Science and technology for rural India

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Though the importance of science and technology for rural India was appreciated in the 1930s by Gandhi, giving rise to the work of the Centre for Science for Villages, advanced institutions of education, science and technology turned their attention to this area only in the 1970s. The most well-known of these efforts was from the Indian Institute of Science with its programme for the application of science and technology to rural areas known by its acronym ASTRA. ASTRA (recently renamed as Centre for Sustainable Technologies) was based on a model of science–technology interactions in a 'dual society' like India with a small affluent elite amidst a large economically deprived majority living primarily in rural areas. The model showed that *inter alia* an extension centre and a mission-oriented programme would be required to develop technologies to address the normally ignored needs of the rural population. While many features of this initial ASTRA model have been validated, it also had several shortcomings that are described. An attempt has been made in this article to indicate some directions along which the model should be updated taking into account the emphasis today on sustainable development. Special attention has been devoted to the failure modes in the generation, commercialization and dissemination of rural technologies. Finally, the barriers to the commercialization and dissemination of rural technologies are discussed.

THE necessity of harnessing science and technology for transforming rural India has long been recognized. In fact, Gandhi had clearly shown an appreciation of this necessity. As early as 1935, at the All India Village Industries Association, Gandhi initiated a movement called 'Science for People', with an advisory board of national personalities including scientists like J. C. Bose, P. C. Ray and C. V. Raman[1]. Unfortunately, very little is known about the deliberations of this advisory board. It is tempting, however, to conjecture that the advisory board did not come out either with path-breaking clarity on institutional mechanisms or profound advice on areas/ topics of work. It was left therefore to the workers at the Centre for Science for Villages, notably Devendra Kumar, to define directions for their efforts. They grappled with this challenge in a heroic manner. However, their efforts were rapidly marginalized by the overwhelming thrust of the mainstream scientific and technological establishment in the post-independence period. This establishment was pre-eminently dominated by the large number of scientists and engineers who returned, after World War II from higher education in Europe and North America, strongly influenced by their studies and sojourns abroad. An even stronger determining force was the demand of Indian industry and the Indian government. The outcome of these forces will now be considered in a brief treatment of the post-independence science and technology scene.

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Post-independence science and technology

Growth

There are a number of aspects of the growth of post-independence S&T that merit mention: (a) There has been a phenomenal growth in the total expenditure on R&D (Figure 1). (b) This growth has been through a marked increase in the number of S&T agencies/organizations (Figure 2). (c) Several of these agencies have shown a spectacular increase in the number of constituent S&T institutions (Figure 3). (d) The establishment and development of these institutions necessitated an enormous increase in the number of technical personnel.

Bias towards urban, industrial and defence needs

By and large, post-independence Indian science became western-oriented and Indian technology focused on the needs of urban settlements, industry, the central government and to much smaller extent, the state governments. Thus, the main thrust of post-independence S&T effort was *not* in favour of the needs of rural areas. This conclusion is supported by (i) the bias in R&D expenditure, (ii) the bias in the distribution of institutions, (iii) the bias in the distribution of technical personnel, and (iv) the bias in the focus of Plans.

ASTRA – an institutional experiment

It was against this backdrop that there arose in the 1970s a number of new attempts to reorient Indian S&T towards the needs of rural India. Notable among these were the stirrings in the institutions of advanced education, science and technology.

Perhaps the most well known of these efforts was effort by the Indian Institute of Science (IISc), Bangalore. In 1974, a presentation[2] on 'The choice of alternative technologies' at the Bangalore meeting to discuss the Science and Technology Plan of the National Committee of Science and Technology evoked a great deal of interest amongst the faculty of IISc. Several of these faculty members were in favour of an attempt to translate the ideas of alternative technology into a practical programme. An opportunity to make a presentation to the IISc's Senate Committee on Research and Academic Policy (SCRAP) was therefore requested. Following this presentation, the Institute accorded permission for the formation of a cell for the Application of Science and Technology to Rural Areas. This cell became known by its acronym ASTRA (which is the word for 'weapon' in Sanskrit) because it was meant to be a weapon against poverty in rural areas. Thus began a pioneering institutional experiment to evolve and apply S&T to rural areas.

Model-based institutional experiment

The ASTRA institutional experiment was based on a model of technology–rural society interactions. Models, it will be recalled, are a path to understanding in the face of a complex reality. They are simplified representations of reality serving to discover its essential features. Model building, however, has to be an iterative process. Starting with an initial model, its ability to reproduce the essential features of reality has to be tested empirically. Then, the mis-match between model-based predictions and empirical results has to become the driving force for the improvement of the initial model.

The model underlying the formation and growth of ASTRA

The following are the main features of the ASTRA model:

- Technological development and societal demands are dialectically related, each transforming the other.

