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SCIENCE, TECHNOLOGY, SOCIETY AND INNOVATION

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1. INTRODUCTION

The aim here is to present an overview of Science and Technology and their inter-relationship in the context of Society. This overview will utilize one of the main features of the scientific method, viz., its construction of models, to analyse the interactions between Technology and Society and between Science and Technology, and to represent the process of innovation which is the sequence of steps to transform an idea into a product or service in the economy.

2. TECHNOLOGY-SOCIETY INTERACTIONS

The starting point of the present analysis is the view that both Technology as well as the productive apparatus of society (its industry, agriculture and services) respond to social wants*, which are in turn modified and transformed through a causal chain, or rather causal spiral. A deeper understanding of technology-society interactions is facilitated by the simple model shown in Figure 1.

Every society generates wants, and these wants can be satisfied through goods and services produced by industry, agriculture and the service sector either with available technologies or with new technologies developed by the institutions responsible for the generation of Technology, viz., the educational and scientific and technological institutions.

All social wants, however, do not necessarily receive a positive response. There is a process of <u>filtering</u> these wants, so that only some of them are transmitted as demands upon technological capability, and the rest are bypassed either by the productive apparatus not deploying available technologies or by technology-generating institutions not developing the required technologies. In other words, there are <u>ignored wants</u> that are not included in the product-mix of the economy despite the availability of technologies, or that the educational, scientific and technological institutions avoid in their research and development programmes even though the satisfaction of these wants requires the generation of new technologies.

The process by which a society arrives at a particular product-mix is outside the scope of this lecture -- it is a matter of conventional political economy. In contrast, the filtering process which results in a particular set of social wants being responded to with Science and Technology is important for the analysis here.

This filtering process is operated by decision-makers at four levels:

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*At this stage, the neutral word "wants" has been used quite deliberately. The conversion of "wants" into "demands" and the distinction between "demands" and "needs" is discussed later.

(i) the national level through the apportioning of national research and development budgets,

(ii) the agency or corporation level where each agency or corporation gives a specific orientation to its mission or charter,

(iii) the institutional level through the special emphasis given to various programmes, and

(iv) the individual level through the motivations, predelictions and capabilities of scientists and engineers.

All these decision-makers are either conscious agents of social and economic forces, or are unconsciously influenced by those very forces.

In untempered market economies, the forces are simple - they are the forces of the market-place. Only wants which can be backed up by purchasing power become articulated as demands upon the research and development institutions, and the remaining wants are bypassed, however much they may correspond to the basic minimum needs of underprivileged people. Thus, like all commodities in these economies, Technology too is a commodity, catering to the demands of those who can purchase it, and ignoring those who cannot afford it.

The generation of Technology involves the so-called "innovation chain" which is the sequence of steps by which an idea or concept is converted into a product or process. This sequence of steps varies with the circumstances, but can often by schematically represented thus:

Idea ----> Research ----> Development & Design ----> Engineering for Manufacturing ----> Manufacturing ----> Product/Process.

The step of Development and Design may include Pilot-plant trials and that of Engineering for Manufacturing may include Scale-up, Production/product/process engineering and Plant fabrication.

It is essential to note that socio-economic constraints and environmental considerations enter the process in an incipient form even at the stage of formulation of the research objective that evokes the idea, and then loom over the chain at several stages. These constraints are in the form of preferences or guidelines or paradigms, for example, "Seek economies of scale!"; "Facilitate centralized, mass production!"; "Save labour!"; "Automate as much as possible!"; "Don't worry as much about capital and energy (in the days before the energy crisis) as about productivity and growth!"; "Treat polluting effluents or emissions as externalities!"; "Only worry about the unit cost of the product from the point of view of the entreprise, and let social costs, e.g., damage to community health or increased load on the transport system or exhaustion of non-renewable natural resources, be society's problem!"; etc.

Thus, every Technology that emerges from the innovation chain already has congealed into it the socio-economic objectives and environmental considerations that actors in the innovation chain introduced into the process of generating that Technology. Further, at a previous stage in the spiral the very decision to respond to a particular social want by generating the necessary Technology is the result of a deliberate filtering process wielded by decision-makers.

The Technology that emerges from the innovation chain will become an input, along with land, labour and capital, to establish an industry or agriculture or service if and only if the aforesaid socio-economic and environmental constraints are satisfied. Thus, it is not only the technical efficiency of the Technology, but also its consistency with the socio-economic values of the society, that determine whether a Technology will be deployed and utilized.

Social wants are not static. The products and services that are produced create new social wants, and in this process the manipulation of wants through advertising, for example, plays a major role, and thus the spiral:

Social wants ----> Products/services ----> New Social wants ----> .....

