measured by units of output) and the process of information flow regulates the speed by which the actual computer stock adjust to the (moving) target level. The following account of Chow's study will show in more detail the method of this two stage approach (from Bower, 1973). Equilibrium long run stock of computers that users demand is a Cobb-Douglas function of price and activity:

$$Q_t^* = b_0 \, P_t^{b_1} \, GNP_t^{b_2}$$

Q_t^* = quantity of comuting power that is a target or equilibrium level for use under year t conditions;

P_t = monthly rental for a unit of computing power relative to other prices, in year t;

GNP_t= real GNP of users in year t.

Adjustment to this equilibrium takes place by a process in which the growth rate of a computing stock reaches its maximum early and is fairly constant thereafter. The diminishing pull of the target is at first more than offset and then just offset by the increasing impact of experience with the growing stock. Stock adjustment takes place according to:

$$\ell n \, (Q_t/Q_{t-1}) = A_0 \, \ell n \, (Q_t^*/Q_{t-1}).$$

Q_t = actual quantity of computing power in stock in year t.

The next step is to substitute out the non-observable target stock.

Chow estimates information value coefficients for multiplication time, memory size and retrieval speed from a pooled regression explaining, in terms of these characteristics, the rental charges of 82 computer models introduced from 1960 to 1965. These coefficients, applied to the characteristics of any computer model, provide an index of that model's capacity to produce information.

Estimation: GNP is dropped because of high serial correlation with the price variable.

Results of fit: $A_0 \ell n\, b_0 = 2.950$ $A_0 b_1 = -0.3637$ $A_0 = -.2526$

$R^2 = .834$ (-2.107) (-3.414)

This indicates a long run price elasticity of -1.44 (b_1), and a short run price elasticity of $A_0 b_1 = -0.3637$. combined learning and price adjustment factor (A_0) is .2526.

Thus the approach to target is about half-completed in 3 years.

The diffusion process itself is usually expressed by an estimated logistic curve although, with reason, Chow favours the Grompartz curve. The logistic structure has received much support in the literature with evidence coming from studies in agricultural technology, medicine, manufacturing technology, nuclear power, computers, plastics, synthetic fibres, and elsewhere (see Parker, 1978, for references). A generalized picture emerges from these studies showing a series of fairly distinct stages in the life cycle of innovation, namely, introduction, growth, maturity and decline.

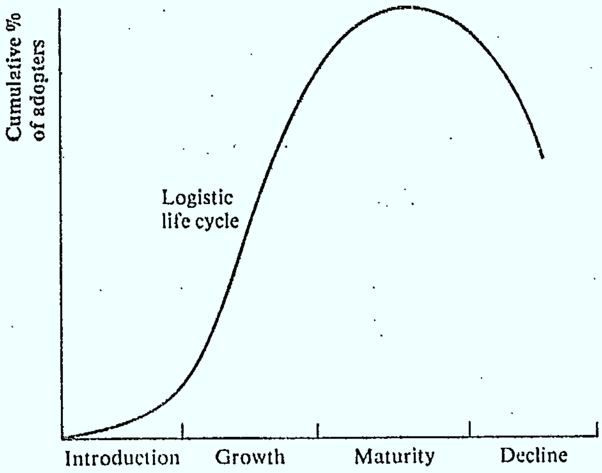


Figure 4

Logistic Pattern of Adoption

Source: Parker

One analytical justification for this pattern is that given below (adopted from Kaimien and Schwartz, 1970). Suppose a firm (or group of firms) are in possession of a new process technology and are willing to licence the technique at a price. The owners of the new technique know that eventually their monopoly position will be eroded as information on the technology leaks out and reach other producers, and as others finally discover the technology by themselves. An expensive licencing fee, while beneficial for short run profits, will in the long run accelerate the effort by others to find alternative sources for the technology. An optimal pricing strategy by the monopoly then has to trade off short run gains for longevity of its relative monopoly position. Suppose as a monopoly it can make profits π_2 but the presence of new entrants depresses this to π_1, $\pi_1 < \pi_2$. These levels essentially depend on product market shares, but they would also incorporate revenue from licencing fees; hence we write $\pi_1(p)$, $\pi_2(p)$.

Let the probability of new entry at time t be denoted by P(t). This may be measured by the proportion of total firms with the new production technology. Then the expected profits of the "monopoly" at time t will be

$$E(\pi(t)) = P(t)\ \pi_1\ (p(t)) + [1 - P(t)]\ \pi_2(p(t))$$

Let the objective function of the monopoly be the present value of discounted future profits, so that

$$\max_{p(t)} \int_0^\infty E(\pi(t))\, e^{-pt}\, dt$$

rules the time pattern of licencing price choice. However, this maximum is subject to the motion of the cumulative probability function P(t), whose density function is denoted by $\dot{P}(t)$, its first derivative. This motion in turn is regulated by the licencing price and alternative sources of the technology. The probability of a new firm at time t entering the ranks of those using the new technique, given that it has not done so before time t is

$$\frac{\dot{P}(t)}{\int_0^\infty \dot{P}(\sigma)\, d\sigma} = \frac{\dot{P}(t)}{1 - P(t)}$$

As this is influenced by licence price and alternative sources, write

$$\frac{\dot{P}}{1 - P(t)} = g(p(t))\, P(t)$$

Here g is a non-decreasing function of p and models the effect of licencing price on new entry. For a given price, the probability shown on the left side is taken as proportional to the cumulative probability of all entries, representing the extent of available alternative sources of knowledge on the innovation.

Apart from some important assumptions regarding functional forms we have all the components to study the diffusion process. The existence of a maximum depend on weak assumptions about the form of π_1, π_2 and g, but the necessary conditions will not be detailed here. Assuming existence, the monopolist is required to solve the following to obtain the optimal time profile of the licence price:

$$\max_{p(t)} \int [P(t)\ \pi_1(p(t)) + (1 - P(t))\ \pi_2(p(t))]\, e^{-pt}\, dt$$

subject to

$$\frac{P(t)}{1 - P(t)} = g(p(t))\ P(t)$$

In another context Kamain and Schwartz has shown, under certain assumptions, that the "entry preventing price" derived from a similar optimal programming problem is constant. If we suppose that such a solution holds for our problem also, then we can specify the function g to be time independent and write

$$\frac{\dot{P}(t)}{P(t)} = g\,[1 - P(t)],$$

where g is a parameter which can be different for different economic and technical circumstances.

The solution of this differential equation is the logistic function. Thus the logistic function emerges from a simple model of diffusion even where the likelihood of innovation spread from a specific source can be impeded by licencing policy. Different adjustment speeds are associated with different parametric values of g and these in turn are fixed by those economic factors which serve to fix the licencing price p.

