MEASURING CONTRIBUTION OF TECHNOLOGY FOR POLICY ANALYSIS

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Abstract

Technology is nowadays considered as an important strategic variable for development. The growth of the developed economies is said to be due to productivity enhancement which is largely attributed to technological innovation. Thus the need emerges for a fuller understanding of the contribution of technology. For improved decision making a new set of technological data will have to be made available and a reorientation of traditional thought will have to be fostered.

In the economic production context, technology is simply a means for achieving transformation of available inputs (natural resources and semifinished goods) into desirable outputs (consumer, semifinished and capital goods). To gain a better insight into the role of technology in economic development, it is necessary to view technology as comprising of four embodiment forms (object-embodied physical facilities; person-embodied human abilities; record-embodied documented facts; and institution-embodied management techniques) which interact dynamically at any production system.

A framework for measuring the contribution of the four embodiment forms of technology in a production system is presented in this paper. The procedure requires an assessment of the status and interrelationships of the individual components of technology being utilized by a firm vis-a-vis the best practice elsewhere and then to determine the overall "technology contribution coefficient" (TCC) of the transformation operation. The paper suggests the use of the TCC measure for assessing the technological capability of a production system. A careful analysis of the interaction among the four components of technology in relation to the market and policy environment may lead to a better understanding of the technological behaviour of firm with significant policy implications. For such an analysis, the "systems dynamics" approach is considered to be suitable because of its ability to deal with complex, interacting and dynamic behaviour of the variables.

Introduction

The role of technology in economic growth has long been accepted in the context of industrialized economies. It has been said that, for good or evil, economic growth draws its vital nourishment from technology without which -- no matter how favourable all other factors might have been -- modern development would have been essentially inconceivable. Many attempts have been made to assess the specific contribution by technology to economic growth. According to one analysis [Choi 1987] over 87% of productivity growth in the United States between 1950 and 1980 was due to technological improvements, while another [Hirono 1985] estimates it to be between 30% and 56%. In spite of these differences, it may be said that technological progress has enabled the United

States to become a highly industrialized and developed nation. In the case of Japan, it has been estimated that nearly 29% of growth in the manufacturing industry (overall) between 1955 and 1979 could be attributed to technological innovation [Hirono 1985]. The same study also shows that the corresponding value for the machinery industry was 40%. It has been further estimated [Subramanian 1987] that technological progress could conribute as much as 65% to the economic growth of Japan in the 1980s. In fact some writers have even referred to technology as the "wealth of nations".

The strategic importance of technology has been accepted for other reasons as well. The ever increasing materialistic aspirations of the people caused by the global mass-media and the impossibility of self-sufficiency due to resource and time constraints have made international trade a must for sustainable socio-economic development. The recent experiences of the newly industrializing countries clearly indicate the declining significance of comparative resource advantage and the growing importance of attaining a technology-based competitive edge in the international marketplace. It is also clear that, although economic performance in recent years has been particularly impressive for many developing countries, sustaining higher growth rates will require achieving competitiveness in high technology content products that are becoming increasingly important in world trade [Sharif 1988a]. All developing countries are therefore keen to introduce a strategy of technology-led competition for sustainable export earnings.

The technological capabilities of a country reside in its production system. Therefore, capability enhancement must necessarily be considered in the production context, where the purpose of technology is to transform available inputs (natural resources and semifinished goods) into desirable outputs (consumer goods, semifinished goods and capital goods). It should also be recognized that, technological capability enhancement is a progressive process starting with the utilization of existing mature technologies; adaptation of evolving technologies; introduction of emerging technologies; and eventually leading to the production of state-of-the-art technologies.

Technological capability assessment, and the conditions that will enhance national performance in industries where technological competitiveness is important, are of widespread interest these days in developing countries. However, these analyses must pinpoint technological weaknesses which could be remedied so that national technological capability could be enhanced. In this presentation an attempt is made to describe a preliminary methodology for assessing the technological capability of production units in a developing country. It may be noted that if the proposed approach is to be used for policy analysis in a meaningful way, the dynamic behaviour of the variables and the the incorporation of the manifold loops of the real-world system that influence them need to be incorporated into the analytical framework. The use of a "systems dynamics" approach could greatly facilitate such an assessment. In the subsequent sections of this paper, firstly, an attempt is made to disclose the "technology black-box". This is followed by the introduction of the concept of "technology content added" at a production facility and its significance for technological capability development is highlighted. In conclusion, the usefulness of the systems dynamics approach for evaluating the dynamic behaviour of production systems from a technology capability development perspective is pointed out.

