Public Policy and Organization Design Considerations for Science and Technology Development*

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Abstract

This paper views the design of science and technology policy as a problem solving process rather than the facilitation of production of a good or a service. Viewed so, a clear and penetrating description of the problems to be addressed must precede any policy design effort. These problems may not be seen as snapshots in which a welfare element or a perceived technology ingredient is missing, but as a set of historical trends or a patterns that have defied policy intervention. The former view would invoke the design of a machine that would produce the missing ingredients whether or not they address a prevalent problem, the later would create operational agenda to alleviate the illusive problem. An attempt is made to define the problems requiring technological solutions and to offer a general policy framework to invoke those solutions.

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Introduction

The design of science and technology policy seems to be driven by a number of *a priori* assumptions:

- That technology is a panacea that would bring net prosperity to a people.
- That technology can be created and exchanged like a commodity.
- That technology would increase productivity whose benefits would transfer to public.
- That technology would alleviate any resource constraints.

There are indeed diverse experiences of performance of technology which have been evaluated in different contexts summarized in Table 1. The diversity of experience shown in Table 1 most likely arises from applying technological solutions irrespective of a problem context.

Table 9.1: Technology application contexts and experience

Technology application contexts	**Experience of technology implementations**
Resource Environment	Consuming, Polluting, Sustaining, Resource Efficient, Energy-based
Social Class Structure	Biased, Inappropriate, Appropriate, Dysfunctional, Disruptive
Factors Market	Economically Efficient, Labor Intensive, Capital Intensive
Industrial Relations	Labor Substituting, Employment Generating
Production Process	High Tech, Low Tech, Intermediate Tech, Efficient, High Productivity

This paper proposes that the design of a technology policy should be viewed as a problem solving process and not as a design of a production process. In this way, technology policy can be used as a lever for sustainable development with a more reliable performance and fewer surprises. The design of technology policy in this context would, however, require a careful effort to recognize problems to be addressed. Such problems must be defined as historical patterns that have been illusive to policy intervention. The problem must not be seen as creation of artifacts that have been observed to have yielded benefits elsewhere but are missing in a given context.

A learning framework for defining a policy problem

As pointed out in the report # ST/ESCAP/1771-1997 and Saeed (1998), the conceptualization of a problem requires the implementation of a learning process, which is also the key to implementing the subsequent steps involved in the system dynamics method. The subsequent steps include the development of a dynamic hypotheses, the construction of a model, the creation of the model understanding and the design of a policy for system improvement. I have also proposed in those writings that these steps should be built around Kolb's model of experiential learning drawing on the faculties of observation, concrete thinking, experimentation and reflection [Kolb 1984, Hunsacker and Alessandra 1980, Kolb, et. al. 1979, Kolb 1974, 1998].

The 8 steps shown in Figure 1 attempt to describe the learning process entailed in conceptualization of a problem to be addressed by a policy. This process incorporates two learning cycles, the first to identify the system boundary, and the second to construct a problematic pattern within that boundary.