The final equation above can be linked in a crude way to the stock adjustment logistic model, simply by writing y^* as the desired computer output for the economy or sector, y as the actual output, and setting y as proportional to the number of firms using computer technology. Then y^* is in the same proportion to the total population of firms and we write:

$$\frac{y}{y^*} = P(t)$$

yielding (from above):

$$\frac{\dot{y}}{y} = \beta(y^* - y)$$

where $\beta = g/y^*$. It is interesting to note that Chow uses the log form:

$$\frac{\dot{y}}{y} = d\ell n\, y = \beta(\ell n\, y^* - \ell n\, y)$$

The foregoing model deserves greater attention, both as to questions of theory and of possible extentions. One direction it would be worthwhile to take the analysis is to include government, through fiscal variables affecting investment, regulatory variables affecting rates of return, and length of patents. To my knowledge such work has not been completed in the literature.

Some of the important economic determinants have not been included in the diffusion discussion up to now. These can be summarized below in terms of four hypotheses employed in conjunction with industry studies (Mansfield, 1968).

1. The greater the number of firms in an industry adopting an innovation the greater is the probability that a non-user will adopt (this was used above).

2. The expected profitability of an innovation is directly related to the probability of adoption.

3. The probability of adoption is smaller for innovations of equal profitability, where a large investment is involved.

4. The adoption probabilities will vary from industry to industry (see our result above).

These are formalied in terms of the relation

$$\lambda_{ij(t)} = f_i\left(\frac{M_{ij(t)}}{N_{ij}}, \pi_{ij}, S_{ij}, \ldots\right)$$

$\lambda_{ij(t)}$ = proportion of firms not using the innovation time t, that introduce it by time t+1;

N_{ij} = the total of firms for the jth innovation in the ith industry ($j = 1, 2, 3$, $i = 1, 2, 3, 4$);

$M_{ij(t)}$ = the number of firms having introduced this innovation at time t;

π_{ij} = profitability of installing this innovation relative to that of other investments;

S_{ij} = the investment required to install this innovation as a percentage of the average total assets.of these firms.

The data are drawn from twelve innovations in the bituminous coal, iron and steel, brewing and railroad industries in the U.S. The model explains practically all the variation in the rate of diffusion with high R^2. The variables shown come out as strong explanatory variables in the regression results. Durability of equipment is not so important, for example.

To summarize, diffusion studies may be carried out on two levels, the examination of empirical curves given for impressionistic or better reasons; or through case studies involving firms or the industry using specific innovations. Case studies may or may not offer a basis for generalizations but they are probably most revealing in terms of how diffusion actually takes place.

5. SIMULATION OF TECHNOLOGICAL UNEMPLOYMENT: NATIONAL ECONOMIC MODELS

The expulsion of labour attributable to the introduction of innovation, and to computers in particular, can be partly or entirely offset by re-employment as final demand and inter-industry outputs adjust to the change. Depending on the research resources available and one's major interest, several options are available to study empirically this job displacement and job creation that occurs as a new techniques diffuses through one or more industries. Below we examine three levels of empirical research; a partial approach relating to direct displacement and creation of jobs attributable to the new technology; a generalized partial approach involving inter-industry adjustments that include the direct and many indirect effects, and finally, a full equilibrium approach which allows for all effects including income and substitution effects.

Stoneman's study is a prototype of the partial approach as he looks at direct effects only. Since the largest implications for labour demand in the 1960s was in the area of administrative use of computers, Stoneman's research is restricted to this use. Two manpower surveys among EDP users for the years 1964 and 1971 gave benchmark indications of labour saved due to computers in the management and executive, supervisors, clerical, typists and machine operator categories. The surveys also give data on EDP jobs created, from which it was possible to calculate net labour savings. These savings were then related to the stock of quality adjusted computers, the latter was determined using the hedonic index method of Chow. An estimated empirical diffusion curve served to indicate the saturation stock of computer power (i.e. 100% diffusion of computers throughout the economy for administrative purposes) through which the maximum net job saving can be calculated. Finally, a 1972 forecast of new computer installations form the basis of projecting labour saving for each year up to 1978. By this method it was found that one third of a million man years would be saved, equal to 1.3% of the labour force, if we assume all machines are imported. The net labour saving, ΔL, in any particular year for a computer satuated economy over an economy without computers is expressed by the empirical formula

$$\Delta L = 113.3\ y_t^{0.7}\ ,$$

where Y_t is the GNP in year t. For Britain the net man years lost was not regarded as alarming.

The merit of Stoneman's work consists in the attempt to place forecasts of labour expulsion caused by computers on a scientific basis. The idea of matching computer output (i.e. quality adjusted stock) to reasonably well identify jobs loss and gain is fundamental, but also important since it offers a methodology for this type of policy analysis. Although only two survey years were involved, both showed a remarkably consistent pattern of job loss by occupational type per computer unit. This consistency suggests a technology for functioning computers in which a unit computer requires a fixed number of work-hours (man-hours) and is interchangeable for a fixed number of work-hours. On this basis a stability of net labour savings per unit of computer can be assumed.

However, some caution is required in interpreting the results and in applying the technique to Canada. The most obvious setback to a Canadian study of this kind is the lack of any surveys indicative of job loss attributable to computerization. One way of overcoming this difficulty would be to suppose the British circumstance is applicable here, largely on the grounds the administrative purpose of computers is the same everywhere especially as IBM dominates world markets. But even if we go along with this assumption, which moreover includes a denial that peculiar institutional arrangements in Britain have no influence, it must be borne in mind that the surveys are not directly applicable to the computers introduced in the decade of the seventies. With the advent of the microprocessor the flexibility of computer systems were increased, entailing a possible change in the pattern of job loss per unit computer. Additionally, the software and maintenance work most likely experienced great changes, thereby affecting the pattern of job creation. These observations would tend to weaken any suggestion that the British surveys have general applicability to the present generation of computers in Canada.

A further problem arises because of Stoneman's particular specification of computer characteristics involving machine floor area. The shadow price for this characteristic turns out to be positive so that the smaller machines of the 1970's are less powerful because of this, even though in every other respect the new machine is superior to the bulkier older types. Indeed, reduced floor space would be universally accepted as a positive, rather than negative attribute. In view of this it seems that Stoneman's extrapolations into the 1970's may be faulty, but it is hard to tell to what extent they will be biased.

Finally, the use of computers outside the administrative sphere such as process control is becoming increasingly important. Stoneman shrugs off process control as unimportant for employment implications since this type of technology saves chiefly on capital. The logic of this view is suspect, for the capital goods industry itself is a large employer and any reduction in demand there clearly has consequences for overall employment. In other words, one should not presume that technological change will not have notable reprecussions downstream and upstream in the chain of production.

Stoneman's results included only the direct employment impact and in this sense the approach is limited. It would be highly desirable to try and capture other no less important effects which may lead to a reabsorption of the labour directly expelled. Such a study is very complex since the entire economy is involved, and large input-output models or econometric models are called for. Before selecting a suitable model, the sector or industry to be the site of a innovation introduction must be identified and the diffusion process to the full industry somehow has to be stimulated.

In general terms, a model with large industry detail is wanted if innovation located in one industry is to be studied. Such detail is available only through the use of input-output tables. Input-output tables can also be used to investigate the effect of an innovation which emerges in all industries rather than in a single industry only, such as office automation. Again the industry detail is useful since the extent of office computerization varies as between industries. There exist three national final demand models with an unusual degree of industry disaggregation available to us, the Statistics Canada Structural analysis (input-output) model, CANDIDE 2 and TIM, the latter being Infomatrica's outgrowth from the CANDIDE family of models. All three models have an input-output component. The specific structure of these models will shape the outcome of any simulation exercises and therefore a brief discription of each is presented later, but below we examine some general problems associated with input-output models and technical change simulations.