Disclosing the Technology Black-box

Technology, from the point of view of production, is still commonly perceived to be only the physical means used for transformation. As such the importance of other related elements such as skills, information and organizational arrangements for effectively using the physical means for production are often ignored when technological aspects are examined. Therefore, to facilitate a thorough understanding and for effective decision-making, it would be useful to disclose the technology black-box. One possible way of doing this would be to decompose technology into its embodiment forms.

Technology, from a production perspective, could be defined as the totality of means employed for production [Sharif 1988b]. It has four embodiment forms: (i) Object-embodied physical facilities (eg. equipment, machines, factories), called technoware, which changes through a process of substitution and diffusion; (ii) Person-embodied human abilities (eg. skill, expertise, proficiencies), called humanware, which changes through a process of upgradation; (iii) Record-embodied documented facts (eg. specifications, designs, manuals), called inforware, which changes through a process of revision and addition; and (iv) Institution-embodied organizational frameworks (eg. linkages, practices, techniques), called orgaware, which changes through a process of evolution. In this paper henceforth technology will be viewed based on this four component definition.

Technoware enhances muscle-power and brain-power. Humanware generates, operates, maintains and improves technoware and inforware. Inforware stores systematized knowledge for time compression by humanware. Orgaware makes any economic endeavor effective by coordinating the interactions among technoware, humanware, inforware and the market.

All four components of technology (technoware, humanware, inforware and orgaware) interact dynamically. All four components are complementary and are required simultaneously in any production transformation operation. In the present-world economic production context, attempting resource transformation without any technoware is impractical; without any humanware, technoware is idle; without any inforware, humanware is inefficient; and without any orgaware, there is no harmonized action and hence transformation is ineffective.

It may be relevant to state here that economists, who have raised the role of technology in production and growth to elevated levels, decompose technology into "embodied" and "disembodied". They state that technology may be embodied in machines (technoware) or people (humanware). Embodiment in people, better known as human capital, includes managerial and entrepreneurial capacities as well as worker skills. The disembodied part refers to some facets of what has been mentioned as inforware and orgaware. According to economists, disembodied technology raises productivity and growth without any addition of or more than proportionately an increase in constant-capacity men and machines.

Degrees of Sophistication

If real life production activities are examined, it is possible to perceive increasing degrees of sophistication within each component of technology in different parts of the world. Such variations in the degree of sophistication, within each component, comes about due to four reasons. Firstly, increased operational complexities lead to the need for the development and usage of technoware with higher degrees of sophistication. Secondly the increased requirements of skills needed to develop, improve, install and operate technoware of varying degrees of sophistication also requires humanware with appropriate sophistication. Thirdly, as the degrees of sophistication of technoware and humanware increase, the sophistication of inforware required to guide the use of these also increases. Lastly, as a production system attempts to increase the quantum and scope of its operations, the organizational linkages, practices and arrangement techniques required could become increasingly complex and thus greater sophistication may be required in the orgaware to effectively integrate technoware, humanware and inforware.

Technoware sophistication is represented in the increasing integration of additional functions in plant and equipment for increasing productivity and for carrying out specialized production activities. One possible classification and examples of increasing degrees of sophistication of technoware could be as follows:

- Manual and powered tools and equipment;
- General purpose machines and other similar facilities;
- Special purpose machines and other similar facilities; and
- Computerized and robotized facilities.

Humanware sophistication is achieved by the amplification of creativity through continuous education and training which eventually results in increased organizational efficiency. One possible classification and examples of increasing degrees of sophistication of humanware could be as follows:

- Ability to operate production facilities;
- Ability to acquire, install and repair facilities;
- Ability to manage production and marketing functions; and
- Ability to perform R&D and innovate production systems.