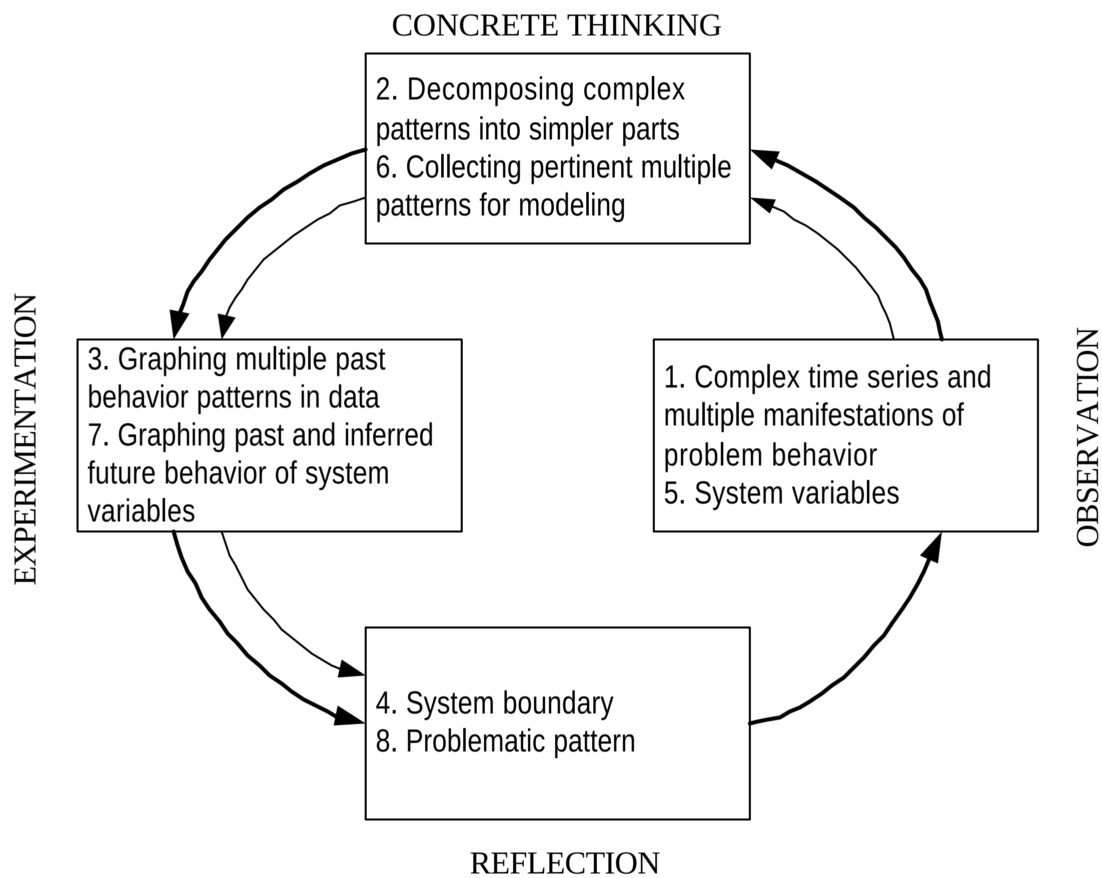

Figure 1 **Learning process guiding conceptualization of a policy problem**

One must begin by carefully examining historical information, both quantitative and qualitative, residing in the complex time series and event descriptions as well as in the multiple manifestations of the problem behavior in different periods and in different places. This is followed by thinking on concrete lines to decompose or slice observed complex patterns into simpler parts, which leads to experimental graphing of multiple simple patterns representing slices of the complex behavior we initially observe. A careful examination of the decomposed graphs helps delineate the system boundary in terms of the variables that must be considered to describe the discerned patterns. These variables may or may not be the same as in the historical data. Some of the variables in the data can be aggregated while others substituted by more abstract concepts, depending on the problem focus, the time horizon of interest and the policy space considered. The time horizon of a problematic patterns would invariably be longer than the historical information it is based on as it would include also information about an inferred future.

I have discussed the process of partitioning a complex problem in Saeed (1992). Since models representing problems cannot be made overly complex if they are to remain understandable, complex problems must be sliced into smaller parts so that the parts meet the requirements of the intended policy design. This calls for separating the *multiple modes* contained in complex historical information in a rather special way.

The term *multiple modes* is not new to system dynamics, although it is used a bit loosely. Not all classes of behavior implied by *multiple modes* may be relevant to creating a penetrating problem definition. In fact, many intuitively sensible schemes of partitioning a system may create models that do not incorporate policy space for investigating the possibilities of change. The *multiple modes* relevant to a problem may refer to the simultaneously existing components of a complex pattern of behavior that is exhibited by a system over a given period; they may represent patterns experienced over different periods of time in a system of relationships; or even patterns experienced in similar organizations that are separated by geographic space. The conceptual space in which *multiple modes* can be found is, therefore, three dimensional as shown in Figure 2.

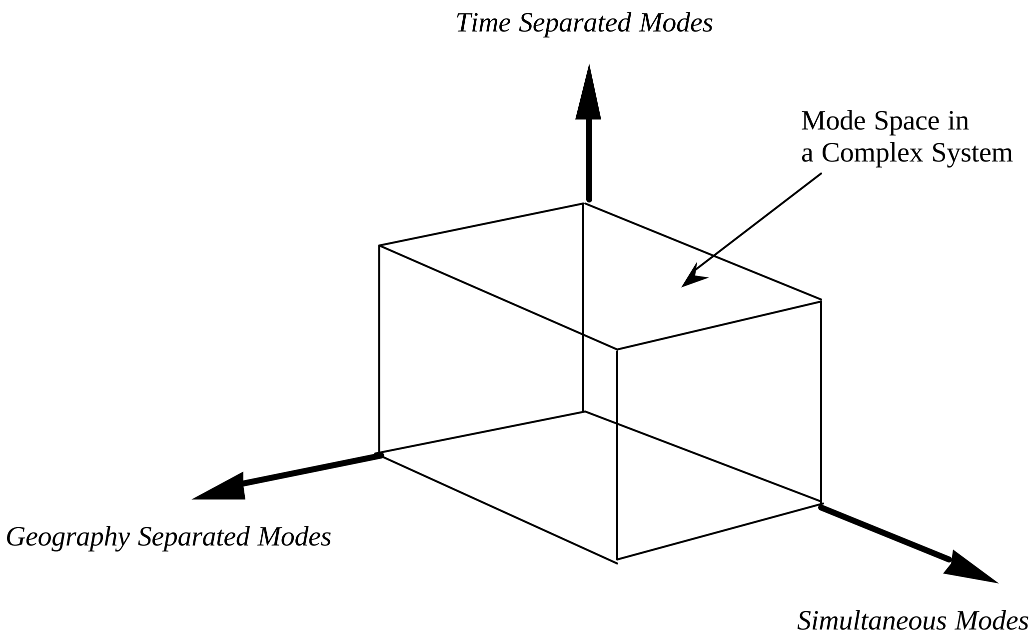

Figure 2 **Multiple mode space**

Source: Saeed (1996)

When multiple modes contained in a complex historical series are the focus of a modeling effort, the complex modal space will be sliced as shown in Figure 3. The simultaneous modes constituting the complex historical pattern will be subsumed in a selected partition while the variety of patterns in the temporal and geographic dimensions are ignored. Such a problem slicing process will create situational theories and forecasting models that may explain a unique and complex pattern, and also extrapolate it into the future, but that do not shed any light on the possibility to change it.

