From the linear model to incremental innovation: Science and Industry in India

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1 Introduction

In the historical process of evolution of production systems, the industrial revolution was the great marker. It was the turning point after which scientific knowledge became, to an increasing extent, an organic part of the knowledge of the production process, or of *technology* (Bernal, 1971a). In other words, science became the driver of technological advance. However, the relationship was not one way; increasingly, technological demands began to set the agenda for scientific research and science and technology became two interacting, if not interpenetrating, systems of knowledge. In the period spanning a century and a half between the industrial revolution and Indian independence, there were two further milestones in developments in technology; and in the nature of the science-technology interaction: the chemical or continuous processing revolution of the late 19th century and, above all, the Scientific and Technological Revolution (STR) of the post Second World War period (Bernal, 1971b: Teich, 2008).

It has been argued, perhaps provocatively, that the STR is not merely a milestone in technological development, but marks a truly epochal change from the dominance of the mechanical mode of processing material (cutting, forging, stamping, shaping, and so on) to the increasing use of biological, chemical and, in general, molecular and atomic level transformations of the materials used in production (Kolontayev, 1981). For countries such as India, the significance of such a qualitative change in the basic processes underlying technology, was that they had now not only to achieve comparable levels of expertise in the domain of pre STR production processes; if they were truly to achieve world parity as nations with developed systems of industrial production, they had also to manage the transition to the new forms of production.

Unlike the single task set for the innovation systems in industrialised economies, in 1947, India had simultaneously to complete the prior task of bringing its more conventional technological systems of production to contemporary standards while initiating research into the novel processes. There were, then, three industrial research systems that had to be conceived, institutions established to undertake relevant research, and credible linkages with the production systems forged and sustained: for the post STR or epochal technologies, for the new technologies of the pre-existing epoch and, finally, the upgradation and modernisation of technologies which industries in India utilised at the time (Tyabji, 2000). The historical record shows that while the understanding of India's partial and lopsided industrialisation was apparent to the political leadership of the Independence movement, questions of technology and the issues connected with it obtained only partial recognition, and this too, in highly segmented areas. In the area of energy supplies, the combination of the post war euphoria over the seemingly unlimited

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prospects of atomic energy, and the personal standing of Homi Bhabha led to the early recognition of the role of this new source of energy, and a concerted drive to establish the scientific and technological infrastructure to develop this source (Phalkey, Chowdhury). On the other hand, the investigation of new materials, an important component of the STR, had to wait for 20 years until the space effort was firmly established in the 1970s. While developments in organic chemical technology, dependent on the petro chemical industries originated in the mid 1960s, sustained attention to the biological processes began in the 1980s (Bhagavan, 1997).

Of course, given Indian scientific and technological expertise in the first two decades after independence, not much more could have been expected even if the potential of biological, and chemical industrial processes had been more early and more comprehensively comprehended. The real basis for a fair estimation of the forethought in Indian scientific and technological planning lies in the second and third science and technology systems, of new technologies of the current epoch, and the upgradation of pre-existing technologies already in use in Indian industry, principally cotton and jute textiles, sugar, cement, and light and medium engineering. In these cases, there was an integrated approach which found expression in the constitution of the Council of Scientific and Industrial Research (CSIR), and the thrust of this paper will be precisely on evaluating the role of technology policy, centred on the CSIR, in India's attempt to enter the technological world of the post World War II era.

2 The Indian National System of Innovation

Industrial development in India can be dated from the mid 19th century, with the establishment of the cotton and jute textile industries. This was followed by the initiation of steel production at the Tata Iron and Steel Plant in the first decade of the twentieth century, some heavy inorganic chemical units and the more widespread growth of sugar and cement manufacturing units in the interwar years. These initiatives were enabled by the presence of specific niches in the imperial balance of payments systems (cotton and jute), or by specific considerations of the imperial state (steel, sugar, heavy chemicals) which granted special exceptions to the generally obstructionist, if not overtly hostile, state policies towards Indian industrialisation (Tyabji, 1995). As a result, by the time of Independence in 1947, India had a significant though both structurally and geographically highly imbalanced industrial base.

