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# TECHNOLOGICAL CHANGE : THE IMPACT OF INNOVATIONS ON SOCIETY

## INTRODUCTION

Technological change is based on ideas, the conversion of ideas into inventions (working devices/processes), the commercialization of inventions into innovations (commerically viable devices/processes), and finally, the widespread adoption and dissemination of innovations by users. There are four important aspects of technological change:

(1) its definition and measurement,
(2) its classification, and
(3) its mechanism or causes.

## THE DEFINITION AND MEASUREMENT OF TECHNOLOGICAL CHANGE

(a) The Census Approach : According to the census approach, technological change is defined by the quantitative change in the indicators of technological change. These indicators are technology-related events with uniqueness and novelty, such as the number of publications in a field, the number of R & D personnel, etc. But, the two most widely used indicators are patents and major innovations.

Patents satisfy the criteria of originality, technical feasibility, and commercial worth. It must be noted, however, that patents concern inventions, not innovations, and not all inventions are patentable or for that matter patented. Also, the tendency to patent varies widely across firm and industries. Finally, the importance of an invention is not indicated in the patent.

When major innovations are used as indicators, it is assumed that innovations are discrete events. But, in fact they may involve a continued process. Further, the emphasis on innovations overemphasizes the initial event and ignores the long-term development of the innovation. Finally, it is difficult to distinguish major innovations from minor ones, particularly because it is not clear whether a major innovation is a stimulus for minor innovations or whether or the culmination of minor ones.

After identifying the indicator of technological change, a census study of patents or major innovations provides direct measures of technological change. It must be noted, however, that a census study emphasizes the number of technologies rather than the changes in the technologies, and they stress the origin of technologies rather than their development. Above all, they throw little light on the mechanisms and causes of technological change.

(b) The Production Function Approach : When long-term economic growth is studies, it is obsrved that the actual growth of output, Q, is much greater than the growth that can be attributed to the growth in conventionally defined economic inputs such as capital and labour defined by what is called the production function f(K,L). In other words, there is a residual

$$g(t) = Q - f(K,L),$$

and the problem is to explain the unexplained residual. This can be done by writing

$$Q = A \,.\, f(K,L)$$

where f(K,L) is the production function of the conventional economic inputs, K and L, and A is the non-economic input. Noting that

$$Q/A = f(K,L) \text{ and } Q/[f(K,L)] = A$$

the result of differenting is

$$(dQ/dt) = f(K,L).(dA/dt) + A.(d/dt)\,[f(K,L)]$$

$$= (Q/A)\,(dA/dt) + [Q/f(K,L)]$$

$$[(\ \ f/\ \ K)\,(dK/dt) + (\ \ f/\ \ L)\,(dL/dt)]$$

Dividing by Q,

$$(1/Q)\,(dQ/dt) = (1/A)\,(dA/dt) + [1/f(K,L)]$$

$$[(\ \ f/\ \ K)\,(dK/dt) + (\ \ f/\ \ L)\,(dL/dt)]$$

Multiplying and dividing the last term on the RHS by K and L,

$$dlnQ/dt = dlnA/dt + (\ \ lnf/\ \ lnK)\,(dlnK/dt) +$$

$$+ (\ \ lnf/\ \ lnL)\,(dlnL/dt)$$

Since the exponential rate of growth, $G_x$ is given by

$$X_t = X_o \exp(Gt) \quad \text{or} \quad G_X = dlnX/dt$$

and $\ \ lnf/\ \ lnK = E_{Kf} = E_{KQ} =$ Capital elasticity of Output

and $\ \ lnf/\ \ lnL = E_{Lf} = E_{LQ} =$ Labour elasticity of Output

it follows that

$$G_Q = G_A + E_{KQ} \,.\, G_K + E_{LQ} \,.\, G_L$$

i.e., $G_A = G_Q - [E_{KQ} \,.\, G_K + E_{LQ} \,.\, G_L]$.