A purely labour saving change can be simulated by varying the appropriate primary input coefficients, if they exist. However, most changes in technology involve a new set of ratios between labour and current material inputs as well as some investment expenditures to get the new capital in place. While the investment aspect can be handled in the usual manner of overriding the appropriate autonomous values in aggregate demand or directly at the industry investment equation, the adjustment of intermediate technical coefficients is a more difficult task. This involves changing row elements of the table in a consistent manner. But the extent of change that is required cannot be known without detailed engineering information on the new process technology, on how far it has penetrated the industry and the rate of this penetration. To emphasize the steps involved[4] but keeping to generalities let a_i^0 be the vector of input coefficients for industry i under the old technology and a_i be that under the new. Let d_t stand for the ratio of output generated from the new and old technologies, then the input entries at time t can be expressed linearly as

$$a_{it} = d_t a_i + (1-d_t)\, a_i^0$$

the vector a_i^0 can be obtained from the old table where $d_t = 0$, a_i from engineering data, d_t from a survey, and a_{it} can be calculated. Alternatively, if a'_{it} is the coefficient vector for the current table, d'_t and a_i are known, then a_i^0 can be derived. Having the vector a_i^0 and setting a d_t for simulation purposes the new a_{it} can be determined.

This is the obvious way of integrating the diffusion index d_t into a study of macroeconomic effect but the method is encumbered by some specific problems apart from data collection difficulties. The use of the scalar d suggests a rigid choice between the old and only one new technique. Yet a plant can be upgraded at several points in the production process and an industry definition can include establishments operating different stages in the overall production process. For example, computers have been introduced in textiles to various ends. One firm uses computers in stock control, and in one of its plants the dieing process is completely computerized, while no computers are used in spinning and weaving. Another firm has computerized its carpet plant in Sorel, while a third has computer control over its spinning and weaving process in Kingston and has automated its information systems. This textile example is typical of the variety of configurations that users are able to apply computer technology to control production processes. Because of this diversity, the relation between precomputer technical coefficients and post-computer coefficients will necessarily be poorly described by the scalar d. The point is that the technical coefficients in one year representing as they do an average for a

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heterogenous complex of establishments, cannot relate to another set with the same proportionality constant applied to each and every coefficient, as the latter set will be an average over different process control applications of computers. One pair of corresponding coefficients in the two situations may differ by a certain amount while a second pair may differ by another, violating the logical basis for a proportionality constant. However, such problems of logic occur everywhere and naturally judgement is required when using a simplified representation of technical change, but what this discussion is intended for is to give a warning to the reader of certain problems inherent in any intervention into the input-output table, problems that inhabit even the simplist of hypothesis regarding technology (fixed coefficients) and change (smoothness).

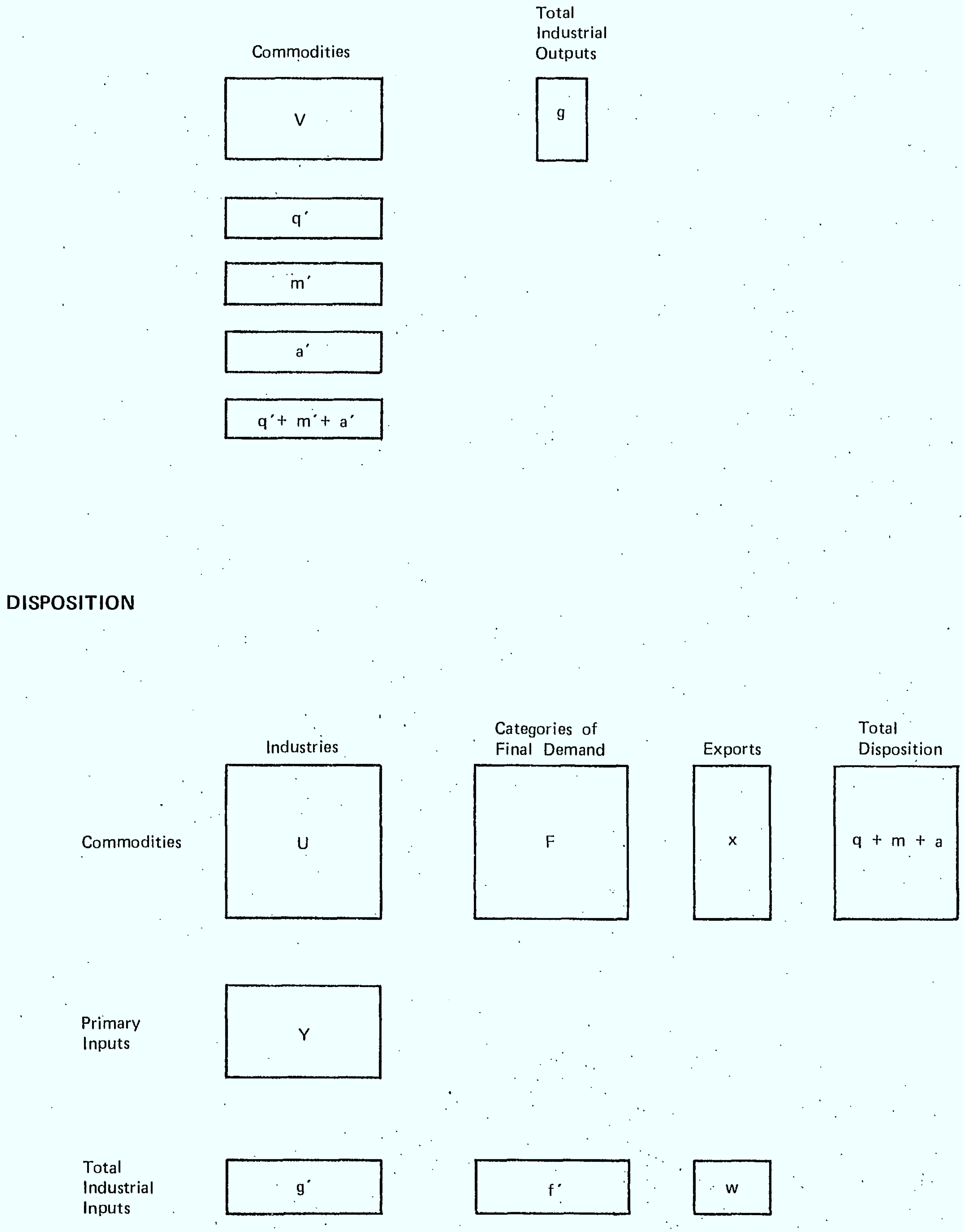
The model with the greatest degree of commodity and industry detail is the Statistics Canada Structural Model of the Canadian Economy. Its usefulness for our purposes lies in this great detail (602 commodities and 196 industries) although it suffers from certain limitations as we see from the following brief outline of the model.