Together with this production structure, an edifice of scientific research institutions had also come into existence, with imperial research organisations dating from the late 19th century, and starting just a little later, the establishment of nationalist supported scientific institutions (Dasgupta, 2011). Neither of these was oriented to the science of industry. By imperial design, the focus of the state institutions was towards a science-of-extraction, the investigation of methods by which India's raw material base could more efficiently be investigated and excavated (Kumar, 1995; Arnold, 2000). The nationalist institutions, on the other hand saw their primary motive as the creation and consolidation of scientific expertise in laboratory based research, unconnected to the demands of industry. Under the pressure of the national movements, there were some attempts by Provincial Governments at development work aimed at encouraging small scale industries (handlooms, leather and simple metal working) but this was essentially derivative work, however ingeniously these initiatives were devised (Tyabji, 1995).

A further factor that militated against the start of a science-of-production, even when opportunities for the scientific analysis of existing technologies were identified, was the general indifference of Indian industrialists to the benefits of this approach (Tripathi, 1996). Thus, proposals to increase the ability of the sugar industry to with stand competition by the investigation of commercially useful by products, thereby increasing the value added of sugar manufacture were spurned by the manufacturers. An unwillingness to devote financial and managerial resources to the improvement of the technologies in use was to prove to be an enduring characteristic of Indian industrialists stretching, in fact, to the present day; this added one more dimension requiring attention before a system of science-of-production could be set in motion (Tyabji, 2000).

These dimensions may be identified as: the process of cognition of the relationship between science and technology in the contemporary era; the elaboration of institutional structures housing specific research activities of the innovation chain; and the creation of explicit awareness of the necessity of linkages between these distinct activities within their institutional structures in the innovation chain. These were, of course, the requirements of any effective national science and technology system in the post WW II era. In an ex colonial country as India, there were three further issues to be considered: the establishment of an up to date integrated industrial structure; ensuring that an economic strategy which aimed to change the terms of India's relationship with the world economy, from a raw material supplying appendage to a role of partnership in international industrial trade was undeviatingly pursued; and, finally, inducing a consciousness amongst industrialists of the role of the firms under their control in ensuring the integrated and coherent operation of the innovation chain. Although the concept of the National System of Innovation was formalised much later, it needs to be emphasised that the Independence movement in India had witnessed considerable discussion on these issues (Nayar, 1983; Abrol, 1995; Sinha, 1995; Godin, 2009).

Both in the sphere of political economy and in the domain of the science-technology system, three phases have been identified in post independence Indian history (Subrahmanian, 1987). These comprise, firstly, the period from independence in 1947 to the mid or late 1960s. The second is from 1970 to the decisive interventions towards liberalising the external economy in 1991, and the third is the period of the deepening of the measures to liberalise the internal and the external economy, post 1991.The first period is characterised by more or less consistent measures to establish an industrial base through the strategy of import substitution, with an attempt to locate critical industrial technologies in the public sector. Towards this end, specifically from the Second Five Year Plan (1956-61) onwards, there was a conscious subordination of monetary and foreign trade policies to the requirements of industrial policy. However, this period was also associated with a prolonged process of learning to grapple with issues of the science technology relationship, and with the easy assumption that transactions in the international capital goods market were synonymous with technology transfer. This was to have, as will be seen, serious effects on stifling the initiation and growth of a virtuous interaction between the science and technology systems and industrial firms (Suri, 1968; Ganapathy, 1971).

By the time of the second phase, there was a much greater understanding of the nature of the science-technology interface and, as the period progressed, institutional mechanisms were identified, designed and operationalised to ensure that the infrastructure was at least in place (Parthasarathi, 1987). However, after a relatively short period, by the mid 1970s, the demands of a changing political economy began to affect the performance of the innovation system (Subrahmanian and Pillai, 1976; Subrahmanian, 1978; Subrahmanian, 1991; Pillai, 1979; Pillai, 1990). Earlier, from the mid nineteen sixties the strategy of import substitution based on the potentially large market for mass consumption goods came across the constraints of the inadequate purchasing powers of the bulk of the people, particularly in rural areas. In response to indications of this crisis, in terms of declining growth rates and underutilised industrial capacities, the decision was taken, from 1976 onwards, to introduce carefully graded measures of internal liberalisation, so as to enable industry to respond to the effective demand for high end consumer non durables and a range of consumer durables associated with upper income urban and a segment of rural households. Although economic and, in particular, industrial growth rates considerably improved, the demands for advanced industrial technology to service these demands led to increasingly apparent contradiction between the aim of technological self reliance and the actual record of foreign technology acquisition decisions

The contradictions experienced by the economy in this period, combined with an increasingly more strident demand that the only route to the resolution of these contradictions lay in the substantial integration of the Indian economy within the world economy, led to the structural reforms of the post 1991 period. This phase, now 20 years old can be characterised, most simply, as based on a variant of market fundamentalism, that the market is not only benign in its operations, but after the historical evidence of the socialist societies of the 20th century the only reliable and effective mechanism for resource allocation. It is within this broad delineation of India's post independence history, that this paper will locate the changing nature of the science-industry relationship.