Inforware sophistication is reflected in the accumulation of knowledge through the collection, processing, dissemination and use of information which are of economic value and which are needed to sustain and strengthen production activities. One possible classification and examples of increasing degrees of sophistication of inforware could be as follows:

- Information needed for the acquisition of suitable technologies;
- Manuals needed for the optimal operation of production systems;
- Facts and figures needed for the maintenance of facilities; and
- Theories required for assessing and improving enterprise operation.

Orgaware sophistication is indicated in the expansion of inter and intra organizational transactions needed for enhancing competitiveness, growth of market share and diversification. One possible classification and examples of increasing degrees of sophistication of orgaware could be as follows:

- Experience-based traditional organizational arrangements and practices;
- Education plus experience-based conventional organizational arrangements and practices;
- Systems analysis and optimization tools and techniques based arrangements and practices; and
- Computers and communication networks based organizational arrangements and practices.

Interactions and Choices of Technology

The demarcation between two consecutive degrees of sophistication of each technology component may sometimes be blurred; but in every case the sequence of a stepwise increase in sophistication can be perceived. For any pproduction activity a certain minimum degree of sophistication of each component of technology (technoware, humanware, inforware and orgaware) is required. The choice of technology depends upon the characteristics of the production activity, the interrelationships among the various degrees of sophistication of the four components and the market opportunities (both national as well as international). Some observable interrelationships among technology components are as follows:

* With the increase in the degree of sophistication of the technoware, the required degrees of sophistication of inforware and humanware are likely to change considerably because high-degree technoware will have many built-in control and monitoring features.

* With the increase in the degree of sophistication of humanware, inforware can be self-generated and the utilization of technoware is improved as it becomes easier to master the usage and assimilation of acquired technoware.

* With the increase in the degree of sophistication of inforware, better choices of technoware and humanware are possible, as improved inforware facilitates a thorough understanding of available technological alternatives.

* With the increase in the degree of sophistication of the orgaware, the effectiveness of technoware, humanware and inforware are all increased, as improved orgaware leads to better links with the market, quicker response to changes in the business environment and and better coordination of internal activities.

For any production activity, there is a wide range of possible choices between the required minimum level of sophistication and the available maximum level represented by the state-of-the-art. However, the selection of the four components are interrelated because the specific characteristics of a production transformation operation are collectively determined by:

- the minimum starting degree of sophistication of technoware necessary;
- necessary minimum degree of sophistication of humanware needed to handle the technoware selected;
- the degree of sophistication of inforware required to match the humanware available; and
- the degree of sophistication of orgaware required based upon the technoware selected as well the attributes of the market place.

Patterns of International Technology Flow

It is known that under a free flow condition, gravitational forces pull all materials in one direction -- from a higher level to the lower level (towards the center of the earth). However, under a free trade situation, market forces pull components of technology in different directions. Furthermore, most technology flows occur among developed countries. Generally, some technoware and orgaware concepts are observed to flow from developed to developing countries. But, humanware and inforware normally flow from developing to developed countries. This is because, internationally, business imperatives rather than welfare motives dictate the direction of technology flow. Even if the flow direction can be partially controlled by external forces, the following observations can be made:

* Technoware, other than the state-of-the-art, can normally be bought internationally for a price determined by the relative bargaining position of buyers and sellers. Less sophisticated imported technoware may very often require quite sophisticated humanware to operate it for quality production.

* Humanware can be imported temporarily, and success in acquiring this ability depends primarily on local learning capability. When humanware is well developed in any particular area of prdduction, importing technoware can be a very effective option for reducing the technology gap.

* Inforware, beyond the level of simple operating instructions, is usually not given to the ordinary technoware importer. Since technoware production costs money and involves risks, critical information, especially inforware with higher degrees of sophistication, is closely guarded for cost recovery and profit making. Thus, importing inforware may be more expensive than the cost of technoware import.

* Orgaware from abroad cannot be easily transplanted in the local environment and needs considerable adaptation to suit local working conditions. Many large enterprises in developing countries are established through external financing and managed directly or indirectlt by transnational corporations (TNCs). As the TNCs use very sophisticated orgaware, the host organizations in the developing countries (which did not have the opportunity to gradually evolve its orgaware through various degrees of sophistication), becomes dependent on foreign experts and the linkages of the external organizations.