The heart of the output determination model of GDP at market prices consists of large input-output rectangular tables which gives the disposition of commodity inputs among industries, primary inputs among industries and industry output by commodities. The structure of this model is more general than the typical inter-industry tables since joint production is permitted. The data are taken from the 1976 input-output tables and all entries in the commodity accounts are valued at producers prices. The industry accounts uses the 1960 3-digit SIC classification of industries, together with two activities (affecting iron and steel, pulp and paper)and eight dummy industries (e.g. office supplies). Primary inputs comprise indirect taxes, wages and salaries, supplementary labour income, net income of unincorporated business and surplus, the latter including corporate profits. The matrix of final demand categories, vectors for exports and government sectors complete the model. Industries are allocated a fixed share in commodity demand. This rigidity can be relaxed,but only slightly, through a model artifact.

A choice of input coefficients is available so that either constant dollar ratios (corresponding to a fixed coefficient technology) or current dollar ratios (corresponding to unitary elasticity of substitution) can

SUPPLY

Figure 4: the structural modal



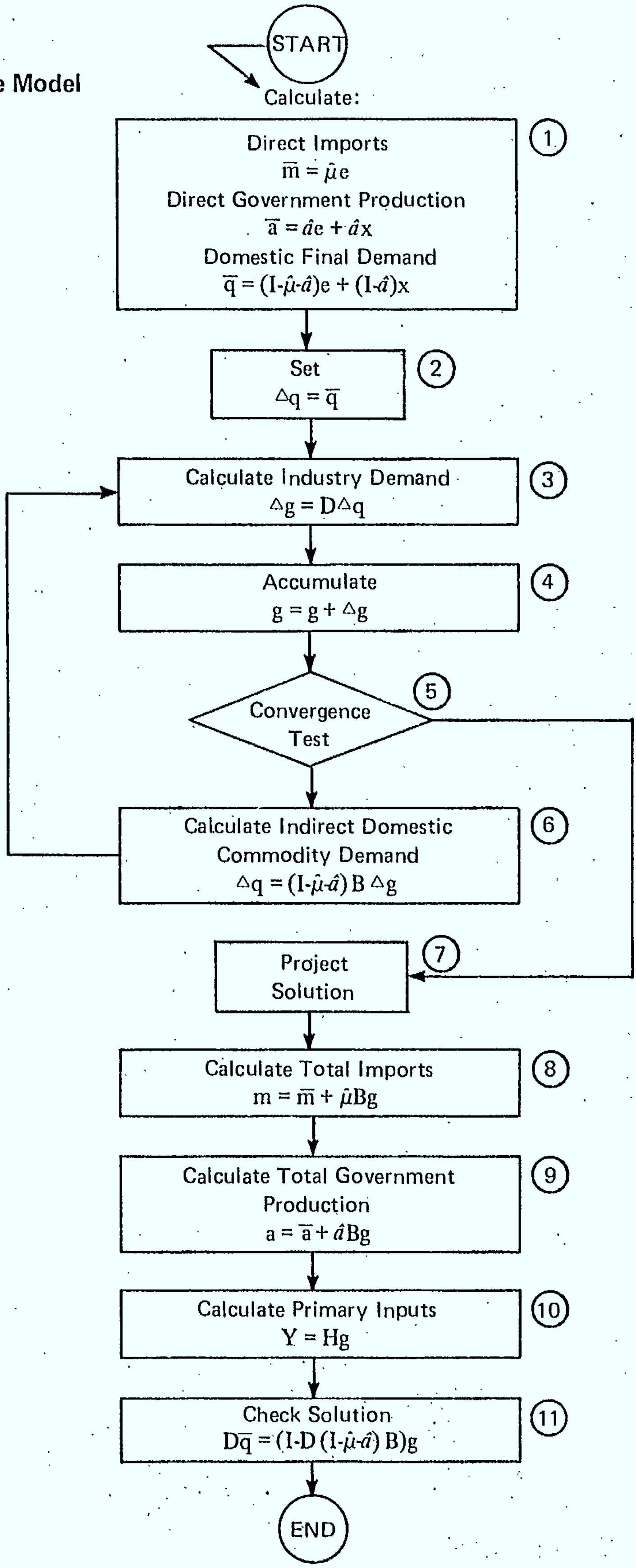
be used provided final demand is specified accordingly. Also there are two versions of the model; the open model where income accruing to other sectors are not respent, and the closed model where the respending takes place. The latter is better for our purpose and the open version is not treated below. Figure 4 shows the model structure. The structure and working of the model can also be seen from the equations below and figure 5.

$g = (g_j)$	gross output of industry j
$q = (q_i)$	output of ith commodity
$a = (a_i)$	government production of ith commodity
$m = (m_i)$	imports of ith commodity
$x = (x_i)$	export of ith commodity
$u = (1,1,\ldots,1)$	is vector of units
$U = (u_{ij})$	matrix of input of ith commodity to jth industry
$Y = (y_{kj})$	matrix of primary input k to industry j
$V = (v_{ji})$	jth industry output of the ith commodity
$d = (d_{ji})$	share of jth industry in production of ith commodity
$F = (f_{ik})$	categories of final demand

Denote by B the matrix of intermediate input coefficients and let H denote the primary input coefficients so that:

Figure 5

The Solution of the Model



$$U(g) = B\,\hat{g}\,, \quad Y(g) = H\,\hat{g}$$

are the input levels by industry corresponding to the industry gross output g ($\hat{x}$ denotes the diagonal matrix constructed from the vector x). Also on the commodity side:

$$V(G) = D\,\hat{q}$$

Total industry output is

$$g = Vu \quad \text{or} \quad g = Dq,$$

thereby relating industry output to commodity output. Assume imports of a commodity are a fixed share of domestic demand [$\mu = (\mu_i)$] and likewise for government production [$\alpha = (\alpha_i)$] we have:

$$m_i = \mu_i(\sum_j u_{ij} + \sum_k f_{ik})$$

i.e.

$$m = \hat{\mu}(U + F)\,u$$

Also

$$a = \hat{\alpha}(U + F)\,u + x$$

now we have

$$q + m + a = (U + F)\ e + x$$

or

$$q = (I - \hat{\mu} - \hat{\alpha})\ Bg + (I - \hat{\mu} - \hat{\alpha})\ Fe + (I - \hat{\alpha})\ x\ ,$$ We