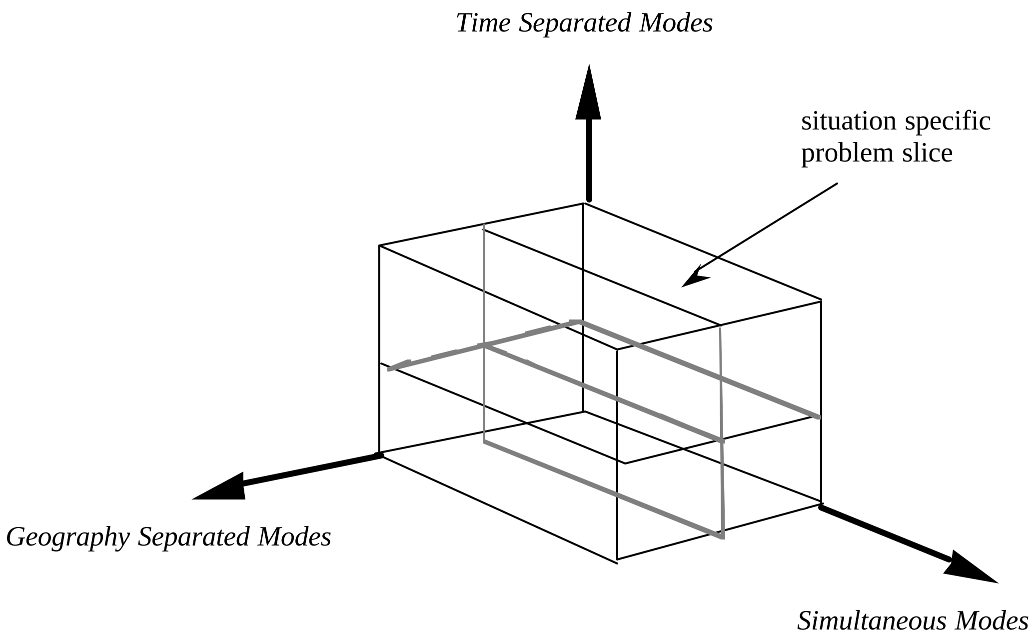

Figure 3 **Problem slices for developing forecasting models and situational theories**

Source: Saeed (1996)

On the other hand, when a model is intended for exploring policy options for system change, the complex modal space must be sliced as shown in Figure 4. The partition selected for modeling will subsume multiple modes that are separated by time and geography since only then its underlying structure would contain the mechanisms of modal change. It may not necessarily incorporate multiple modes that exist simultaneously in system behavior since interaction between the mechanisms creating these modes may not provide any additional policy space, although this may enhance a model's ability to track history accurately. When policy exploration rather than tracking history is the primary purpose of a modeling effort, simultaneously existing multiple modes and their underlying structure can be separated and addressed in different models for limiting complexity contained in a single model.

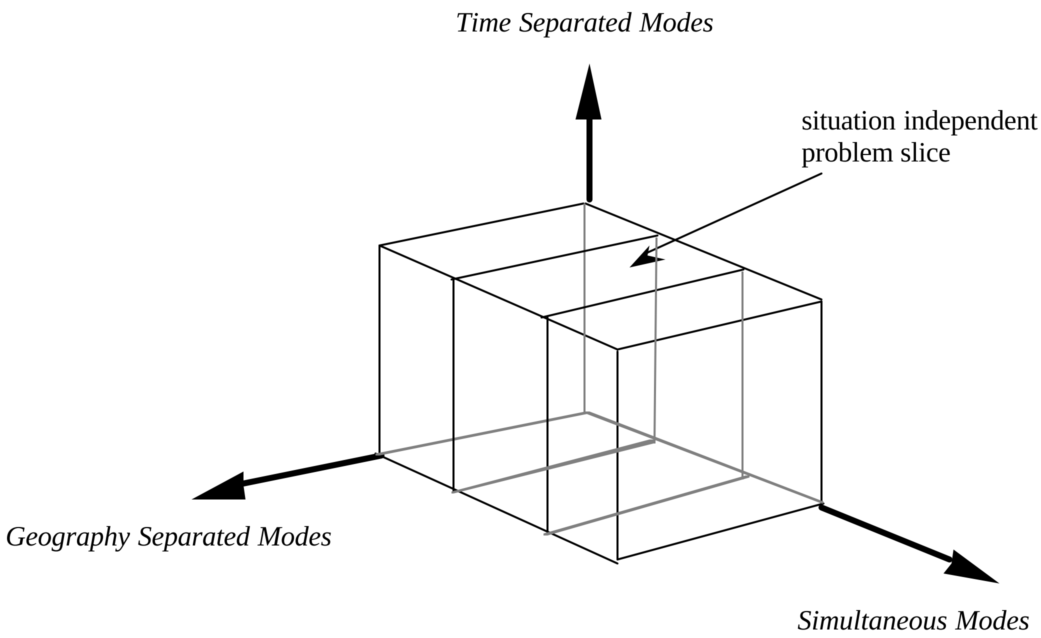

Figure 4 **Problem slices for exploring policy design**

Source: Saeed (1996)

Representing a complex problem as a number of submodels that produce behavior different from what appears in the historical data will require defining a problematic pattern differently from historical behavior. For example, each of the two complex time histories shown in Figure 5 contains a trend simultaneously existing with a cyclical tendency. To be able to address the two issues concerning the cycles and the trends, this problem may be represented by two models: One subsuming the multiple modes existing in the two trends, the other subsuming the cyclical mode existing in both of them. The two models so created will keep together the symbiotic processes underlying the potential multiple patterns thus providing the policy space to attempt a design for change. Also, the two components of the design so created can be pursued quite independently.