Since social wants, which are the driving force of technological development, are themselves transformed by Technology (and its embodiment in industry, agriculture and the services), it is clear that Technology shapes society.

The model also reveals that every pattern of Technology is socially conditioned. Technology is a product of its times and context, and bears the stamp of its origins and nurture. It is in this sense that Technology can be considered to resemble genetic material that carries the code of the society which conceived and nurtured it and, given a favourable milieu, tries to replicate that society.

The replication of society referred to above is neither automatic nor inevitable, it is successful only when a host of environmental factors are favourable - hence, the argument is not tantamount to technological determinism. Further, it has been emphasized that Technology itself is socially conditioned - hence Technology is not viewed as an autonomous factor and a motive force outside society. Of course, all this is obvious to archeologists who must proceed from the material products of Technology, i.e., tools, artifacts, etc., to reconstruct the vanished society and its culture, and to social anthropologists who cannot but consider technology-industry/agriculture-society interactions.

3. SCIENCE AND TECHNOLOGY*

The conventional view is that Science is the activity of understanding nature, and Technology is the activity of applying Science to bend nature to the will of human beings. Also, the outcome of Science is believed to be discovery and an understanding of nature, and the result of Technology, invention and the knowledge required to produce goods and services from natural resources.

This is too simplistic a view and it is necessary to study objectively what are the features that make Science similar to Technology as well as those that make it different.

Such an objective study requires that attention should be focussed on research where lies "the cutting edge of creation where new things are happening."

In both Science and Technology a special value is attached to creativity which invariably consists of combining ideas in interesting ways that do not strike most people.

Competition is a major incentive in both Science and Technology -- the biggest part of the motivation in a technologists or a scientist is "getting there first, before the other fellows."

What is the criterion of having got there first? In Science, it is first publication; in Technology, it is first appearance of the product/process/system in the economy. A scientific activity ends therefore with a publication; a technological activity culminates with publicity for the end-product/process.

In Science, the more openly you publish, the more secure is your claim; in Technology, it is otherwise, the more protective and/or secretive you are till the product or process is implemented (after which you must advertise to sell the product/process as much as possible), the greater the exclusivity you maintain on your property.

Thus, the different outputs of Science and Technology can be used to distinguish them -- if the main outcome of research is knowledge which has to be published openly for priority to be established, then the activity is Science, but if the result of effort is a product or a process which can be bought or sold then the activity is Technology.

The inputs for Science and Technology are also different -- the input to a scientist are all the papers produced by his colleagues and their predecessors ("Each scientific paper seems to build on to about a dozen previous papers."); the input to a technologist is mostly the body of previous innovations and knowledge rather injection of any new scientific knowledge. That is why there is a research frontier in Science, and a state of the art in Technology.

Despite these differences in inputs, the patterns of exponential growth are similar -- under conditions of normal growth, Science begets more Science, and Technology begets more Technology.

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* Quotes in this section are from Reference #3.

The analysis must now shift its focus from Technology- Society interactions to the the relationship between Science and Technology.

This interaction (Figure 2) between Science and Technology takes place through the innovation chain which converts an idea into a product or process. The generation of Technology, i.e., the passage through the steps of the innovation chain, has to be based on an understanding (even of an empirical nature) of the laws governing natural phenomena, including the properties and behaviour of materials, and the process of transformation of substances. If this understanding already exists, then Technology thrives on known Science, but if the relevant aspects of nature are not understood, then Technology throws up basic problems along with a pressure for their solution. Under this pressure, the fundamental questions of Technology become a dominant concern of Science and lead to new knowledge.

But Science is also propelled along by its previous pre- occupations and by the carried-forward balance of unsolved problems. Thus, <u>Science develops through the interplay between the momentum of its past concerns and the continual challenges posed by Technology</u>.

Both these driving forces are invaluable. In the absence of an internal dynamic arising directly from previous work and indirectly from its whole history, Science will become a subservient slave of Technology, rather than an independent ally able to summon accumulated wisdom to cope with the frequent changes in technological goals. In the absence of a technological pressure, Science will be deprived of the invigorating effect of new challenges. For, as social demands change, the goals of Technology alter, the basic problems which Technology poses become different, and fresh scientific tasks arise.

Technology, therefore, is a stimulus to Science and produces the changes in its principal foci of interest. The effects of technological stimuli are amplified through the distribution of funding over the different fields and sub-fields of Science because this distribution is usually strongly influenced by the distribution of funding over the various areas of Technology.