Technology Contribution and Content Measurement

Every production transformation operation carried out on selected inputs, using a chosen technology, to produce the desired outputs, enhances the value of inputs. This enhanced value of the outputs over that of the inputs, when measured in monetary terms, is the economic value added. Similar to this concept of economic value added, one may attempt to develop a technological measure called technology content added. It can be said that, technology content added by any production transformation operation is the difference between the technology content of the outputs and inputs.

It may also be noted that, the interrelationships among the four components of technology and their successive degrees of sophistication have many implications with respect to possible trade-offs and choices. Furthermore, since all four components of technology are so closely interrelated any deficiency or weakness in one can reduce drastically the contribution of other components to the production process.

Since technoware (T), humanware (H), inforware (I) and orgaware (O) are the elements which jointly contribute to the technology content addition, it is possible to state that a production facility utilizing components of technology with high levels of sophistication would be contributing more towards technology addition than one utilizing components with lower degrees of sophistication. Thus, it may be said that:

Technology Contribution Coefficient (TCC) = Function of (T, H, I, O)

$$TCC = \alpha \, T^{\beta_t} . H^{\beta_h} . I^{\beta_i} . O^{\beta_o}$$

where, T,H,I,O represent numerical values of the degrees of sophistication of the four components at a production facility normalized with respect to the state-of-the-art, α is the technology climate factor and β's reflect the relative importance of each of the components ($\Sigma\beta=1$).

The TCC value may be interpreted as the technology content added per unit output. The multiplicative function suggested above is intuitively appealing because it implies that all four components of technology are simultaneously needed at any production facility to carry out the transformation operation. The values of T, H, I, O, for any firm can be evaluated by determining the minimum requirements and the position of the current practice with respect to the best practice elsewhere. The α and β values can be estimated using factor analysis and expert preference analysis. The operationalization of this approach has been illustrated in the case of the iron and steel industry [Ramanathan 1988]. The TCC value of a transformation facility when viewed in relation to the output can provide a good indication of existing technological capability.

Framework for Technology Policy Analysis

Moved by the urgency and enormity of the problems faced by developing countries, governments are seeking ways and means to integrate technological considerations in the development planning process with a view towards accelerating the economic development process. In this context, the use of the concepts mentioned above could be used to assess technological capability. To carry out such an analysis the methodology suggested in the previous section for measuring contribution of technology at the firm level can be integrated into a systems model which can relate the technological and economic attributes of a productive sector, industry or an industrial sub-sector. The model has to incorporate the dynamic interactions among the four components of technology and the market. Only with such an analysis can important decisions be made for the mobilization of scarce resources.

It may be useful, for instance, to relate the degree of sophistication of technoware needed at a production facility in terms of not only the market requirements, scope of operations required, handling required, precision required in managing the operations, control required over the operations and the intrinsic merit of the technoware itself which could make the choice attractive, but also on considerations related to national fiscal and financial policies and other government policy interventions. The degree of sophistication of humanware required could be investigated in terms of abilities required (such as operating, repairing, reverse engineering, adapting, improving and innovating abilities) which would be needed to make effective use of the technoware. The degree of sophistication of inforware needed could be studied in terms of the information required for utilizing, maintaining, upgrading existing technoware and for purchasing, designing and developing new technoware. The degree of sophistication of orgaware required could be analyzed in terms of market characteristics, product variety, workforce size and attributes, and the links needed with other support institutions. Figure 1 shows a hypothetical interdependence pattern among the four components of technology. This pattern could be useful in examining the interactions among the four components.

In an analysis based on the above considerations it should be possible to relate the technology contribution coefficient -- which is a good indicator of technological capability -- to market forces, the policy environment and trade-off considerations. This could help to provide useful information to national policy-makers to help achieve technology-based development. In such an analysis the strategy of the firm can also be incorporated.

In an increasingly interdependent world, it is important that the bi-focal strategies of industrialization - "import substitution" of consumer goods and "export promotion" of commodities be replaced by an integrated approach based on a "make-some" and "buy-some" technology strategy, and international trade be assessed from the point of view of technology content. Furthermore, in the context of a developing country, sustainable development calls for international technology transactions which are economically efficient, commercially attractive, and at the same time environmentally acceptable. For such an analysis, the "system dynamics" approach is attractive because of its ability to deal with complex, interacting and dynamic systems such as production systems upon which the economic future of a country depends.