can solve for g or more generally

$$g(e) = [I - D\ (I - \hat{\mu} - \hat{\alpha})B]^{-1}\ \bar{D}e$$

e = final demand specified in commodity space

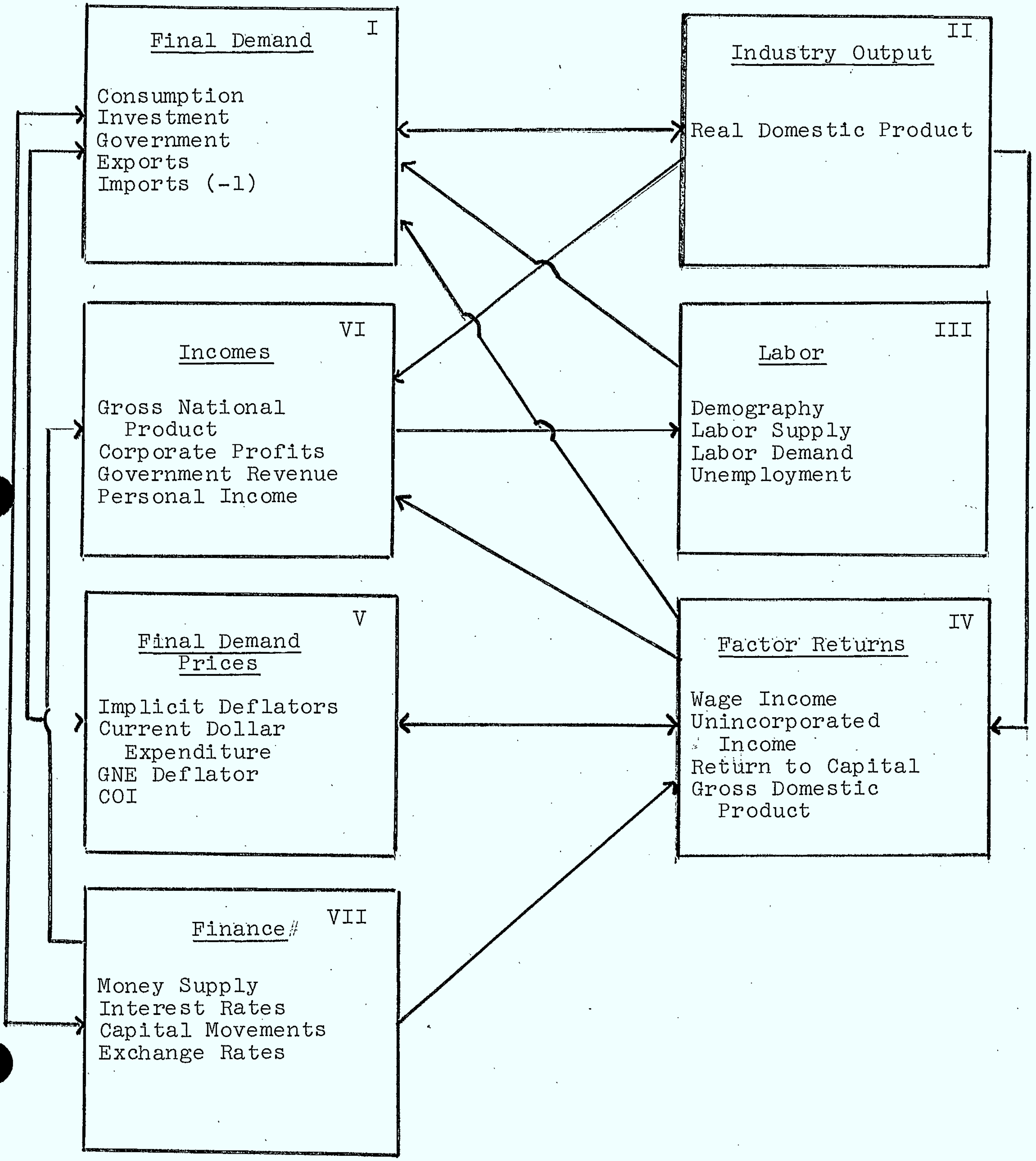
$\bar{D}$ = converts demand in commodities to industries

The model can then solve for q, m, a and Y.

The foregoing outline shows the detail of the model, and associated sofeware has been developed to permit ready change of parameters for simulation purposes. There also exists a parallel price model. The chief shortcoming of the model is the nonexistence of any interaction between price and quantity changes. It follows that any substitution affects occasioned by technical change cannot enter the simulation exercise on this model. This could be an important omission if the change being considered involves a large relative price decline. Additionally the model does not pretend to simulate in 'real time' and hence it is incapable of examining the time profile of layoffs and rehires, giving only the final net effect associated with the new equilibrium.

In contrast to the relatively simple input-output model constructed from cross-sectional data, the CANDIDE 2 and TIM macroeconomic models of the Canadian Economy use many econometrically estimated relationships built from time series data. What make these econometric models of the national economy unique, however, is the integration of an input-output table into their structure. These tables (1971 coefficients) are square with 82 industries in TIM and 48 in CANDIDE 2. In the 48 CANDIDE industries are included the usual manufacturing sectors, hospitals, owner occupied dwellings, college and universities, schools, etc., indicating that there is less useful industry detail than what first appears. The size of these models are large, TIM having 3623 equations or endogenous variables, 740 of which are behavioural (stochastic). Both models estimate twelve employment equations based on productivity functions using data of the Labour Force Survey. These are standard Keynesian final demand models with many individual variations. Price inflation follows wage push which generally issues from a wage bargaining model, although (in TIM) a modified

Figure 6: INFORMETRICA MODEL - SECTORAL LINKAGES



Phillips curve enters in the service sector wage formation. The wage bill also responds to inflation and output per worker. Separate equations for nine sectors (for example, manufacturing comprises one entire sector) specify the return on capital (in TIM) or profits which are used in wage determination. The modules of TIM and their sectoral linkages are shown in Figure 6.

The econometric models are designed to give the direct and indirect effects of changes in government instruments, a final demand category, or exogeneous variables. They allow for substitution to take place in consumption, giving room for relative price change to have an effect. Unlike the previous model, the price and quantity sides of the model are linked as a unity. A reading of the model description will show that model improvement efforts have been guided by the requirements of forecasting. It follows that certain functional specifications make sense only in the light of their effect on the models tracking performance and expost forecasting record. The satisfaction of the forecasting criteria may cause a distortion in the model for simulation purposes, but the issue really constitute an unanswerable question.

A further feature of the econometric models consists in the time time profile of effects following a parameter change.

Again this is determined by the inertial structure of the model designed around some economic theory and the requirements for forecasting. Not infrequently, responses to shocks have shown an unbelievable pattern and while efforts have been made to improve the situation, great care in a simulation context is called for.

In terms of simulating structural change the econometric models have to overcome their relatively high aggregation in certain areas. Their employment structure is the worst offender, one equation for each of ten sectors. A particular industry within manufacturing, for example, does not have its labour requirements differentiated from the sector as a whole and an assumption concerning labour share within the sector has to be made. The likely working assumption will be that the labour share is equal to the output share of the industries within a sector, an approach however which contradicts the production functions specification for employment. For small parametric changes involving incremental employment allied with new fixed capital formation the conflict may be relatively unimportant but its presence ought to be kept in mind.

Inherent in all output determination models in the relatively low penalty attached to a simulated increase in final demand, for example through a change in investment.

An increase in investment has invariably good consequences in the models because it creates new capacity at hardly any cost. The cost is minimized as the entailed increase in current economic activity is accommodated by engaging underutilized capacity and the unemployed; inflation is the only manifestation of economic cost since supply side constraints are rarely fully operative. Yet in reality investment in new technology almost always encounters shortages in specialized labour and investment goods causing any simulation exercise involving investment activity to be over-optimistic in its results.