3 The Science Industry Interface 1947 to 1970

As has been mentioned, the pre-independence period had seen the growth of scientific institutions, oriented to the science of extraction. This was associated with the growth of an industrial structure under the auspices of an industrial class which, though surprisingly entrepreneurial in overcoming colonial constraints, was entirely disinclined to allocate resources for the internal generation of technological expertise. Thus the demand for the establishment of a scientific establishment geared towards generating a science *for production* came from Indian scientists dismayed at the prospect of a continuing dependence on technology imports (Krishna, 1995). From the time of establishment of the Department of Industrial and Scientific Research (DSIR) in post World War I Britain, there were repeated calls for the creation of equivalent facilities in India. When the Board, and then, the Council of Scientific and Industrial Research was finally established in 1941, it was modelled on the institutions in Britain. This was to have a number of consequences: in Britain, itself not a notable example of dedication to technological development, much of the generic research was conducted by industrial research associations, with DSIR organisations (principally the National Physical and Chemical Laboratories) engaging in fundamental areas of research. It was presumed there that the industrial research associations in association with individual firms, would bridge the gap between fundamental research and the final stages of the creation of commercially viable production processes. In India, it was early recognised as inconceivable that industry, unwilling to finance even in-house research, would be prepared for cooperative research (India, 1945). This was so even in the few areas (cotton and jute textiles, sugar, cement and light engineering) where an industry (as opposed to a handful of firms) existed at the time. What was problematical, then, in the design of the innovation system was the (unexplored) presumption that the CSIR laboratories would be able to take their discoveries to a stage where an individual firm would find it profitable to invest its resources in bringing the process and associated products to the stage of commercial production.

The assumptions underlying the design of the innovation system incorporated the concept of the linear innovation chain, from pure (or fundamental) science through applied science, the scaling up of processes to pilot plant scale, and the ultimate development of commercially viable processes (Godin, 2006) . These processes would then be used to manufacture products. In India, it was assumed that the first two phases would be housed in CSIR institutions (cf. Kuchhal, 1995). Pilot plants for scaling up exercises were installed in rare cases (Vishvanathan, 1985). In the event, individual firms were expected to take the process post applied science phase further. In a situation of Indian industry's well recognised indifference to in-house research, these were unrealistic assumptions. A further assumption, unexplored it would be emphasised, underlying the linear innovation chain was that industrial units would acknowledge the commercial viability of processes developed in CSIR laboratories ((India, 1963:29-30). All this presumed that the scientific studies undertaken in the laboratories were themselves amenable to industrial application. In fact, during the first 10 years of the CSIR systems' existence, there was little focus in the initiation of scientific study based on the possibility of its industrial application (India, 1964; Parthasarathi and Singh, 1992, Anderson, 1999b: 346-354).

Recognition of the limitations of the linear model and, more crucially, on the behavioural presumptions on which the institutions were operating, came slowly and obliquely. Thus information that a large proportion of the overall costs of introducing a new production process were incurred in the penultimate phases came from a senior executive of a transnational corporation (India, 1949:26). These phases, under the existing structure, lay beyond the domain of the CSIR, and within the responsibility of industrial concerns; this drew attention to one of the reasons why firms were unwilling to buy CSIR developed processes (India, 1963:30). Setting the context for this hesitation, however, was the aura surrounding foreign collaboration as the preferred (and indeed, the only possible method presumed) of industrialisation amongst influential sections of decision makers (India, 1963; India, 1964; Subrahmanian, 1966; Subrahmanian, 1968; India, 1968; Subrahmanian, 1972).

An additional problem, stemming from the assumed linear model, was the disconnection between the sequence of initiation of CSIR laboratories, and the structure of industry as planned (Parthasarathi and Singh, 1992). Coordination here was critical if import substituting industrialisation were to be accompanied by technological self reliance. However, by the time CSIR came to be associated organisationally with the overall industrial planning process, most of the laboratories had already been established, or priorities had been laid down.