Technology nourishes Science, not only with relevant basic problems, but in a concrete way with materials, fabrication techniques and scientific instruments to tackle these problems. These materials, techniques and instruments are supplied by Technology to Science via industry. Thus, the scientific instruments industry has assumed a commanding influence over Science. There are even situations and periods when it is not clear whether the demands of scientific research evoke the supply of scientific instruments, or the production of instruments creates a demand for them and enforces specific types of enquiry. Indeed, the distortion of research by instruments would be more commonplace were it not for the fact that technological pressures are a powerful orienting force on Science.

It must be concluded, therefore, that Science and Technology are in interaction with each other. This interaction serves to keep the two growths in phase, and makes the exponential growths of Science and Technology parallel each other. Further, since Technology and society are closely coupled, it follows that Science also is socially conditioned, albeit indirectly. But, the influence of society over Science is much weaker than its impact on Technology because the internal dynamism of Science makes it more autonomous and confers upon Science its international character. Technology, on the other hand, is a function of the socio-economic conditions of a society, and therefore much more national in its complexion.

The fact that Science and Technology are relatively loosely coupled suggests that "without a live tradition of Science you cannot engage in technological growth". This fact also leads scientists -- in times of scarcity of funds -- "to promise them Technology, make good if you must, but really give them the pure learning that you want and you know they will need in the end." Moreover, the coupling suggests that we "can adopt a Science for Science's sake policy provided we are clear that this can always be justified by the .... vital link with Technology. We need Science so that technologists may grow immersed in it".

The loosely connected systems of Science and Technology operate "with very different types of people involved for very different motivations and purposes and even trainings."

Further, in Science, only about 20% of the human output of the educational system is recycled back into the educational system; the other 80% are hired by society to do various jobs in Science and Technology. "For every man in the universities that does research and replicates himself at the rate of exponential growth with fresh Ph.D. students there are four or so who work in industry or in government making the things that society wants to buy." There are four technologists produced by the system for every scientist, and in the industrialized countries, about 4 times as much is spent on creating new products/processes as on generating new knowledge.

Finally, it is important to realize that the product/process-mix that emanates from Technology is a function of the country. "In Technology, society can buy what it wants up to a set maximum. In Science you have to buy, more or less, what nature will give you, in quantity as well as quality. In Science, even though society pays, there is still some sort of impersonal dedication to nature's rules. In Technology, there is always something more than the competition. You are supplying something that society wants to buy, and you must be careful that it is something that you want to give your life to make." A technologist therefore has "a citizen's responsibility to judge where to put his weight. All citizens must be clear that they constitute the society that has the power to buy or not to buy any given Technology." Revulsion against the use of technologies must be directed "at the ordinary political processes whereby society decides it wants to buy such a product."

4. THE INNOVATION CHAIN

Before proceeding further, it is worth going deeper into the transformation of research into technology and the process of innovation.

Innovation is distinguished in the literature on the study of Science and Technology from invention even though these two terms are used interchangeably in ordinary language. The term innovation is used to describe the process of transforming an idea or concept into a product/service in the economy. It includes much more than the term invention which is usually restricted to the process of going from an idea or concept to a contrivance or prototype or design. Innovation must involve in addition to invention the crucial process of commercializing or installing the product or service in the economic activity of the country.

The process of innovation can be represented -- as pointed out above -- by the so-called innovation chain which is the chain of steps leading from an idea or concept to a product/service in the economy. The exact sequence of steps depends upon the sector -- industry, agriculture, transport, education, health, communication, etc. In the case of manufacturable product or service, one possible sequence of steps may be as follows:

Idea/Concept ----> Relevant Basic Research ----> Applied Research ----> Development & Design ----> Engineering for Manufacturing ----> Manufacturing ----> Marketing ----> Product/Service

In this model of innovation, Relevant Basic Research (RBR) refers to the synthesis or assembly of understanding relevant to the technological objective; Applied Research (AR), to the activity of demonstrating the technical feasibility of the synthesis of understanding leading to a new product/service; Development and Design (D&D), to the activity of coming up with a version of the new product/service that will "work" in the economy, i.e., that meets performance, reliability and economic requirements; Engineering for Manufacturing (EfM), to the activity of demonstrating that the working product/service can be manufactured at a price acceptable to the economy. The output of RBR is new concepts/materials, that of AR, a feasible device/technique, that of D&D, a working device/technique/system, and that of EfM, a manufacturable device/system:

Concept ----> Feasible Device ----> Working Device ----> Manufacturable Device

The process of research covers Relevant Basic Research and Applied Research, and "development" covers Development & Design as well as Engineering for Manufacturing :

Research = RBR + AR
Development = D&D + EfM
R & D = RBR + AR + D&D + EfM

The research part of an R&D organization has two functions:

(1) it generates relevant research,
(2) it recognizes relevant research wherever it is done.