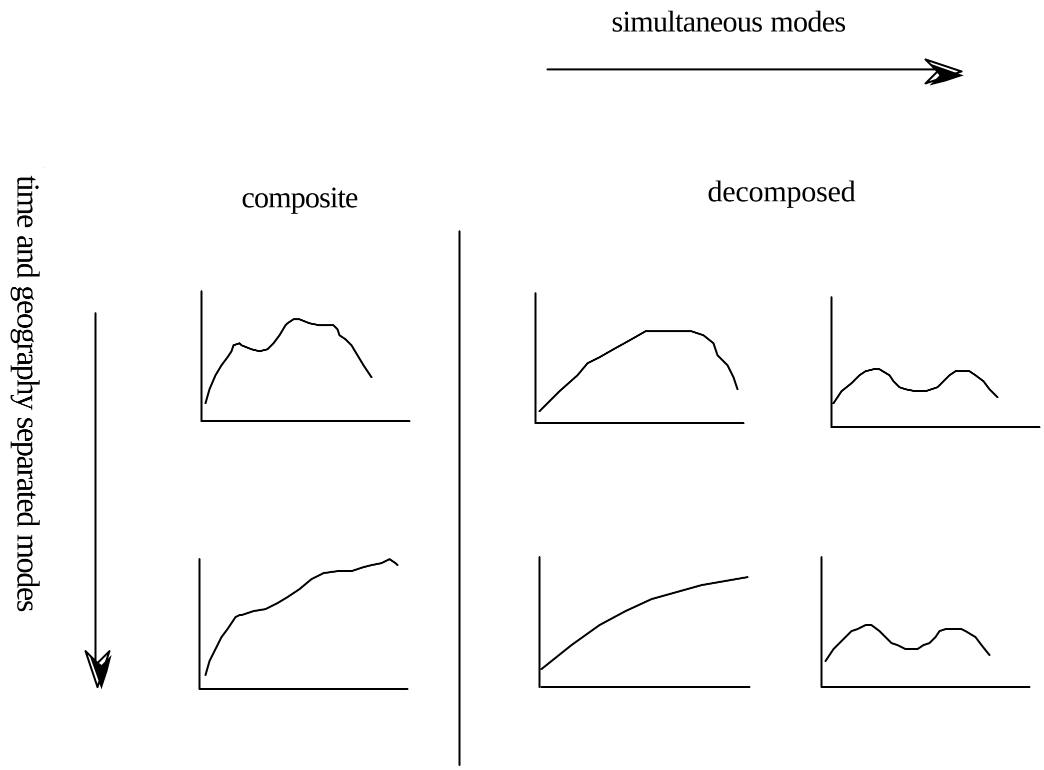

Figure 5 **Decomposing multiple modes for slicing a complex problem**

Source: Saeed (1996)

The second learning cycle begins with a careful examination of the variables discerned within the system boundary. These are then collected into groups representing multiple modes of behavior separated by time and geography. A second round of graphing past trends and intelligently projecting them into the future addresses system variables and their multiple modes. Finally, the drawn trends must be conceptualized as a multi-dimensional fabric - an abstract concept that represents a problematic pattern, which can be readily related to the information in the micro-structure domain for formulating a dynamic hypothesis and eventually building a model. A dynamic hypothesis constructed from such a problem description would often fall into an archetypal category since the decomposition process creates organized generic patterns discerned from situational unique patterns. A model constructed to represent this problem description would address multiple manifestations of the problem and would incorporate in it the policy space for transforming one pattern to another.

Four key problems for technology policy

Using above framework, I have identified four key problems for technology policy in my various earlier writings (Saeed 1994, 1998, 1998a, 1998b): 1) resource and environmental degradation, 2) failure of production and social organizations to create innovation to deal with a multitude of industrial and social agenda, 3) stagnating investment into the development of science and technology, and 4) a pattern of international trade creating transfer of scarce resources and value from the poor countries to the rich. Consequently, science and technology policy must focus on the following agenda:

1. The design of severance instruments to manage technological progress that fosters a rational use of natural resource and the environment to support a sustainable level of consumption.

2. The design of competent innovation organizations to maintain a level of technical competence to foster technological development.

3. The design of government incentives for fostering technological development in the private sector.

4. The design of global accords to facilitate bilateral transfer of value from trade in products, services, information and technologies.

I have discussed above problems at length using system dynamics modeling in my earlier writings. In the remaining part of this paper, I'll attempt to summarize my findings from those writings in terms of the policy frameworks developed in above four contexts.

Policy guidelines for creating sustainable resource use

Technological developments in the West have often been based on consuming the resource slack present either in the well-endowed territory from which the technology emerged or on resource availability through transfers from colonized lands. Application of western technologies in the precariously balanced resource environment of a developing country possessing little slack in it can be quite disastrous [Hardin 1985, Picardi and Siefert 1976]. I have suggested in Saeed(1985) and Acharya and Saeed(1998) that usable reserves depend on the technology that defines a usable resource basket. Figure 6 shows feedback loops in a resource use policy that may limit usable resources in the system.

When technological developments strive to tap low-cost rich minerals as consumption rises, regeneration time rises while the slack in the system is consumed. If such a consumption pattern continues, a catastrophic decline in resource use must follow unless there are significant technological breakthroughs that allow reclassification of some of the spent resources as usable. Such breakthroughs are often not easy to realize. Thus, ideally, we should select a resource mix from our environment whose aggregate regeneration rate matches that of our consumption. When consumption rises, resources with a shorter renewal time should be added to the package in use while those with a longer renewal time should be dropped [Page 1977, Saeed 1985]. This would avoid any inter-generational transfers of resources.