An idea of the contribution of $G_A$ can be obtained from the data for USA for the 40-year period from 1909 to 1949 during which $G_Q$ = 2.75% per annum, $G_K$ = 1.75% per annum, $G_L$ = 1.00% per annum, $E_{KQ}$ = 0.35, $E_{LQ}$ = 0.65. It follows from this data that $G_A$ = 1.5% per annum, and that $G_A/G_Q$ = 1.50/2.75 = 54% --

over half the growth in total output is due to the non-economic input of technology and innovations. This approach provides a definition and measurement of technological change as the residual, $G_A$, that is not explained by the conventional economic inputs, K and L, and the standard production function f(K,L). It also permits a separation of the technical from the economic factors.

## THE CLASSIFICATION OF TECHNOLOGICAL CHANGE

Figure 1 shows a graphical description of a production function of the so-called Cobb-Douglas type. The rectangular hyperbolae Q, 2Q, $Q_i$ each are called isoquants. These curves represent various possible combinations of capital and labour to produce the same output of produce P. The tangents to these curves are called as the iso-cost lines. Point B, for example, represents the optimal technique of production since it requires least amount of both capital and labour. Points C and D are non- optimal production techniques since they use more of both capital and labour. Movement from points C and D towards B correspond to improvements in technical efficiency. This is achieved by improving skills, minor or incremental changes in the production process, etc. These improvements in technology that effect changes in the relative amount of capital and labour required are termed as technical innovations.

Now if the quantity of output is doubled to 2Q, the optimal technique is point E. It is apparent that inputs K3 and L3 are not doubled. This is known as the scale effect.

Assuming that the input prices remain constant, if there is an innovation that causes a shift in the production function or the creation of a new one, then such an innovation is called as a technological innovation. Let us suppose that a new product P1, is developed which is a commercial substitute of P, then its production function will be distinctly different from that of P. This is termed as product innovation. If however, an innovation occurs that requires lesser amount of capital and labour for the same product P, the production function shifts downwards (for the same quantity Q). Such innovations are termed as process innovations. In Figure 1 they are represented by curves $Q_{1,}$ $Q^2$ and $Q_{3.}$ $Q^3$ is called as a capital saving innovation; $Q_{2,}$ a neutral process innovation and Q1, a Labour saving innovation.

The basic expression Q = A(t) . f(K,L) also leads to a classification of technological changes through the question: how does A(t) affect the output. There are three possibilities

(1) If Q = A(t) [f(K,L)] and all inputs K and L are equally affected, then the innovations are considered to be neutral in character and neutral technological change is considered to have occurred.
(2) If Q = f[{A(t)K},L] and only the input K is affected, then the innovations are considered to be capital- augmenting in character and capital-augmenting technological change is considered to have occurred.
(3) If Q = f[K,{A(t)L}] and only the input L is affected, then the innovations are considered to be labour- augmenting in character and

labour-augmenting technological change is considered to have occurred.

Obviously, research is required to identify the relative contribution and importance of each type technological change, i.e., to determine whether the unexplained residual in the growth of output of the economy is due to neutral, capital-augmenting or labour-augmenting innovations. Dennison's study of the US GNP showed that 40% of the residual was due to improvements in the labour force -- this finding stresses the importance of education/training in economic growth. The study also failed to demonstrate the importance of capital improvements in growth. Dennison's findings led to the *embodiment hypothesis*

THE EMBODIMENT HYPOTHESIS

The expression Q = f[{A(t)K},L] assumes that *all* capital stock shares *equally* in technological change, i.e., it assumes that machinery stock is *homogeneous* with new *and* old machines being equally productive. The starting point of the *embodiment hypothesis* is that the capital (machinery) stock in any economy at any point of time is in fact a collection of equipment of various types and vintages. If for instance $S_i$ is the contribution to the stock from machines that are i years old, then

$$S = \sum_{i=0} S_i$$

The embodiment hypothesis then goes on to take the view that innovations are embodied in the *latest* additions to the capital stock and that only these additions contribute to technological change because the productivity of the old machines remains more or less constant. Thus, capital accumulation or new investment is the major method whereby technological change is introduced.