Obviously, the fraction of research that is internally generated must depend on the size of the organization -- the smaller the organization, the smaller the fraction of research that is done internally or "in-house", but this fraction should not be "zero", because "you can't get from the general pool of research without giving something back".

An invention consists of the prototype after development and design, and the technology for the product is the result of research, Development and Design, and Engineering for Manufacturing. But, an innovation is achieved only when the product turns up in the economy. Innovation, therefore, is a much larger task than both Invention and Technology.

The RBR --> Technology system consists of the whole sequence of steps consisting of:

Relevant Basic Research ----> Applied Research ----> Development & Design ----> Engineering for Manufacturing ----> Technology

with each of the steps having special functions, distinctive outputs and measures of performance.

The sequence is not merely a succession of steps, but a system with forward-action from step to step as well as feed- back. It is a system based on people, and what the system handles is information which is passed from stage to stage via the people involved in these stages. Thus, the RBR --> Technology system is a people-based system for information processing, the information flow being affected by: (1) language, (2) motivations, (3) organizational structure, and (4) the accessibility of people. Speaking the same language is obviously a necessary condition for communication.

Another necessary condition has to do with motivations and aspirations. Commonness of goals, leading to the feeling of a shared mission, makes people want to communicate with each other. The definition of the corporate or group goal has to be achieved by making a synapse or conjunction between the knowledge of need(s) and the knowledge of possibilities, but once the goal is defined, the group needs that it implies must permeate the consciousness of individuals. Then, each person in the group can scan his area of expertise and look for those areas and solutions that are most relevant to the goal. Indeed, if the goal is challenging and worthy of pursuit, then the members of the organization have no trouble picking the relevant job and choosing the area of relevance. In this matter, both the societal and the technical nature of the corporate/group goal are extremely important. The formulation and propagation of the purposes of the R&D organization (provided these purposes are broad and challenging enough) does not inhibit the freedom of the members who work there. They still have and make choices but they do this on a conscious basis with the full knowledge of whether their choices are relevant or not. They also play their roles in educating the group by communicating with their colleagues. Thus, sharing the same motivations and aspirations by virtue of a common goal is another necessary condition for the desire to communicate.

But the conditions of a common language and goal are not sufficient, because the flow of information between any two stages also depends upon the organizational relationship between the two stages and their spatial disposition with respect to each other. In fact, the organizational relationship between the two stages and their relative spatial disposition can be so arranged as to either facilitate ot hinder the flow of information. In particular, communication is greatly facilitated both by proximity ("being able to have coffee together") and belonging to the same organization.

These ideas can be used as a basis for the linkages between the successive stages in the RBR --> Technology system. For instance, consider the relationship between RBR and AR stages. There must be feedback so that RBR maintains its relevance, and this can be facilitated by a spatial bond between RBR and AR. However, AR must not be allowed to dictate the choices of the researchers in RBR -- hence, it is sensible that an organizational barrier be interposed between AR and RBR.

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  ---SPATIAL----
        X
RBR     X      AR
        X
   org. barrier
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With regard to the AR and D&D stages, a spatial barrier is important to prevent D&D from over-influencing the directions of AR, but at the same time, an organizational bond will ensure that AR will be responsive to the problems of D&D.

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  --ORGANIZATIONAL----
          ][
AR        ][         D&D
          ][
    spatial barrier
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Finally, in the relationship between D&D and EfM, an organizational barrier is essential to prevent manufacturing crises from stopping D&D, but at the same time the overall efficiency would be improved by a spatial bond to link R&D to manufacturing.

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  ----SPATIAL------
         X
D&D      X       EfM
         X
    org. barrier
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Thus, the whole RBR ---> Technology system can be represented thus:

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BOND          ---SPATIAL-------ORGANIZATIONAL--------SPATIAL----
                    X                ][                 X
STAGE      RBR      X      AR        ][       D&D       X       EfM
                    X                ] [                X
BARRIER            org            spatial              org
```

The possibility of control over information flow through the steps of the innovation chain permits control over the efficiency of the RBR --> Technology system. The guidelines are:

(1) information flow is virtually prevented if there are both organizational and spatial barriers between two stages -- hence, both types of barriers must never come together;

(2) information flow between two stages is maximized if there are both organizational and spatial bonds, but if one of the two stages is organizationally more powerful, the flow will be biased in its favour;

(3) a barrier of one kind must always be accompanied by a bond of the other kind to get the desired flow of information.

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