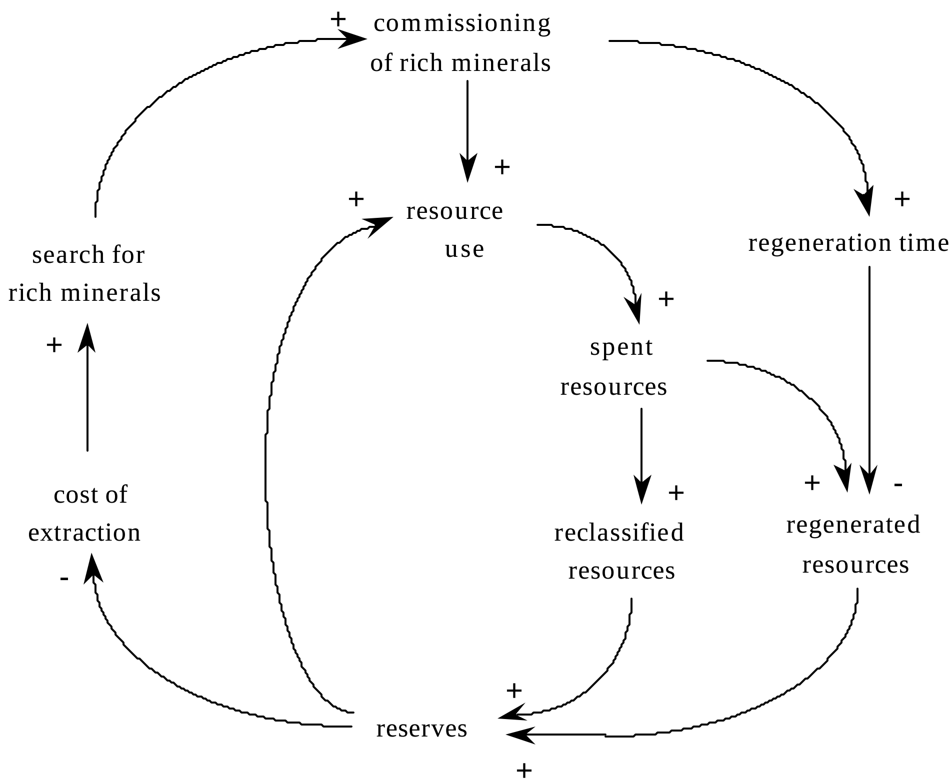

Figure 6 **Feedback loops in the resource subsystem concerned with maintenance of a slack**

(source: Saeed 1990)

An indirect intervention through the provision of a severance taxation system was proposed in Saeed(1985) for facilitating technological progress to achieve above results. Such a severance tax structure must assure that consumption and regeneration rates are matched through an appropriate selection of the resource basket. This requires continuous monitoring of resource use rates and resource stocks to determine coverage time for each stock, which is translated into its availability. The severance tax is, then continuously adjusted in response to resource availability, assuring in the long run that there are no inter-generation transfers of cost.

Ironically, history has generally seen the opposite situation take place. Thus, as consumption pressures have risen, technologies have been developed to tap richer geological resources. This, in turn, has increased the aggregate regeneration time of the resource package in use. Such trends have even led to the formulation of a very phenomenological classical theory of resource use which postulates the abandonment of low quality mines as richer mines are discovered [Robinson 1980]. This pattern is due to the increasing availability of technologies that tap richer resources rather than those with a faster renewable time. Control of technological progress thus appears to be an important entry point for implementing a sensible resource use policy. In this regard, resource use should apparently be based on geological information rather than on economic criteria.

Policy guidelines for sustaining technical competence in organizations

Providing for an innovation capability in the design of a formal organization presents a paradox. On the one hand, there is overwhelming evidence that innovation is nurtured in an informal setting, which should be unfettered by the rigidities of a manifest role structure [Quinn 1985, Roberts 1991]. On the other hand, organizational design, by the very nature of the instruments available to it, may only define manifest roles, which are more a hindrance than a help in sustaining an organization's innovation functions.

The design of formal organizations has traditionally relied on two approaches, mechanistic and organic, and their various combinations, to suit the product, the process, the technology and the environmental conditions [Schermerhorn 1985]. The design considerations of the mechanistic approach include issues such as specialization, hierarchy, span of control, grouping, rule enforcement and external rewards. Those of the organic approach include issues such as decentralization, autonomy, collegiality, job enrichment and internalized motivation [Simon 1976, pp. 20-44]. Simon also pointed out that producing intangible goods and services poses different organizational problems than producing tangible widgets, since, in the former case, output quantity and quality are not amenable to cardinal measurements. Therefore, he noted that the design of the decision and the resource allocation processes are of critical importance in such organizations [Simon 1976, pp. 288-308]. Since innovation organizations must constantly concern themselves with the identification and solution of new problems, they must provide for decision processes that allow the organic components of the organization to work effectively.

An innovation organization must necessarily incorporate a strong interplay of three subsystems - 1) the production system, which allocates resources between production and administration activities so the production of intangible goods can be sustained, 2) the learning system, which regulates the creation of knowledge and its mobilization in the organizational context and which would constantly improve operations affecting productivity, and 3) the governance system, which maintains a balance between collegial authority and manifest authority, thereby creating an environment in which a largely invisible output which sustains income potential is maintained [Gouldner 1957, Waters 1989, Weber 1978]. As I have pointed out in Saeed (1998a), Figure 7 shows the feedback loops governing the interplay of the three subsystems.