There is also a labour version of the embodiment hypothesis. Whereas the expression Q = f[K,{A(t)L}] assumes that all labour inputs can be simply counted in for instance labour hours, this view is unrealistic. The labour force consists of workers with varying degrees of skill and experience. If $L_i$ is the contribution from workers who joined i years ago, then

$$L = \sum_{i=0} L_i$$

If new workers are equipped with better skills, then technological change is embodied in these new workers, i.e., the labour force is not homogeneous.

Also, workers will learn to perform a job more efficiently the longer they remain on it -- there is a *learning curve*. A learning curve which is an important factor in technological change was first observed in aircraft manufacture. The learning process is normally reported in terms of learning factors -- a learning factor of 0.8 means that after a couple of manufacturing cycles, the workers take only 80% of the time that they took in the initial manufacturing cycle.

Thus, the effectiveness of the labour force is a function of (1) the educational and training levels of workers with various lengths of service, and (2) the fraction of the total labour force accounted for by workers with various lengths of service.

## THE ECONOMIST'S VIEW OF TECHNOLOGY

Until the middle of this century, economists tended to avoid technology as an economic variable. The incidence of new technology was considered equivalent to other major exogenous events such as wars or gold strikes. Since the 1950s, however, a vast amount of literature is available on the subject of technological innovations and related activities.

"There are two basic ways in which economists have approached inventions, innovations and the associated technical advance. The first one, widely used in macrogrowth models, treats invention and innovations occurring such that technical progress continues at an exogenously determined rate (often constant). The second one treats inventions and innovations as the production of new knowledge which can be subjected to analysis similar to that applied to the production of goods and services, with some account taken of the special features of the product 'knowledge'. Freeman (1974) suggests that most attempts to build a theory of innovation have focussed on either `technology push' or `demand pull' and this dichotomy corresponds approximately to the one made above. These approaches to the understanding of the process of innovations are not exclusive of each other but are complementary." [Sawyer(1980)] .

## THE EXOGENOUS TECHNOLOGY-PUSH APPROACH TO TECHNOLOGICAL CHANGE

This approach to the study of innovations and technical change is based on the production function treatment described above. As a result, it suffers from the same weakness as all production function aproaches in that it is based on the following set of `unrealistic assumptions'. [Rosegger(1980)]

a. Each decision making unit consists of a single plant which produces a single homogeneous output;
b. Decision makers possess perfect technological knowledge;
c. All the techniques of production can be fully described in terms of the amount of capital and labour they require;
d. Each decision maker has access to an unlimited number of input units at prevailing market prices;
e. The inputs K and L completely characterize production
f. K and L are homogeneous and continuously varying -- they differ only in quantity but not in quality.

Further, if technological change is neutral, i.e., if $Q = A(t) [f(K,L)]$ and all inputs K and L are equally affected, the implication is that technological change is exogenously determined outside the economic system and that it is driven by an autonomous <u>technology</u>-<u>push</u> driving force. In fact, however, the process of innovation and technological change are implemented through more or less conscious decisions. They are the results of activities that are <u>endogenous</u> to the economic system. Thus, the exogenous view of technological change is an unsuitable approach for the study of economics of R

& D.

## THE ENDOGENOUS DEMAND-PULL APPROACH TO TECHNOLOGICAL CHANGE

The second approach considers the development of technology as an endogenous variable in economic growth. It views technology like any economic product (good or service) and seeks to answer the same questions as those that are normally asked of other products/services.

(1) Production Function for Invention : By assuming that invention is the rate-determining step in technological change and that invention is an output that depends upon the inputs into inventive activity, one can think of a production function for inventive activity. On the basis of such an approach, the output of invention depends upon the inputs of labour (of varying degrees of creativity, experience, etc.) and capital (i.e., infrastructure, equipment, etc.). Thus, one can ask: how much substitution is there between labour and capital? Can computers replace people? Can average inventors backed by good equipment substitute for geniuses? What are the returns to scale in inventive activity? Are large think-tanks productice? Are there dis-economies of scale because for instance managerial supervision problems increase with expansion of R & D units? and so on.