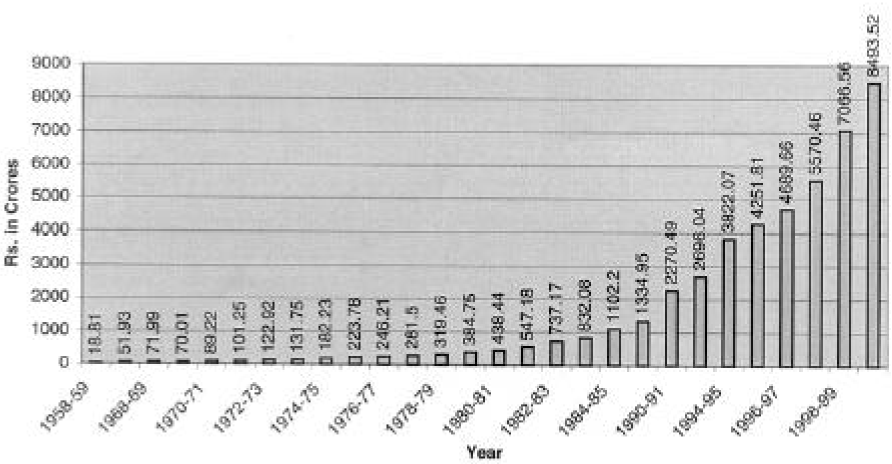

Figure 1. Growth in total R&D expenditure.

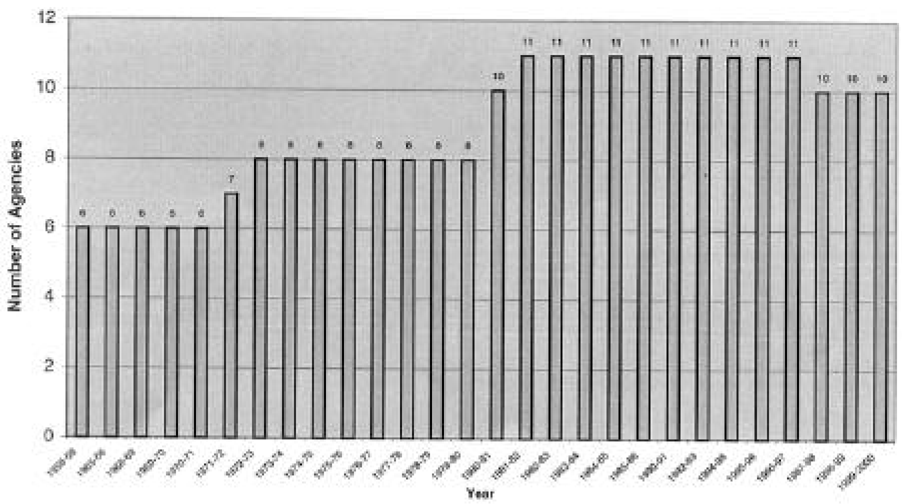

Figure 2. Growth in number of S&T agencies/organizations.

- Technological development is driven by societal demands (cf. technology–society interaction scheme, Figure 4).
- Demands (backed by purchasing power) must be distinguished from wants (defined by human needs).
- In a 'dual society' such as India, with a small affluent elite amidst a large economically deprived majority living primarily in rural areas, the technology–development system ignores (i.e. filters out) the wants of the rural masses because they are not backed by purchasing power, and emphasizes the demands of those (elite) sections of society that have the purchasing power.
- The first step in the development of technology for the underprivileged rural masses consists therefore of the identification of their felt needs.
- This identification is best done, not from a remote/alien environment, but through direct contact and 'learning from the people'.
- Hence, the importance of an 'extension centre' located in a rural setting.
- The felt needs thus identified must then be translated into technical challenges.
- These technical challenges must excite technical personnel and motivate them to come up with solutions that are appropriate to the rural context.
- The technical challenges involve stringent constraints of low cost and ease of operation. Hence, the technical solutions that succeed are unlikely to be trivial or 'low' technology. They are also unlikely to be successfully tackled by technical personnel working casually in their spare time 'after office-hours'.
- Hence, the talent and expertise of advanced institutions must be harnessed to address the 'sophisticated' technical challenges.
- Whether the proposed solutions are appropriate or not can only be determined by going back 'to the people' and 'test marketing' the solutions.
- Imperfect solutions have to be refined in an iterative process.
- The identification of felt needs, the formulation of technical challenges, the provision of infrastructural support to those interested in tackling the technical challenges, the operation of an extension centre in a rural setting, etc. require a special organization/group with the mission of developing and disseminating technologies for rural felt needs.

ASTRA

The ASTRA experiment brought to bear on the challenges the prestige and competence of the Indian Institute of Science, which is one of the premier institutions of education, science and technology in the country. The Institute's infrastructure for technology generation was combined in the ASTRA programme with a new rural development and poverty-eradication perspective. Several key technology areas were identified such as energy (particularly biomass), low-cost housing, drinking water and agro-processing. The scientists and engineers involved quickly became pioneers in the field. There was a tremendous feeling of excitement, as ASTRA became a hub of intellectual activity inspired by sensitivity to social concerns and a moral fervour. There was support from a large number of faculty including several Fellows of the Academy of Sciences. Equally important was the top-down support from the institute (in particular, its Director, Satish Dhawan) and its council.