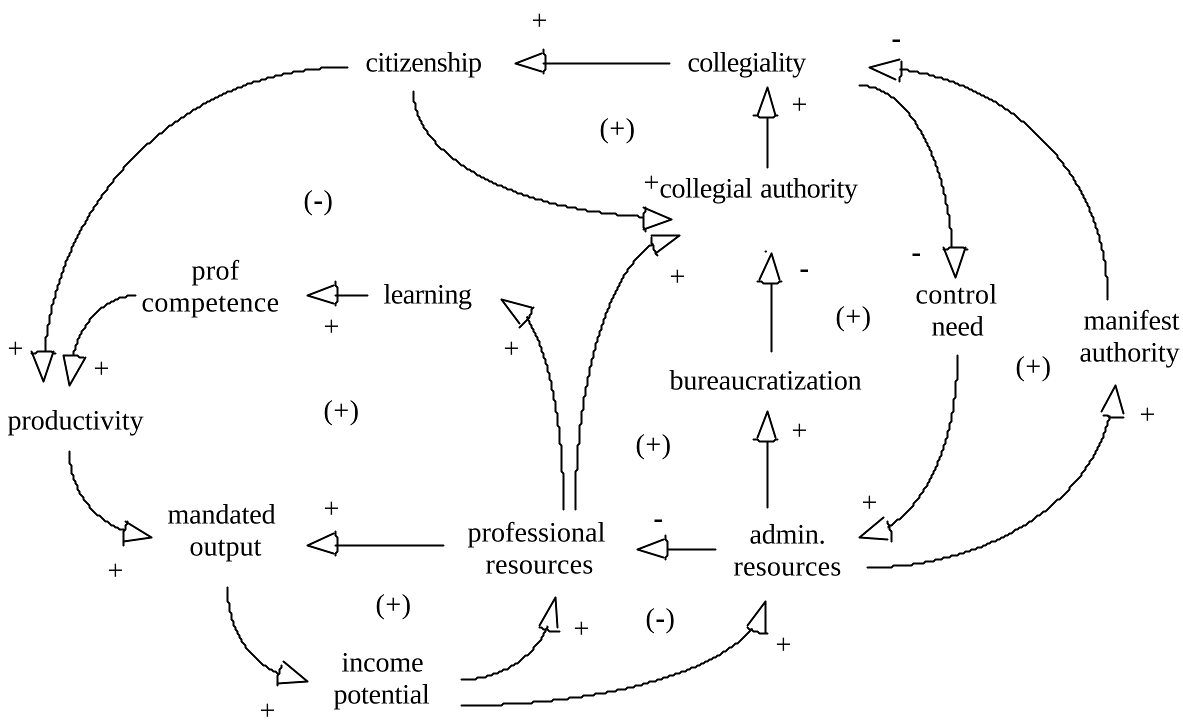

Figure 7 **Feedback loops underlying the decay of technical competence in organizations**

(Source: Saeed 1998a)

Positive feedback loops towards the bottom left of Figure 7, which arise out of the working of the production and learning systems, are self-reinforcing and create growth when not influenced by the governance system. When the governance processes are also linked up with this system, several new positive and negative feedback loops are formed. The negative feedback loops end up influencing the goal of production- and learning- related growth since growth also fuels expansionary trends in administration which, aside from constraining resource allocations to production also supports the growth of administrative scope and bureaucratization. The former promotes manifest authority, which decays collegiality, and the latter limits autonomy through expanding rule-based decision-making and centralization; both these trends impose constraints on commitment and organizational citizenship which are critical to the mobilization of professional competence in the organizational context and, consequently, to supporting innovation and improving productivity.

Meanwhile, collegiality is further weakened through the local positive feedback loops it forms with control need, manifest authority and citizenship. Through the resource allocation process, all of these also push up the level of bureaucratization. These processes accelerate the imminent downturn in income potential. Thus, the functions of an innovation organization cannot be sustained unless changes occurring in the value system can be controlled.

At the level of a nation, a charter must define the rights and the prerogatives of the public and the limitations of the government that is charged with the responsibility of delivering them, otherwise, a government would lose its commitment to public welfare and would allocate increasing amounts of scarce resources to preserving its own power interests [Popper 1977, Saeed 1994]. Likewise, in an innovation organization, a charter must define the rights and prerogatives of the manifest as well as latent roles. The nature of this charter, for a specific application, can be discerned through the type of experimental procedure that is outlined in this paper, using system dynamics modeling and computer simulation. Broadly speaking such a charter must define role prerogatives for the collegial context and role limitations for the manifest context of the organization. This will help to keep power interests at bay and maintain an appropriate blend of manifest and collegial forms of authority in the governance system so as to cultivate an appropriate level of collegiality. Further, the citizenship and autonomy that are activated by such a charter should help to mobilize existing professional competencies for meeting organizational remits, which is a key to sustaining an innovation organization.

Policy guidelines for fostering technological development in the private sector

Technological Development (not technology *per se*)has indeed been established as a significant source of economic growth in the analyses concerning the developed countries [Abramovitz 1956, Solow 1957, Denison 1962, Griliches 1963]. Seen as a function of human ingenuity, innovation and entrepreneurship, it is also often seen as powerful means for effecting economic development by the scholars, yet it is seldom explicitly incorporated into the planning policies of the developing countries [Schultz 1979, Hirschman 1958, 1970]. The potential of technological development as a policy lever is often underutilized because the operational means for its implementation are not clear. At the same time, the development planners have come to view technological growth mainly as a function of transfer rather than a process of indigenous development, hence few attempts are made to search for an operational means to promote technological development, even though its efficacy is widely recognized.