(2) Demand as a Driving Force for Innovation : The pressure for demand creates an environment in which it pays to innovate, and therefore demand is a driving force for innovation. The crucial question is: what is the unfulfilled demand for innovation?

(3) Cost Reduction as a Motivation for Innovation : Though demand provides a driving force for innovation, and cost reduction is a major motivation for the effort of innovation, the direction along which cost reduction is to be achieved still remains undefined. The question is : what type of cost reduction should innovation achieve? For instance, should the innovations be neutral in the sense of saving all inputs equally? or should they be biased towards labour-saving innovations, i.e., economizing relatively more of one input, e.g., labour, than another, e.g., capital?

(4) Market Penetration : It is expensive for a firm to adopt new technologies -- apart from the financial costs of adoption of new technologies, there are the costs of taking risks with new products/processes, the costs of getting information, and the "psychological" costs associated with the employees' resistance to change. Hence, the penetration of the market is not an "overnight" affair. Many studies (starting with the classic study of Griliches on hybrid corn) have suggested that the time-dependence of the penetration of the market follows an S-shaped curve (also called a logistic curve) in which a slow initial acceptance is followed by a rapid increase in market penetration, culminating in an asymptotic levelling off corresponding to a saturation (figure 7.1). If N is a measure of diffusion, the differential equation for the S-shaped curve is

$$dN/dt = r \cdot N \cdot (K - N)$$

i.e., $$(1/N)\, dN/dt = r \cdot (K - N) = r K - r N$$

where r is a constant and K is the saturation value. On integration, the result is

$$N = K / [1 - a \exp(-bt)]$$

where a = r K and b = r, the rate of growth parameter. The "slope" or shape of the S-shaped curve is a functio0n of the profitability of the innovation -- the more profitable the innovation, the more rapid is the penetration of the market.

## PROFITS AND R & D

Though it is generally assumed that R & D is predominantly profitable, it is not easy to disentangle the influence of R & D on profits. The point is that R & D and profits are dialectically related so that if the focus is on profits, R & D is the cause, and if the focus is on R & D, profits are the cause.

The first model considers that R & D expenditures produce profits, i.e., that profits are a function of R & D expenditures. But, it is well known that profitable firms devote resources to R & D which leads to the second model that R & D activity is a function of profits. On the basis of the principle that causes precede effects in time, the empirical evidence that R & D is more highly correlated with <u>future</u> profits (with a 1 to 3 year lag) than with current profits can be taken as strong support for the first model that R & D expenditures lead with a 3-4 year lag to increased patenting and to increased profits. If a production function is written with R & D expenditure as an input, then the marginal rate of return to R & D expenditure is about 15% in US industries such as apparel, chemical, food and petroleum.

## FACTORS AFFECTING RESOURCE ALLOCATION

(1) <u>Sources of Funding for R & D</u> : In the industrialized countries, private industry provides most of the funds for R & D. In 1975, for example, the average percentage of funds from private industry was 77 $\pm$ 15% in a set of OECD countries with the country-specific figures being France (67%), Italy (95%), Japan (95%), UK (64%), US (61%) and West Germany (80%). In India, the corresponding contribution from private industry was 12% in 1975 and 13% in 1984-85. The enormous difference is because of the much larger markets for R & D and the greater profits resulting from satisfying these markets in the industrialized countries in contrast to the lack of market demand for R & D in dveloping countries like India where there is a greater demand for the import of technologies.

If the bulk of the resource allocation to R & D is controlled by market forces, the next set of questions that arise are: What are the characteristics of the market that ensure adequate resource allocation to R & D ? What are the characteristics of the firms that respond successfully to these market forces ?