Because of the input-output industry structure all three models are capable of simulating technological change by adjustments made on the intermediate input coefficients for the target industry. But such an exercise will likely be expensive and the choice of model can be influenced by the amount of software in place and the level of expertise acquired by the model's team.

The national economic models can give a notion of the intermediate and final effects of technological change, once flaws are attended to and corrected for. But a successful simulation study requires information on the extent and size of parameter changes entailed by the introduction of a new technology, and this knowledge can only be made available through industry or establishment case studies, and engineering studies. These studies would be designed to show how material and primary input requirements change under the new process method and indicate the proportion of firms in the industry that are affected.

A General Research Programme

In this exploratory study we attempted to show the many parts that together constitutes a complete research programme on technological change. In one major respect the work is made more difficult, but more specific and relevant, by seeking out the effects of a single cause to technological unemployment, the computer. But the lines of causation running from the newly introduced computer to even the immediate direct employment effects are not easily visible, and even worse so for the indirect effects. The problem is just not one of data, and without question much data remains to be collected, but it also is one of tenuous linkages that are apt to get lost among all the other motions frozen in the input-output table, or merged in the time series data. Therefore, good advise for a research programme is that it should proceed on a step-by-step basis, in which each stage is designed to help reveal whether to continue is warranted or the decision should be to stop. These stages are laid out in the chart in their obvious order. The chart is self-explanatory, after the reader has become acquainted with the main text.

Research Area	Function	Results
1 . Develop crude computerization series (roughly corrected for price level change)		. Rough approximate series for computer quantity, by industry.
. Computer occupations employment series		. computer direct job creation
2 . Exploration of time series data (by industry)	. Compare industry employment series with computerization series obtains in 1, 'investment'; general economic conditions	. Economic narration giving general impression of size of employment impact
. Analytical investigation	. extention of economic analysis	. Guidance for design of studies in areas 7 and 8.
3 . Case studies; various firms in selected industries	. background on time and type of computer installations	. local data of job displacement
	. timine and location of innovation change within overall production process	. information for diffusion index
	. nature of associated capital investment	. information for simulation studies
	. change in material requirements	
	. direct job displacement/creation effects	
4 . develop computer data base . statistical tests of sample . run test regressions and cross refer to rough measure 1 . regress base year rentals on characteristics	. index of computer quantity	. industry time series on computer quantity corrected for price and quantity change.
5 . Develop diffusion rate measure	. to obtain direct employment effect (6)	. industry forecast rate of computerization . extend local effects to industry
6 . Develop model for direct employment based on 3-5 above		. forecast of industry direct employment effects
7 . Structural I/O model	. to examine practicality of using models of national economy for simulation	. simulation of employment effects produced by innovation in one or another industry.
8 . Econometric models	. simulations, with policy intervention	. simulation of technological unemployment . fiscal remedial policy actions

Referring to the chart, areas 1, 2 and 6 will be the cheapest to promote, while areas 3, 7 and 8 will be relatively costly. Area 4 will have an intermediate cost wholly dependent on the computer related cost of preparing the data. Fortunately, some case studies are about to commence under contract to DOC and any liasion between researchers should reduce case study expenses, although overall costs will naturally depend on the breath of industry coverage.

At least three years, but likely four, would be required to complete the full programme; one year for areas 1 and 2, two years for 3, with one year overlapping all of 1, 2 and 3. It is essential that the first years work be completed before entering stages downstream, although area 4 <u>could</u> be completed in the second year, if some preliminary work is accomplished towards processing the data. Otherwise its completion will come a little later. In the third year the areas might overlap to bring the final completion to the end of that year, but the simulation studies are required to wait upon the results of 6, and for that reason about 3.5 years would be required. However, by shortening the time frame for the earlier stages a 3 year deadline could be met, but again that would be difficult for university based research to comply with.

The entire programme would be one of the most comprehensive undertaken in this area and could yield very major policy insights on technological unemployment. Given that we are able to obtain the appropriate information from case studies, the unique hybrid models of the Canadian economy which combine an input-output table with the econometric side of the model, offers an opportunity to investigate the policy issue in its full economic ramifications, an opportunity scarcely equalled elsewhere among the OECD countries. It is interesting to learn that the concern in Europe over the job displacement issue is very intense, yet giving rise to debatable conclusions because the indirect employment effects have not been taken together with the direct unemployment effects. Such a task requires extensive simulations of the kind suggested in this study. While recognizing the numerous serious shortcomings of econometric modelling,, in Canada we appear to possess the special type of simulation tool suitable to the job which is available in few other countries. Our initiative in this important research direction could prove to be an example the OECD policy research directors are ready to emulate, in view of the real social urgency being created by the widely acknowledged changes microelectronics will bring to society.

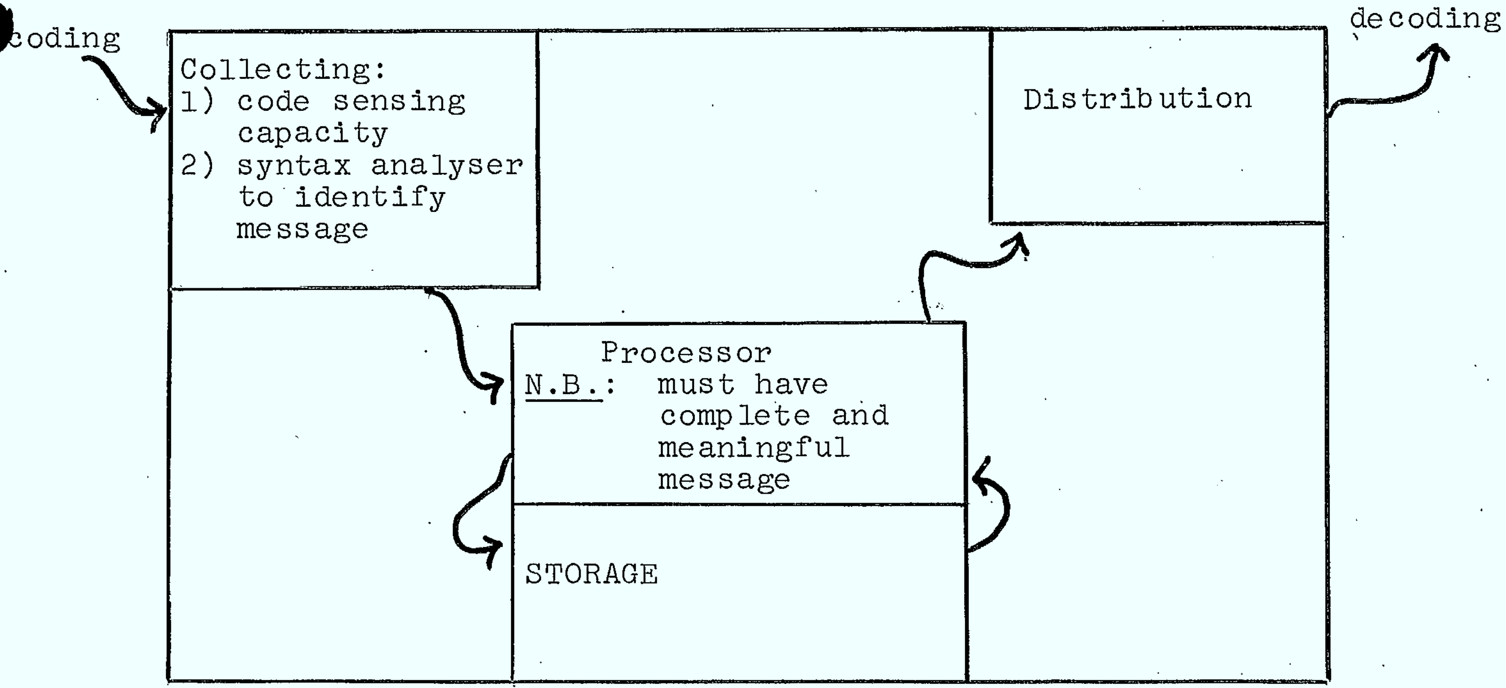
7 Appendix

In this appendix the structure and nature of information processing is presented in an abstract and schematic form. Also included is a glossary of communication terms as well as costs and capabilities of storage media.