The developing country economies have been observed to be pervasively dual. They incorporate two equally significant production modes: a profit maximizing formal sector and a consumption maximizing self-employed sector. Yet, only their formal sectors have been targeted for much of the economic and technological development effort. On the other hand, although the developed country economies consist predominantly of profit maximizing firms but their small self-employed sectors are often targeted for assistance for technological development.

The concept of economic dualism was first recognized by Boeke (1953), who observed that a modern capitalist economy and a traditional informal economy often existed side by side in the developing countries. Its manifestations included commercial and peasant farming in agricultural economies, formal and informal firms in industrial economies and a modern industrial sector and a traditional agricultural sector in a national economy [Lewis 1954, Sen 1966, Bardhan 1973]. More recently, I have also suggested that the side by side existence of advanced industrial economies and the developing economies is another manifestation of dualism at a global level [Saeed 1998b]. Well-meaning developmental instruments based on aggregate models of economic growth have been implemented in the face of this pervasive duality.

Having accounted for a significant part of economic growth in the industrialized countries, technological development instruments offer a good promise also for the developing countries for accelerating economic growth and affecting income distribution. These instruments, however, remain underutilized. Even when used, they often disregard the dual structure of the developing country economies whose relations must be understood for creating any effective policy designs.

I have explored in Saeed and Prankprakma(1997) the efficacy of technological development instruments for the developing countries using a system dynamics model of economic growth, income distribution and technological growth in a dual economic system. Figure 8 shows the information relationships governing technological development in the two sectors in this model. For the formal production sector, the increase in the average technology embodied in the capital causes an increase in both the marginal revenue product of workers and capital, which causes its size to expand. The increase in the technology of the formal production sector also induces an increase in the profitability of the production activity compared to the renting activity so the capitalists in the formal renting sector tend to transfer more resources to invest in the formal production mode.

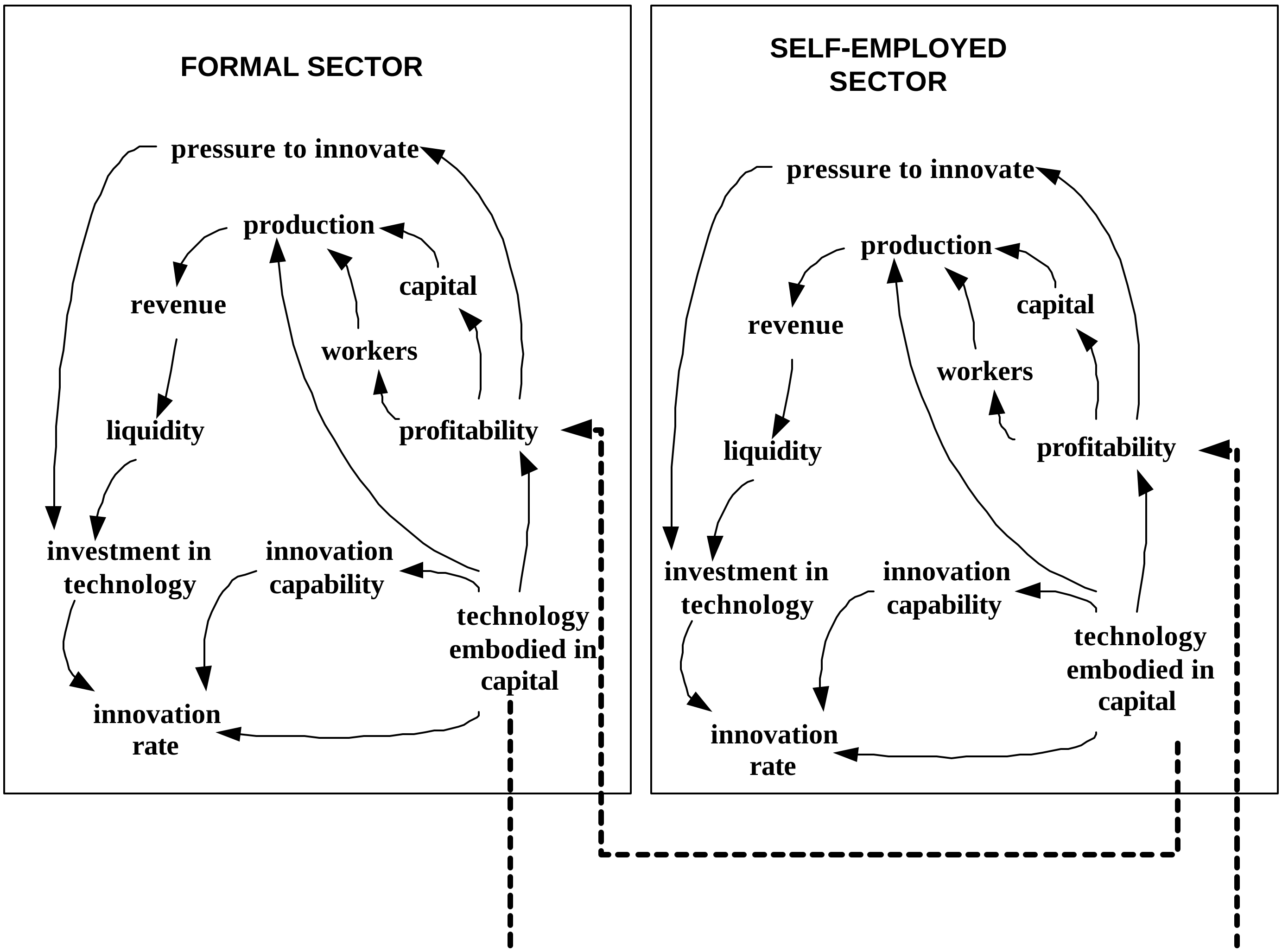

Figure 8 **Information relationships governing technological development in a dual economy**