A characterisitic of the market that has been extensively studied is its market structure i.e., whether the market is monopolistic, oligopolistic or perfect (from the competition point of view). The most commonly used characteristic of the firm is the firm size. Economists have studied its effect on R & D intensity and R & D efficiency.

The superior allocative efficiency of the perfect economy is one of the most popular canons of economic theory. However. it has been argued that a monopolistic market structure is most ideally suited for the development of new technology, and that large and perhaps monopolistic firms are best suited to conduct an effective R & D effort. The assumptions underlying this view are:

a) The large amounts of capital that have to be assembled in order to permit effective research programs are only available with large firms with large amounts of resources at their disposal.

b) The risks that are associated with R & D projects can be distributed among the large number of projects that go to form the R & D program of a large firm -- this possibility may not exist with the smaller portfolio of a small firms.

c) In an industry with several competitors, an innovator enjoys 'special' profits from his innovations as long as there are no competitors capable of imitating his product. The moment competitors enter the market his special profits are lost. These special profits beside being an incentive for firms to innovate also act as a source of investment for further R & D. Since in a monopolistic market, these special profits are not challenged, there is lesser hesitation on the part of monopolistic firms to invest in innovation. In other words, the larger time lag before imitation increases the potential profit for monopolistic firms.

d) The Ticketless-Traveller (Free-Rider) Problem: One of the most important barriers to investment in innovation is the problem of a competitor appropriating or exploiting the innovation. An imitator may be able to develop a new product without the high costs and risks faced by the innovator. In the case of basic research this is most clearly apparent since scientific information is not protectable. However, in the case of a monopolistic market, this problem is not present since there are no competitors. Further, large firms can enforce patent laws more effectively since they can fight longer battles in courts to protect their intellectual properties.

In recent years, the above hypotheses about firm size and market structure in innovation have been subjected to empirical analysis. The results of these have been summarised by Kamien and Schwartz(1975):

Data availability has allowed more extensive investigation of the association of inventive activity with firm size than with market structure. A commonly tested hypothesis is that R & D activity increases more than proportionately with firm size. The bulk of empirical findings do not support it -- with the notable exception of the chemical industry. Relative R & D activity, measured either by input or output intensity, appears to increase with firm size up to a point then level off or decline beyond it.

Studies of market structure and R & D activity commonly employ a concentration ratio as a measure of monopoly. Little support has been found for the standard hypothesis that R & D activity increases with monopoly power. Instead, recent evidence suggests that rivalry in R & D may be non- linearly related to industry concentration. A new empirically inspired hypothesis has emerged to the effect that market structure intermediate between monopoly and perfect competition would promote the highest rate of inventive activity.

" From the point of view of organisation and management, there is an ongoing debate about the relative advantages and disadvantages of firm size in innovation. On one hand, it is argued that large firms are able :

1) to spread risks by undertaking more and a wider selection of projects;
2) to employ and utilize highly specialized skills;
3) to operate on a large scale and with greater sophistication;
4) to have their own fundamental research laboratories; and
5) to afford management and market planning techniques.

On the other hand, small firms are better able :

1) to make more rapid decision and act upon them;
2) to avoid vested interests in the firm;
3) to encourage personal commitment to and identification with projects; and
4) to 'couple' the activities of research-development-product-marketing more effectively.

Some observers feel that both large and small firms play essential roles in the process of technological innovation and ... these roles are complementary, interdependent and ever- changing." [Pavitt and Worboys (1977)]

ROLE OF GOVERNMENT INTERVENTION

Of the two major factors affecting investment in R & D discussed above, viz. market structure and firm size , the market structure has wider ramifications. Despite the fact that empirical support for the hypothesis that monopolistic market structure is better for resource allocation was meagre, there is no doubt that some amount of monopoly power is essential for continued resource allocation. This fact is the rationale behind the patent laws of a country.