ASTRA as a programme of the Institute has survived for over 25 years. It has the infrastructure for technology generation and micro-diffusion. It has built an excellent reputation in Karnataka, India and abroad for past work. It is sufficiently well funded. It has excellent linkage with state-wide and countrywide technology dissemination agencies (KSCST, CAPART, MNES, GEF, etc.).

Above all, the ASTRA programme of IISc served as a model for emulation and inspired a number of efforts in

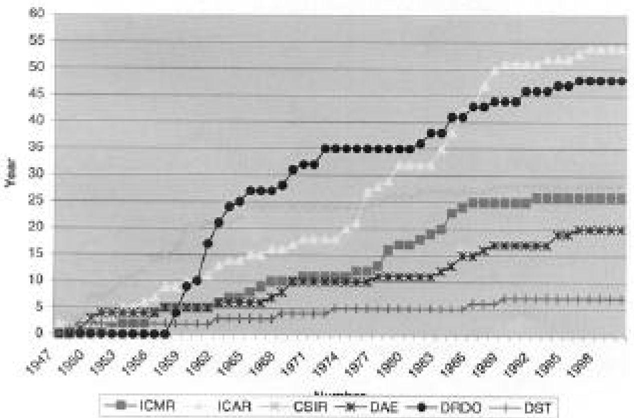

Figure 3. Growth in number of constituent S&T institutions.

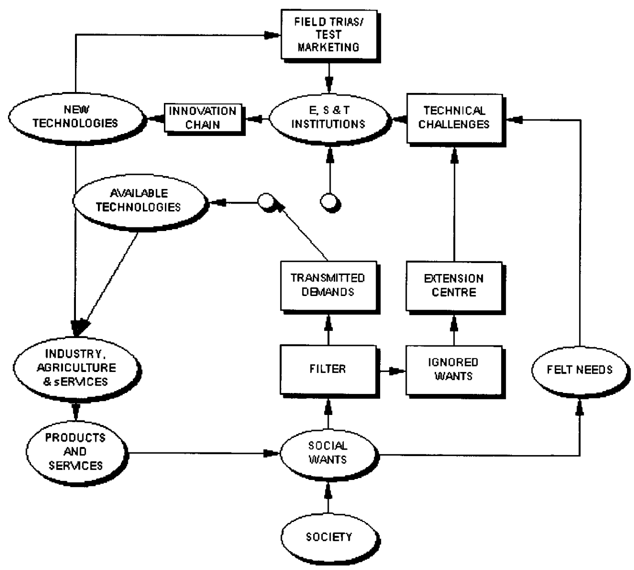

Figure 4. Technology–society interaction scheme.

other institutions such as the IITs. Perhaps even more important was ASTRA's success in placing rural technology on the agenda of national institutions. Thus, towards the late 1970s and the 1980s rural technology started finding a place in the Plan documents.

What was right with the ASTRA model

Several key features of the initial ASTRA model have been validated. First and foremost is the importance of identifying felt needs. Whereas in industrial R&D work, these needs are communicated through the market mechanism, in the case of rural work, one is invariably dealing with sections of the population that do not have the purchasing power to articulate their demands through the market. The rural studies of energy, buildings, water, etc. carried out by ASTRA proved a powerful platform for its work of technology development.

In this process, the extension centre proved crucial as an entry into rural life. Had the effort depended merely on hearsay or on 'conventional wisdom' regarding what was required or on foreign-consultant-type 'hit and run' visits, it would have been seriously handicapped. The ASTRA experiment also foresaw the interdisciplinary nature of the work, which it could address because it transcended the discipline-constrained character of departments. Finally, the model rightly appreciated that success required first-rate S&T backed by the best scientists and engineers. However, subsequent experience has shown several inadequacies of the initial ASTRA model.

What was inadequate in the ASTRA model

When an organization is set up, its objectives are developed in interaction and by negotiation, with its environment. It has to earn active interest from the environment by sustaining the continued delivery of outputs of relevance to the environment. *Relevance* is therefore the first crucial requirement of a sustainable institution. Relevance is not measured merely by the quantity of outputs, but also by the quality of these outputs. Relevance is inevitably, intimately and inextricably dependent upon excellence of the organisation's outputs. *Excellence*, therefore, is the second crucial characteristic of a sustainable institution. The achievement of excellence earns for the organization national and international recognition (that society tends to accept as an independent external assessment of the organization). Relevant excellence also ensures excellent relevance.

Unfortunately, the initial model upon which ASTRA was based did not pay enough attention to establishing and ensuring mechanisms for peer review and quality control. Work that is relevant is not *ipso facto* excellent – just as there can be third-rate work on conventional technology, there can be third-rate work on rural technology.

The threat to excellence can come from a wide variety of devices used to circumvent and subvert the quality control system. Foremost among these devices are avoiding publication in peer-reviewed journals and instead courting the local lay press and its non-specialist columns; steering clear of technical conferences; courting generalist bureaucrats instead of interacting with technical peers; publicizing funding as a proxy for technical achievement; presenting proposals as if they have been implemented, and plans and hopes as if they are actual accomplishments; never making performance transparent with detailed reports.