(Source: Saeed 1997)

For the self-employed production sector, the rate of increase in the average technology embodied in capital is slow compared to the formal production sector. Therefore, its production efficiency and quality are also low. The marginal revenue products of workers and capital in this sector decrease, which causes its size to decline, also further decreasing its liquidity. The decrease in the liquidity cannot be checked by borrowing since the size of the available collateral also declines, which suppresses its investment in technology and hence its innovation rate. Thus, the average technology embodied in the capital of the self-employed sector will further lag behind that of the formal production sector. The decrease in the production output of the self-employed also decreases the income share of the workers which reduces the average consumption per worker. This suppresses wage rate also in the formal sector.

Both the decrease in the wage rate and the increase in the average technology embodied in the capital of the formal production sector fuel expansion in the production of the formal sector. The spiraling action of these changes allows gradual adjustment of the workers, the capital, the debt of the two production sectors and the deposit of the formal renting sector in a way that the formal production mode expands, while the self-employed mode declines. However, as the profitability in the formal production sector rises, the pressure to innovate declines and the investment in technology is neglected. In the self-employed sector the investment in technology is low any way due to the constraint from its liquidity position. Hence, the aggregate technological capability is also restricted.

Experimentation with this model shows that technological development related instruments might offer a promising alternative to the traditional direct and indirect policy levers used for fostering economic growth and influencing income distribution. It is observed, however, that for a technological development initiative to successfully facilitate growth and influence income distribution, it must attempt to promote competition among the monopolistic formal firms while providing positive assistance to the competitive informal firms. This inference can be extended to all contexts of economic duality, e. g., in the agricultural sector, between agricultural and industrial sectors, between leading and lagging regions and between industrialized and developing countries.

Policy guidelines for creating a sustainable global transfers of products, services and technologies

Trade, competition and specialization are the cornerstones of the neo-classical concept of economic efficiency now being extended to the global economic system, although without adequate consideration of its structure. In contrast to the protectionist policies applied at the time the industrialized countries were developing, free enterprise and free world trade are emphasized at this time. Unfortunately, the terms of this trade arrived at through the adversarial processes currently applied are likely to be biased by the bargaining power of the concerned parties rather than being cognizant of the stated development/environment contentions. Indeed, the current terms of trade remain unfavorable to the developing countries, creating a net transfer of value from the developing to the industrialized world. The evolving patterns of regional composition of production and trade are also poised to transfer a wide range of environmental costs from the industrialized to the developing countries. The specializations of production emerging in this system are characterized by the developing countries covering highly competitive market niches dealing with products with a high resource content and low added value while the industrialized countries cover monopolistic niches with a high added value content. The manufacturing processes involved in these niches are, likewise, more taxing to the local environment for the former than for the later group [Todaro 1994, Saeed 1998b]. Such patterns can create much conflict and confusion in the future. It appears a bit ludicrous, therefore, to issue appeals for global cooperation on developmental/environmental issues while concomitantly pressing for free trade without considering the economic structure in which this trade is conducted.

At the outset, the global economy can be divided into the industrialized and the developing country blocks which are intrinsically different in terms of their markets, motivations, enablements and access to production resources and technology. The former block consists of profit maximizing coalitions operating in established niches and controlling a major part of the global production as well as its technology. The later constitutes fringe producers competing in small market segments often with the responsibility to maximize consumption rather than profit. Capital movements in this economy are free while the labor movements are restricted. Surplus labor must be absorbed by the developing economies while capital owned by industrialized country capital is often employed under various rent agreements in the developing countries. The global economy, therefore, can be viewed in the aggregate to have a dualist economic structure, with a formal sector consisting of the industrialized countries and an informal sector comprising the developing countries [Saeed 1998b].

The prices of both factor inputs and commodities traded, including technological information, in a dualist economic system may not have any relevance to their true worth since claims to income depend on the bargaining position of the contributors to production and supply and demand conditions of the market rather than being determined by a fair valuation process. An increasing interaction between the subeconomies of this dualist system in the face of an unequal bargaining power yields a value transfer from the developing block to the industrialized block. Since the resource base of one country often extends to other countries, trade pricing structure and the nature of trade flows also transfer of natural resources and environmental costs in a similar way [Chichilinsky 1994, Saeed 1998b]. World trade policies and tariff structures need to be reexamined to check such transfers of value as pointed out by Professor Lewis a long time ago [Lewis 1984].

Conclusion

Technology has often been viewed as an artifact that the developing countries must import or create in order to facilitate economic development. The design of technology policy has often been aimed at finding ways to import or produce technological artifacts which have little relevance to the problems the developing economies face. Technological development, nonetheless is an important policy lever that can help address developmental agenda, provided it is addressed to problem solving rather than to the indiscriminate creation and import of production processes. This paper has attempted to outline a problem identification process that should precede any technology policy attempt. It has also identified four key areas in which technology policy could be productively applied. Further work on technology policy should aim at problem identification and problem solving in those areas in specific contexts. Creating institutions entrusted with the task of problem identification and the design of corrective instruments in those areas should also be helpful.

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