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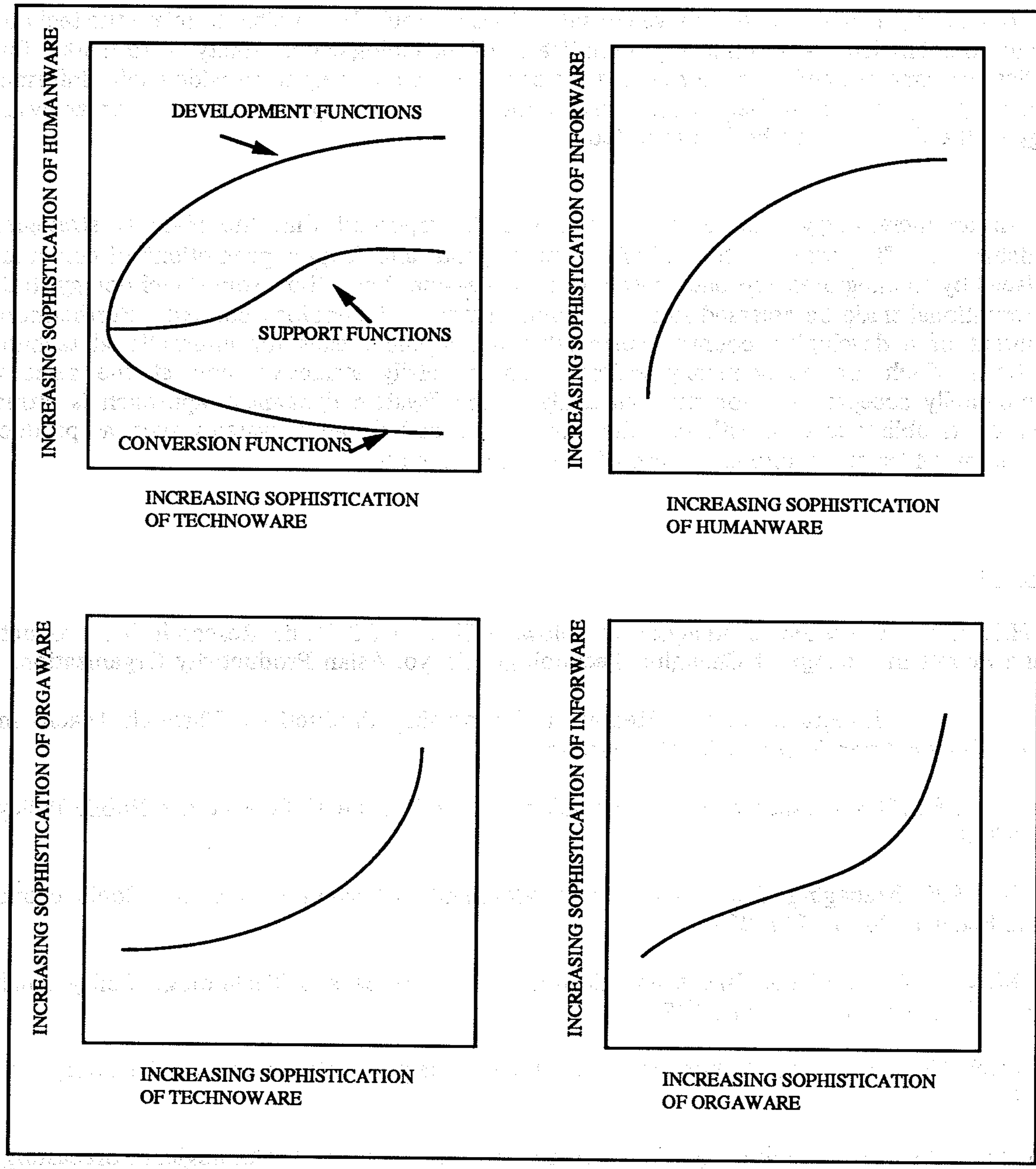

Figure 1: Interdependence Among the Components of Technology