Communication Diagram

- stress physical nature in transfer process → limited to technology
- garbage-in/garbage-out → system only as good as components (e.g. manual files which work in conjunction with EDP)
- EDP is not attached to an organization → must view it from System's Approach (integrated)
- relevant concern is Information/not simply Data.

Four Functional Attributes of Data Transmission



Problems and Notes

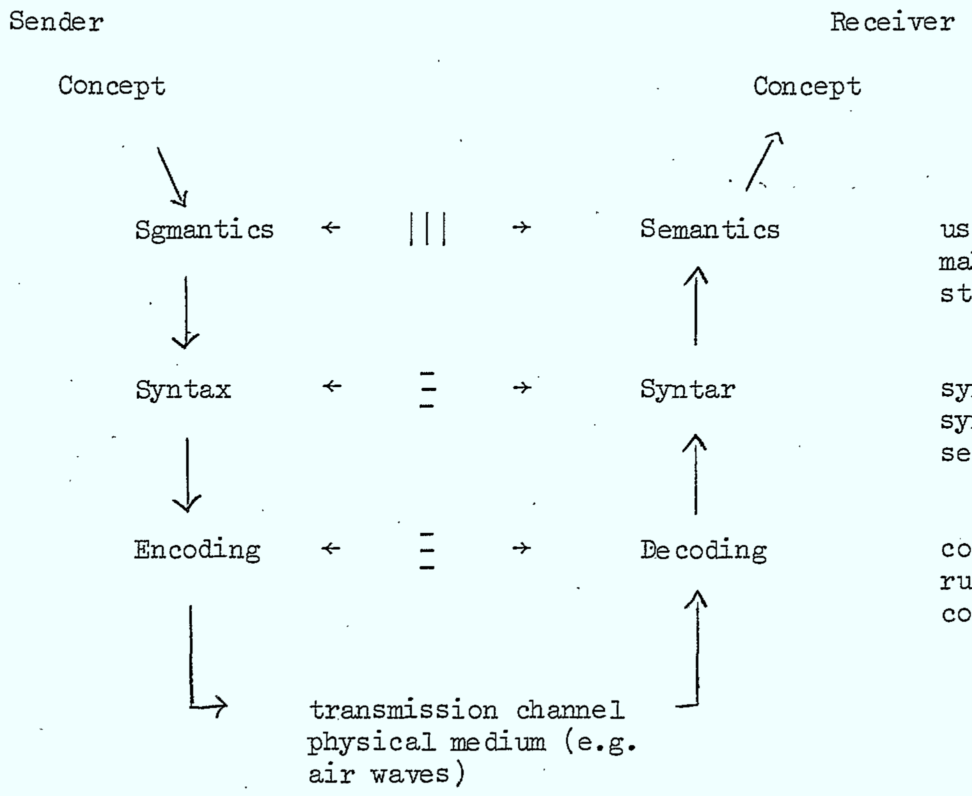
1) mismatch between 1) encoding and collecting
    2) distribution and decoding

2) storage capability

3) Internal speed is limited by technology.

Communication Diagram

1. some idea about real world
2. symbols
   - semantics relate the real world to symbols
3. statement; message
   - syntax rules allow one to put ideas into a meaningful form
4. rules for encoding

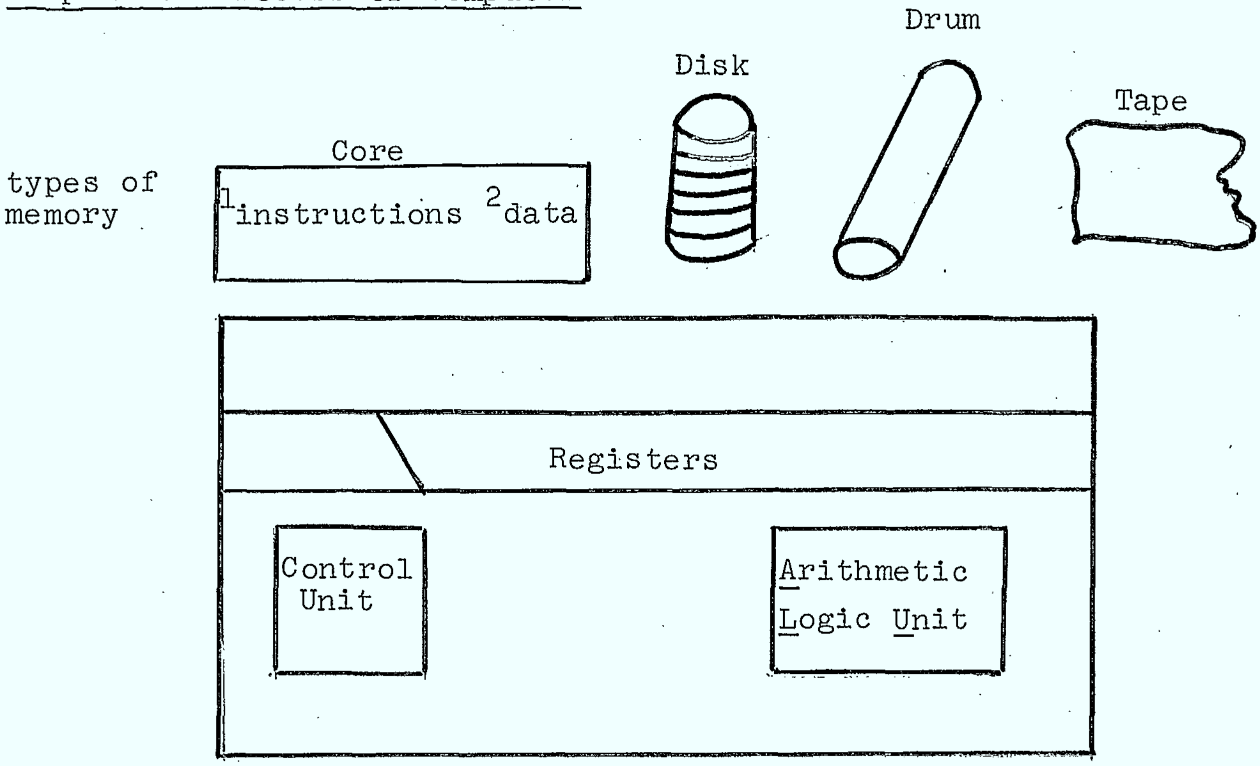


use semantic rules to make sense out of the statement

syntax rules combine symbols into a valid sequence

coding and decoding rules must be vo coordinated

Simplified Process of Computer



1. Core has been abstracted from its rightful position within the mainframe.

Control Unit:- retrieves instructions in the proper sequence

- interprets the instruction
- then signals the RLU to execute the instruction

ALU: performs the arithmetic and logic functions

Registers: the workspace for calculations and a conduit for interaction between the Control Unit and the Core.