" The logic of the use of patents is closely tied to the free-rider problem in innovation. It should be noted first that the free-rider problem is a two-pronged difficulty, potentially giving rise not only to inequities but also to a serious misallocation of society's resources. The issue is not only the injustice that occurs when the bulk of the benefits of an innovation flow to persons who have contributed little to its creation. Perhaps even more important is the likelihood that if nothing is done about the free rider problem, private enterprise will find R & D unprofitable and so the flow of resources to R & D activities will be far smaller than is optimal from the point of view of the community. The small amount of basic research carried out by private firms is probably attributable to this phenomenon. Patents are designed to remedy this defect in the market mechanism. By giving the inventor exclusive rights over the financial fruits of the product of his research, it is intended to eliminate free riders for the life of the patent. Thereby, it is hoped to restore the financial incentive for investment in R & D. A secondary purpose of the patent system is the encouragement of disclosure of new inventions. The law requires that patented ideas be made available to the public, thus enabling the fruits of the invention to percolate to the entire society."[Braunstein et al.(1980)]

The above description of the patent system is but one method of governmental intervention in the process of national R & D. Governmental intervention in the process of innovation has been found essential for a healthy R & D scenario. Beside the free- rider problem, the huge amounts of uncertainty that R & D processes are beset with introduces imperfections in the market economies [Arrow (1962)]; and under such conditions relying on market forces alone for the allocation of resources to R & D will lead to suboptimal allocations.

In order to augment the R & D process, it is necessary for the government to intervene into it. Because of uncertainties and risk, the market for R & D is an imperfect market that cannot be relied upon for optimal allocation of funds for R & D. For instance, private industry in the US devotes nearly 3/4 of its R & D budget to design and development, and only about 1/4 to relevant basic research and applied research. This bias is perhaps it is not possible to predict who will be the ultimate beneficiary of relevant basic research and applied research.

Thus, governmental intervention becomes imperative to correct market imperfections. This intervention may be of two types: active and passive. Active intervention includes the direct actions of the government to improve the R & D process, like its direct investment on a set of projects which it thinks is either essential for national goals or is being neglected by the private enterprise. This intervention is bought about by setting up Government owned/funded laboratories; sponsoring projects in the private industry; and, sponsoring projects in the universities. This form of intervention, though prevalent in industrialised countries, has been the thrust of R & D progress in developing countries where there is no market worth speaking of to encourage private investment in R & D.

Passive intervention by the government in the process of R & D consists of enacting laws and regulations to encourage investment in R & D. The patent system described above could be thought of as being a passive intervention by the government to eliminate the free rider problem and encourage disclosure of new inventions. Other passive interventions include, say, providing tax rebates for investment in R & D activity [for e.g. section 35(a), of the

Indian Income Tax Act (1974)]; enacting suitable laws for bans on import when a satisfactory indigenous product is available, etc.

SOCIAL RETURNS ON INNOVATIONS

Besides the necessity of governmental intervention in the production of innovations, the government is also responsible for its usage and the relative social costs one incurs to obtain an innovation. It thus, becomes essential to measure the benefits and costs of innovation, in order that proper institutions are designed to monitor the costs and benefits of R & D programs in the country.

"To make rational decisions concerning the allocation of resources to technological innovation, information is badly needed concerning the returns that society has obtained - and is likely to obtain in future - from investments in new technology. To estimate the social benefits from an innovation, economists have used a model of the type illustrated in Figure 7.2. If the innovation results in a shift downward in ;the supply curve for a product ( such as from S to S' in the figure ), they have used the area under the products's demand curve (DD') between the two supply curves - that is the shaded area in the figure - as a measure of the social benefit from the innovation during the relevant time period. If all other prices remain constant, this area equal the so social vale of the additional quantity of the product plus the social value of the resources saved as a consequence of the innovation. Thus, if one compares the stream of R & D and other inputs relating to the innovation with the stream of social benefits measured in this way, it is possible to estimate the social rate of return from the investment in the innovation." [Braunstein et al.(1980)]. Griliches(1957) for e.g. uses this method]. Estimates of the social rates of return generally have been, happily, on the higher side; 37% (Griliches) and 56% [Mansfield et al.(1977)]

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