Sufficient attention was also not devoted to the establishment of appropriate reward systems. There was far too much dependence on dedication and commitment beyond the call of duty. The situation was aggravated by the fact that most technologies required a seven-to-ten-year gestation period to go from concept to penetration of society. This extent of commitment from the average scientist/engineer was perhaps too much to expect without adequate rewards/recognition.

Above all, the ASTRA model paid inadequate attention to the commercialization and dissemination of technologies. Apart from the extreme cases where it was naively believed that R&D was enough, there was excessive reliance on technology dissemination via government agencies. The power of the market and the potential role of entrepreneurs were inadequately appreciated.

It was also not initially appreciated that the quest for appropriate technologies often reveals three stages – first, the enthusiasm of amateurs, then the entry of competent technical expertise, and finally the enlightened and competent management of the commercialization process.

Yet another major weakness of the initial ASTRA model was the absence of a gender emphasis in the dissemination of rural technologies even though many of these were of special relevance to women as beneficiaries as well as participants and actors. This was the case for instance with regard to the improved stove-dissemination programme. In fact, it was only when women were made the focus of the programme did it start showing success.

Since the ASTRA experiment was initiated in 1974, there has been a drastic change in the macroeconomic framework with the implementation of liberalization, privatization and globalization. Obviously, therefore the model must be updated in the light of these changes.

Perspective of sustainable development

The late 1980s and the early 1990s also saw the emphasis on so-called *sustainable development* – an equitable, self-reliant and environmentally sound development.

It is widely believed that the concept of sustainable development must be attributed to the Brundtland Commission (World Commission on Environment and Development 1987) which defined it as 'development that meets the needs of the present without compromising the ability of future generations to meet the future needs'[3]. There is no doubt whatsoever that without the emphasis and publicity given by the Brundtland Commission, the concept of sustainable development would never have attained the standing that it has. For the record, however, it should be mentioned that the Brundtland Commission had cited the energy work of Goldemberg *et al*. who authored the publication *Energy for a Sustainable World* published in a mimeographed form in 1985 and in a World Resources Institute booklet version[4] in 1987 and in a book form[5] in 1988. Goldemberg *et al*. stressed that sustainable development should have the elements of 'equity, economic efficiency, environmental soundness, long-term viability, self-reliance, and peace'.

With this perspective of sustainable development, ASTRA's objectives have to reckon with the dimensions of economic efficiency, equity, environmental soundness, long-term viability and self-reliance. It is necessary therefore to set rural objectives in the broader framework of sustainable development. The emphasis has to be not merely on rural technologies but on *sustainable* technologies.

An updated model

An updated model must above all take into account the critical steps that determine the 'success' or 'failure' of the generation, commercialization and spread of rural technologies. In developing countries, the dissemination of rural technologies is basically a 'push' process in which the technology champions – the R&D scientists, the manufacturers, entrepreneurs and the State – act as technology-transfer agents. Occasionally, however, the rural poor may provide a weak technology pull.

In a comprehensive framework, the underlying premise is that the commercialization sub-system (consisting of the manufacturer/user relationship interacting with the technology generator and the technology champion) is embedded in a larger system. This larger system consists of resource producers-cum-distributors and financial institutions, both of which have a strong influence on the commercialization process. Even this larger system is subject to the influence of its environment, which consists of the governmental decision-making process and the political systems, which transmit their will supporting or impeding the process of commercialization of improved technologies for rural areas. The comprehensive framework has to take into account the environmental influences, the manufacturing strategy and the mode of commercialization.

The failures of commercialization of improved rural technologies are considered as occurring at two levels.

Failure at policy level

If the government responsible for the national planning of resources does not emphasize the efficient use of those resources as the core of development strategy, the relevant technology faces potential failure in commercialization.

Failure at supporting-institution level

Failures of commercialization may also occur because (a) resource producers and distributors ignore the efficiency of resource use, restrict themselves to increasing the supplies of resources (and not improving the efficiency of their utilisation!) and monopolise the right to provide supplies, thereby precluding the possibility of alternative sources; and (b) financial institutions make investment decisions on the basis of an unfair comparison between centralized and decentralized technologies and have a bias towards the supply aspects of the resource rather than towards the efficiency of its use.

Hence, attention has to be turned to a more elaborate model that has been developed[6] (Figures 5 and 6) to emphasize the special precautions that must be taken to avoid failures of technology generation, commercialization and dissemination.

Regarding technology generation, Figure 5 shows that there are two failure modes: (i) *Failure to identify needs, F1* – A cognitive failure to understand and act on the basis of the true felt needs of technology users in rural society; and (ii) *Failure of the R&D effort, F2* – A failure of the