Machine Cycle:

I Time   E Time

I-Time: instruction time (Control Unit)

E-Time: execution time (ALU)

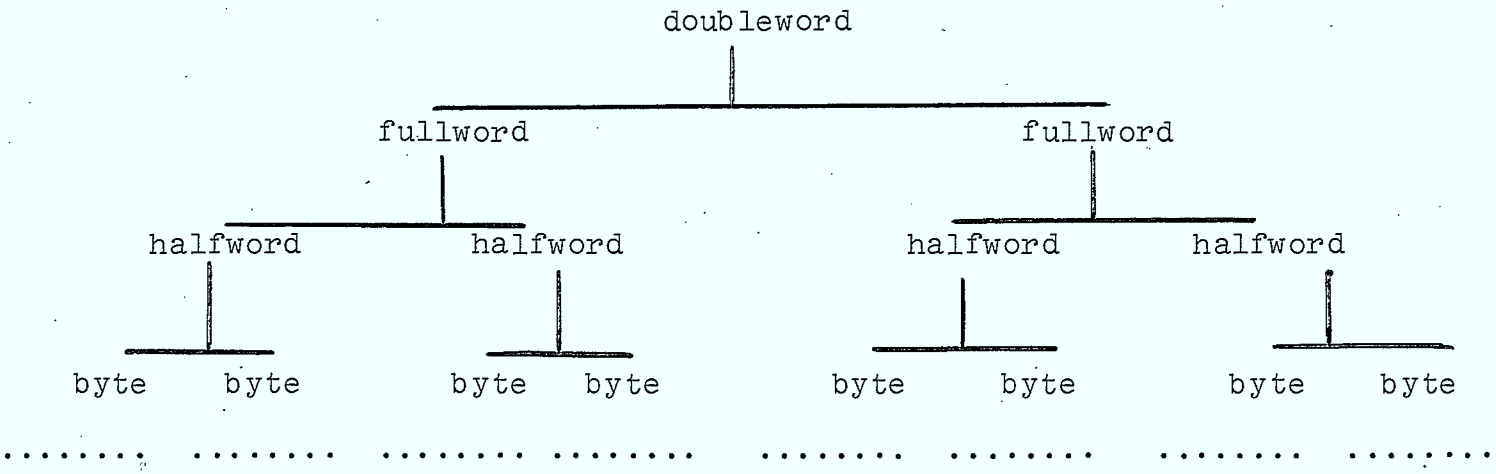
Binary → 2 state (e.g. on/off) possibilities
- smallest unit of information
- suited to machines (e.g. electric current on/off)

Bit → a binary digit NOTE: -4 bits is enough code one decimal digit $2^4 = 16$
-6 bits (2^6) allows 64 different combinations and therefore enough to code alphanumerics.

Byte → - a sequence of adjacent binary digits operated on as a unit
- basic unit of memory

for I.B.M.
- a Byte is an 8 bit code and I.B.M. calls their code → EBCIOTC

Addressing main memory on an I.B.M.



Telecommunications

Narrow Band Lines

- used for telex
- not sufficient for voice grade communication
- capacity 100 Baud

  NOTE: 1 Baud = 1 bit/second

  ∴ 100 Bauds ≃ 10 characters/second

Voice Grade Lines

- 300 Baud
- low speed

Medium Speed Lines ≃ 2400 Baud (2 x 2400 Baud)

High Speed Lines ≃ 4800 Baud (uses 2 lines together)

Conditioned Lines ≃ 9600 Baud (very specialized)

NOTE: it is critical to match the speed of the line to the speed of the computer you have.

Simplex line: data flows only in one direction (Terminal → CPU)

Half duplex line: data can flow in either direction but not in both directions simultaneously (Terminal ⇄ CPU)

Full duplex line: data can flow both directions simultaneously (Terminal ⇄ CPU)

Modem (also called data set)

- modulates and demodulates
- converts pulses to waves and then back to pulses again

Figure 8:

Typical Storage Capabilities: 1978

milli second = 1/1,000
micro second = 1/1,000,000
nano second = 1/1,000,000,000

storage medium	storage cost 1,000 ch/yr.	storage capacity characters	data transfer rate ch/sec	access time	Remarks
cards	pennies	----	1,000	minutes	storage problem slow feeding devices
tape	5¢	(40M) per tape	300,000	minutes	rewind ~ minutes
disk	10-15¢	300M	800,000	10-50mill/ mill/s several multi seconds	
drum	25¢	4M	1,200,000	2-10 m/s few milli sec	faster rotation and seek time
core	$100	6M	4M	several micro sec	

References

Arrow, K. & R. Hahn (1971), General Competitive Equilibrium, Holden Day.

Blattner (Feb. 1979), "On Some Well-Known Theoretical Propositions on the Employment Effects of Technological Change", mimeo.

Bower, R.S. (1973), "Market Change in the Computer Services Industry", Bell J. Economics, August, Vol. 4, 539-92.

Chow, G.C. (1967), "Technological Change and the Demand for Computers", Amer. Econ. Review, Vol. 57, 1117-30.

Heertje, A. (1973), Economics and Technical Change, London

Kaimien, M. & N. Schwartz (1971), "Limit Pricing and Uncertain Entry", Econometrica, Vol. 39 (3), 441-54.

Levhari, D. (1965), "A nonsubstitution Theorem and Switching of Techniques", Quarterly J. Econ., Vol. 79, 98-105.

Mansfield, E. (1968), Economics of Technical Change, Norton.

Mark, J.A. (1979), "The Impact of Technical Change on Labour", mimeo.

Nikaido, H. (1975), Monopolistic Competition and Effective Demand, Princeston University Press.

Nordhaus, W.D. (1969), Invention Growth and Welfare, MIT Press.

Parker, J. (1978), The Economics of Innovation, Longman, London.

Rosen, S. (1974), "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition", J. Political Econ., Vol. 82, 34-55.

Samuelson, P. (1961), "A New Theorem on Substitution", in Money, Growth, and Methodology, Vol. 20, 407-423, Lund Social Science Studies, Lund, Sweden: CWK Gleerup.

Simon, H.A. (1951), "Effects of Technological Change in a Linear Model", in T.C. Koopmans, ed., Activity Analysis of Production and Allocation, Wiley, New York.

Stoneman, P. (1975), "The Effects of Computers on the Demand for Labour in the United Kingdom", Economic Journal, Vol. 85, 590-606.