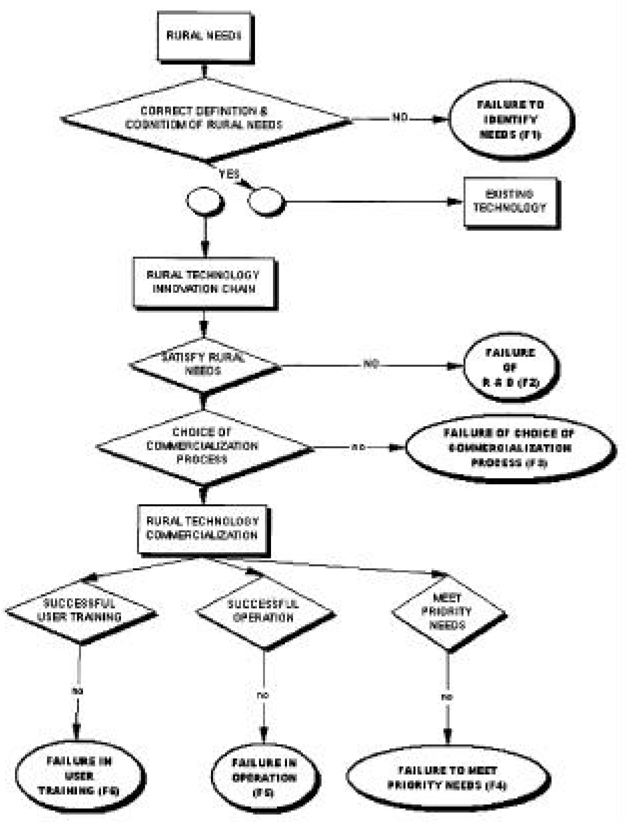

Figure 5. Failure modes in technology generation and commercialization.

R&D process to develop a technology that satisfies the true felt needs of technology users in rural society.

Figure 5 also shows that there are four possible failure modes in technology commercialization: (i) *Failure in the choice of commercialization process, F3* – A failure caused by an inappropriate manufacturing strategy and/or an ineffective mode of distribution leading to inefficient demand signals; (ii) *Failure to meet needs in order of priority, F4* – A failure to meet the needs of the villagers according to their order of priority; (iii) *Failure in operation, F5* – A failure to provide the inputs, to operate and maintain the technology, and to distribute or utilize the outputs, all under rural conditions; and (iv) *Failure to modify behaviour, F6* – A failure of the change-agents to modify the operational behaviour of the technology users to take advantage of the technology, i.e. a failure to train the users.

The model shows that all the above six failure modes must be avoided if the commercialization of improved technologies in rural areas is to be successful. If the technology avoids the first five failure modes (i.e. the needs are identified, the R&D is successful, the correct commercialization process is chosen, the needs are met in order of the users' priorities and the technology can be operated successfully under rural conditions) but failure mode F6 occurs because no training is provided to help users to benefit from the technology, the whole undertaking will inevitably fail. On the other hand, a good opportunity is lost if a successful technology avoids failure modes F1, F2, F3, F5 and F6 but encounters failure mode F4, i.e. the technology does not meet the priorities of the villagers.

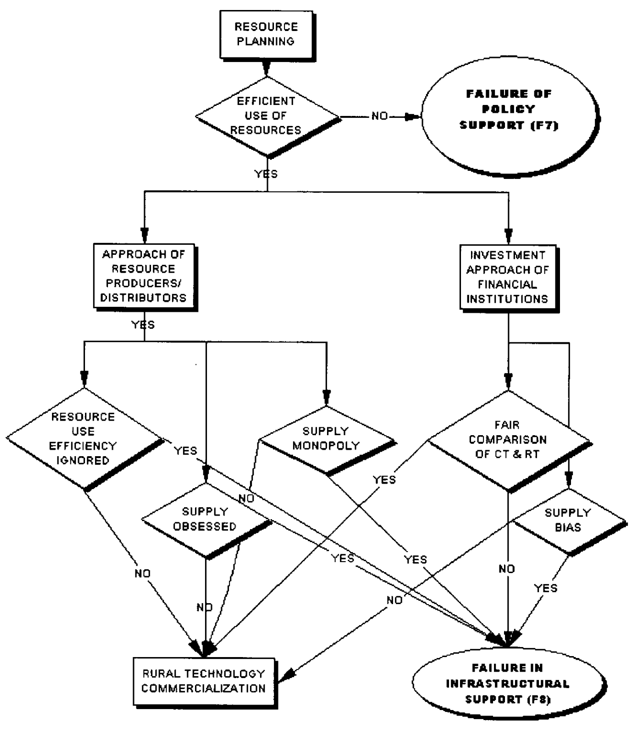

Figure 6. Failure modes in technology dissemination.

Defects at the infrastructural and policy levels can cause the following two failures (Figure 6), which are as serious as the first six: (i) *Failure in policy support, F7* – A failure of government to support the promotion of rural technologies with a proper emphasis on the related issue of resource planning; (ii) *Failure in infrastructural support, F8* – A failure of the methodology of comparing technologies and of decision-making as to the choice of technologies for investment.

Though a correction of policy may eliminate failure mode F8 and create a proper environment for the choice of technologies, F7 may still occur because of disjointed decision-making.

Above all, the model implicitly emphasizes that iterations of certain of its segments are essential for the success of commercialization. It is here that the political, administrative and scientific will of the organizations involved becomes important.

The above description of failure modes does not refer explicitly to the question of which persons or organizations must determine the needs. It is obvious, however, from failure mode F4 that meeting the priority needs of the villagers according to their order of priority is a result that is far more important than the process of who determines the needs and how the needs are identified. Nonetheless, some processes of identifying needs – for instance, processes that avoid gender biases – are much more likely to lead to the desired result than others.

A related issue that is often raised is whether priority should first be assigned to income-generating technologies and only then to technologies that as directed towards the satisfaction of basic needs, or whether basic-needs satisfaction is addressed before income generation. Obviously, the answer depends upon the relative importance that the villagers, or rather their decision-makers, attach to basic-needs satisfaction and income generation.

Barriers to commercialization[7]

The commercialization of improved technologies in rural areas has been shown to involve a number of actors operating at various levels. In particular, the following are mentioned – technology users, technology manufacturers and providers, technology generators, technology champions, financial institutions, and local, state and national governments and their decision-makers. Thus, action is required at the lowest level of the technology user (individual, household or community) through the highest level of government.

Barriers to the commercialization process can arise at all these levels. An attempt will be made in this section to list the main barriers, to explore their origins and suggest ways of overcoming them. Once such a scheme is formulated, it can be expanded and improved. In that sense, this section is intended to initiate a discussion of barriers to commercialization.

Technology users

The unaware: The commercialization of an improved technology in a rural area requires the concurrence of the ultimate user (individual, household or community) of the technology. In turn, this concurrence depends upon the potential user understanding the costs and benefits of the various technological options, knowing about the improved technology and being aware of its relative advantages. A large number of technology users, however, are unaware of the advantages of the technology and of its cost-effectiveness.

The obvious way of overcoming this barrier is to provide information in various ways. Whereas door-to-door canvassing, leaflets through the mail, newspapers and magazines are effective in urban areas with literate target audiences, in rural areas, demonstrations must play a key role in addition to radio and television. And, of course, the training of technology users is a powerful way of educating them with regard to the advantages of the technology. Thus, the supply of relevant information to, and the education of, the technology user is the means of overcoming the barrier posed by the uninformed.

The poor and/or first-cost sensitive: Even if a potential user is fully knowledgeable about the net benefits accruing from the improved technology (designed as a replacement for the conventional version), this user may not necessarily make the required investment on the associated device or equipment. Improved technologies may be more resource-efficient and therefore have lower operating costs, but they tend to have higher initial capital costs. This higher initial cost of the improved technology can become a serious barrier.

The technology user naturally asks: do the benefits of the improved technology justify the increased investment? The answer to this question depends upon whether the technology user is prepared to invest capital resources now in order to reap the regular benefits in the future. In other words, is the technology user prepared to postpone current consumption for the sake of future benefits?

The index of this preparedness is the user discount rate (UDR). When empirically determined UDRs are compared with the usual interest rates earned by money, it is found[1,8] that the UDRs of individuals and households tend to be much higher than commercial discount rates of around 10 per cent. Obviously the UDR is a reflection of the availability of capital with the technology user – the more disposable cash the user has, the greater the preparedness to invest this cash now to earn benefits in the future.

One would expect, therefore, that as the income of the technology user increases, the UDR used for investment decisions will decrease, and conversely, the poorer a user is, the less the likelihood of being prepared to sacrifice scarce capital on new devices and equipment, however great the advantages accruing from the improved technology.

If this first-cost sensitivity of the technology user is to be overcome, the rate of return must be increased so that it exceeds the UDR The way to make rural technologies affordable even to the poor and/or to the first-cost sensitive is to convert the initial down payment into a payments stream that coincides in time with the benefits stream. It is even better if the payments stream is financed out of the benefits stream. This situation can be achieved by a loan being advanced for the improved device or equipment and the principal being recovered with interest. Alternatively, an agency can lease the improved device or equipment to the technology user, who then pays the regular leasing charges. Thus, innovative financing is the method of overcoming the barrier posed by the poor and/or by first-cost sensitive.

The helpless: There is the class of technology users who are knowledgeable, can afford the improved technology and are motivated, but are nevertheless completely helpless in the face of all the problems that must be tackled in identifying, procuring, installing, operating and maintaining the associated devices and equipment.

The origin of all these problems is that it is relatively easier for a technology user to purchase conventional equipment. Well-tested economic systems exist for making the associated transactions, and both producers and technology users understand the value of the devices involved. This is not always the case for investments in improvements. Compared with the mature industries associated with the conventional equipment, the improved technology industry may be in the initial and infant stages of development and may quite often be limping along with government support, subsidies, etc. This invariably means that there is a great deal of paperwork to secure the requisite credit, negotiate with the suppliers/erectors of the improved devices or equipment, and get them installed. Unfortunately, it looks as if the technology user must have a great deal of know-how to identify, procure, install and maintain improved devices and equipment. Such a situation will prevail until the technology user can obtain total packages of hardware plus software (the latter being all the instructions and knowledge to run the hardware). In turn, this means that an efficiency-improvement industry must be established and developed to provide these packages.

Thus, to overcome the barrier of the helpless technology user, it is necessary that an industry devoted to improved technology must be developed so that it can provide technology users with know-how in the form of total hardware plus software packages.

Technology manufacturers

The manufacturer with incompletely engineered technology: The innovation chain leading from a concept to a product/ process in the economy involves the crucial step of engineering for manufacturing in which the working device or process produced by research, design and development has to be converted into a manufacturable product or process. The step of engineering for manufacturing is essential because making 100, 1000 or 10,000 units (items or quantities) is a completely different matter from making one unit – the design, materials and manufacturing procedure may have to be changed radically. Further, in many technologies, the design of the product/process may have to be modified to suit local conditions. The engineering for manufacturing involves a considerable product/process development effort. Further, the effort requires competent manpower, technical facilities and substantial funds.

The manpower, facilities and funds all present problems. R&D personnel tend to feel that their job is over with producing a working device, and they tend to be uninterested in the product/process development because they consider it to be a trivial task. In fact, specialized personnel with competence in design, materials and manufacturing procedure are required for the challenge. R&D institutions tend to be reluctant to allow their facilities to be used for product/process development. R&D funding agencies dislike funding the engineering for manufacturing because it is not R&D, and financial institutions hesitate to fund the activity because the product/process is not yet proven – the activity cannot find funds easily because it 'falls between two stools'.

Thus, there are several barriers associated with engineering for manufacturing – the barriers of non-available specialists, non-existent facilities and no funds for the crucial task of product/process development. The barrier of non-available specialists must be overcome with training programmes for engineering for manufacturing; the barrier of non-existent facilities with the establishment of special product/process development centres; and the barrier of no funds for the crucial task of product/process development, with the provision of venture capital from venture-capital institutions.

The efficiency-blind: It is generally the case that the sales of devices and equipment are insensitive to the efficiency with which the equipment uses resources. In fact, these sales depend far more on the initial capital cost, because poor customers are sensitive to this cost; and since cheaper equipment invariably means lower efficiency of resource use, the sales of improved technologies may actually be less than the sales of inefficient technologies. Such an environment encourages efficiency-blind manufacturers of end-use devices and equipment. Part of the problem is that the manufacturer and distributor of end-use devices and equipment are not obliged either by market pressure or by law to reveal the performance of the devices and equipment with regard to resource consumption. For example, an Indian technology user cannot know which of a number of agricultural pumpsets has the lowest energy consumption.

The barrier to commercialization of improved technologies arising from efficiency-blind manufacturers can be overcome by government intervention enforcing the labelling of end-use devices and equipment, so that the prospective buyer can take the resource consumption of the equipment into account even before purchasing it. The technology user will be further motivated to ascertain the performance of equipment if the financing of this equipment (e.g. the interest rate) is tied to its performance.

Resource producers and distributors

The supply-obsessed: The producers and distributors of resources (water, electricity, petroleum products, etc.) are invariably so obsessed with the supply of their resources that they devote little attention to the utilization of these resources. In particular, they do not bother about the efficiency with which their resources are being used. This supply-obsession on the part of the producers and distributors of resources has become a major barrier to the marketing of improved, resource-efficient technologies.

The problem is aggravated by the fact that the marketing of improved technologies of resource-use is inherently more complicated than the marketing of resource supplies and conventional end-use technologies. Attention must therefore be paid not just to the production of improved devices, but to the full spectrum of relatively novel marketing problems. To promote improved technologies effectively, efforts should address all these aspects of the marketing, i.e. the efforts should be concerned not just with the production of the hardware involved but with all the necessary supporting 'software' as well.

The producers and distributors of resources (irrigation departments, the electricity boards, oil companies and gas utilities) are good candidates for marketing the services required for such an effort. Accustomed to handling large quantities of capital, the producers and distributors of resources are well positioned to direct these resources to investments on improved technologies. Also, they have an administrative structure for channelling the capital to essentially all potential technology users (including households). Moreover, the billing systems of the suppliers of resources offer the opportunity for technology users to invest in improved devices with loans from the suppliers and to pay back these loans through their resource bills.

If the charter of the producers and distributors of resources is restricted to the supply of carriers, they cannot undertake the comprehensive marketing of improved technologies. What is required, therefore, is a conversion of resource-supply agencies into resource-service companies, that is, companies that market the services provided by resources in much the same way they market resources today. Resource suppliers must diversify in this direction of resource services. Then, they would come to play a role similar to that originally envisaged for electricity companies by Thomas Edison when he invented the incandescent bulb – he proposed that utilities sell illumination, thereby giving them a financial interest to provide this illumination in the most cost-effective way. Similarly, if irrigation departments sell irrigation, rather than water, they would develop a vested interest in the efficiency with which water is used for irrigation.

Thus, the barrier of supply-obsessed producers of resources can be surmounted through a change in the charter of the producers from suppliers of resources to vendors of the services provided by resources, and/or a growth in independent resource-service companies.

Financial institutions

The supply-biased: Just as the producers and distributors of resources are obsessed with the supply aspect of the resource system, the financial institutions that provide the capital can also be supply-biased.

The origin of this barrier is the conventional approach to resources followed by financial institutions. According to this approach, the purpose of the resource system is to increase resource consumption, which means that the emphasis has to be on increasing the supply of resources. Improved technologies become a separate issue that is automatically ignored because it does not lead to increases in supply and consumption.

This barrier has to be tackled firstly at the conceptual level, by propagating the paradigm that it is the *level of resource services*, rather than the *magnitude of resource consumption*, that is the true indicator of development. But a given resource service can be obtained either by increasing the supply of the resource or by using more efficient devices – for example, better irrigation, i.e. uptake of water by crops can be achieved either by increasing the supply of water or by using more efficient irrigation pumpsets and/or reducing the losses in the water distribution channels. To know which is the best way of obtaining that service, the various options must be compared with each other. Hence, sound financial management requires that tenders must be called, not merely for augmenting supplies, but for providing the resource services that are necessary. In addition, improved technologies must be included in the least-cost planning process.

Thus, the best way of dismantling the barrier posed by the supply-biased is to shift the emphasis from resource consumption and supplies to the service provided by resources, to include improved technologies in the list of options for providing services and to pursue the least-cost planning process.

The unfair: If there is concern for least-cost resource planning, then it must be ensured that the comparison between supply increases (of centralized and decentralized sources) and conservation measures is fair. In the first place, resource savings should be treated symmetrically with resource production, because a unit of resource saved is equivalent to a unit of resource generated. This might mean, for instance, that the expenses associated with resource efficiency are considered as the cost of service and used for a 'cost plus' method of charging customers, as in the case of supply technologies. Then all three contenders – centralised sources, decentralised sources and conservation measures – must be compared on the same terms of credit (including interest rates), benefits, incentives, subsidies, etc.

At present, the competition is certainly not fair. In particular, financial institutions tend to be unfair in their comparisons of supply increases and improved technologies – the advantages are heavily weighted in favour of centralized sources and against conservation measures, with decentralized sources in between. The origin of this unfair discrimination can be traced to the fact that the financial practices regarding resources have grown in association with the development of the centralized supplies, and over the course of time, a number of hidden subsidies and other supports for such supplies have evolved.

This barrier of the unfair financial institution must be overcome by an emphasis on fair competition through the elimination of subsidies to resource supplies, correct pricing, same terms of credits, benefits, incentives, etc.

Government decision-makers

The cost-blind price-fixer: Resource prices in developing countries are generally no reflection at all of the true (or real) costs to society of generating that resource – they include large elements of subsidy. In such situations, the frugal are not rewarded and the profligate are not punished. Technology users do not 'feel the pinch' of resource prices and do not receive the proper signals regarding the value of resources. Also, the resource consumption of these technology users tends to be largely unaffected by small increases in the price of resources. Since resource prices in these countries are fixed by government decision-makers, the cost-blindness of these decision-makers has become a barrier to the commercialization of improved technologies.

Prices should be determined, however, not by the average cost of cheap supplies established in the past, but by what it will cost to generate resources in the future. What matters is not the sunk cost of the previous unit of resource but how much it will cost to generate the next unit for the next technology user in the future. That is, prices should reflect the long-run cost of producing the next unit of resource in new generating stations – what the economists call long-run marginal-cost pricing – because that is what the resource companies will have to pay to set-up facilities to deliver this next unit.

Attempts have to be made to move in the direction of long-run marginal-cost pricing, but the political barriers to increasing electricity prices must not be underestimated. An important guideline in this context is that technology users are more concerned about their expenditures on resources than about resource prices. This means that technologies involving improvements in resource efficiency must be implemented simultaneously with price increases, so that the decrease in expenditure brought about by the efficiency improvement compensates (fully or partially) for the increase in expenditure resulting from the price increase.

Thus, the barrier of the cost-blind price-fixing government decision-maker can be surmounted by a move towards long-run marginal cost pricing and by ensuring that price increases are implemented along with improved technologies.

There are two categories of barrier to the effective commercialization of rural technologies: (i) *Endogenous* barriers, which are internal to the process itself at the level of technology users and technology manufacturers; and (ii) *exogenous* barriers, which arise out of non-supportive (or even hostile) elements in the environment for the process of commercialization at the level of resource producers and distributors, financial institutions and government decision-makers.

The model that has been presented here involves both a systems approach and a hierarchical approach. The interaction between the environment of the rural technology and the commercialization process is explicitly considered in the model to achieve a total systems viewpoint.

The aim of the analysis is to achieve understanding, rather than evaluation, because the former is enlightening and encouraging, unlike the latter, which is threatening. The objective of the understanding is threefold: (i) designing the commercialization of technology before a project is undertaken; (ii) improving the commercialization of technology *ex post facto* by analysing the degree of success that has been achieved; and (iii) understanding the institutional, policy and other environmental constraints to technology design and commercialization and shaping governmental policies and institutional mandates and functioning to promote the commercialization of improved technologies in rural areas.

The above analysis is helpful in developing a checklist that can be used when a new technology is under consideration for commercialization. The checklist can serve as a tool for highlighting pitfalls of which the planner has to be wary. This will help in systematically increasing the probability of success of the commercialization process.

The process of commercialization has been modelled in detail much in the same way as mechanical systems are depicted, mainly to highlight the failure modes of the system. Such modelling exercises are essential because they reveal many types of failure that cause concern to the R&D personnel involved in the generation of the rural technologies as well as to the decision-makers and policy-makers attempting to provide the commercialization of improved technologies in rural areas.

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