A major development in the science-industry system came as a consequence of the Scientific Policy Resolution of 1958. The resolution, which spoke with some inspiration on the role of science, was noticeably less comprehending of the role of technology (Tyabji, 2007). However, at a series of conferences attended by scientists, industry representatives and government officials in subsequent years, the problems underlying the presumptions under which the CSIR organisation had been developed became evident (India, 1958; India, 1963; India 1966; Nayudamma, 1966; India 1971). Apart from the skewed distribution of the costs of development of new processes mentioned earlier, there was new information from Japan: although technology transactions were as prevalent there as in India, the Japanese research effort was concentrated on a cyclical model of technology upgradation, where investments were made in the incremental improvement of processes. By this, the Japanese were able to compete effectively with their erstwhile technology suppliers, surely the desired goal for Indian industry (India, 1963:63; Oldham et al, 1968).

4 The Science Industry Interface 1970-1991

The outstanding achievement of the first period was the advance in the understanding of organic chemistry, specifically, the chemistry of the pharmaceutical industry. Chemical processes were the precursors of the characteristics of the STR era, atomic energy above all, in basing themselves on fundamental laboratory investigation. In that sense, the linear model could be said to be not so much to be invalid, as a generalisation based on the new epochal processes. The physical processes which underlay the mechanical sciences, the base of the engineering industries, were well understood. As the Japanese had shown, it was through applied research on established technologies that productivity gains accrued. These distinctions were later to be theorised as sectoral patterns of technical change (Pavitt, 1984). Indian expertise in pharmaceutical chemistry was to be made evident in the growth of the indigenous industry after the enactment of a new patent law in 1970, which allowed “import substitution” of pharmaceutical processes to manufacture drugs discovered elsewhere (Bagchi et al, 1984; Chaudhuri, 1984; Chaudhuri, 2005).

A more nuanced appreciation of the innovation process was evident in other areas, in addition (Parthasarathi, 1969a; Parthasarathi, 1969b; Nayudamma, ; Parthasarathi, 1970). Recognition of the critical need to encourage in-house research, by inducing firms to establish research and development (R & D) units, was accompanied by the introduction of fiscal incentives to encourage import of the necessary equipment together with other state support measures (Subrahmanian, 1971). The more or less perfunctory technological appraisal of foreign technology transactions gave way to considerably more rigorous scrutiny (Subrahmanian, 1966; Singh, 1971; Parthasarathi, 2007). An attempt was made to establish a planning process for science and technology with the formation of the National Committee on Science and Technology. Although the effort to introduce this exploratory exercise on an institutionalised basis failed, it was itself a sign of the recognition of the dynamic nature of the science-industry interaction process (Bhaneja, 1976). The abandonment of this exercise was largely the result of the liberalisation process initiated in the middle 1970s, noted earlier, which made projection exercises of commercially oriented scientific research less viable.

The cleavage, between an increasingly more focussed technology policy and a more market oriented economy was characteristic of this period (Aurora and Morehouse, 1972; Reddy, 1977; Bhatt, 1978; Bhatt 1980; Morehouse, 1980; Mitra, 1981; Kumar, 1985; D’Mello, 1985; Subrahmanian, 1986; Kumar, 1987a; Kumar, 1987b; Kumar, 1990). There was a process of divergence between the more sophisticated cognition of the nature of the innovation process, of the linkages entailed by this new understanding, and the controls placed on indiscriminate technology transactions on the one hand, with a growing reliance on the market for individual firm’s decisions in the area of new product introductions (Desai, 1980; Alam and Langrish, 1984; Kathuria, 1987; Singh, 1987b; Gumaste, 1988; Subrahmanian, 1991).

One of the features of the earlier period had been the growth of production capabilities in critical areas of technology within the public sector (Pillai, 1978; Dasgupta, 1981; Khanna, 1984; Mani, 1989; Ram, 1990). As in the private sector, the emphasis here had been on the acquisition of production expertise, sometimes to the detriment of technological expertise; however, in many cases the actual scale and complexity of the technology made in-house process knowledge imperative (Dhar, 1984; Dhar, 1985; Ghosh, 1986). In a few cases, this was developed to the stage of high grade R & D capability, of an order which posed a challenge to the original technology suppliers, allowing these firms to compete internationally. Here there was evidence of an integrated science-industry interface within the organisation, along the lines of established transnational corporations: these corporations embodied the fruition of the Indian conception of self reliance in industrial structure *and* self reliance in technology (cf. Nath and Misra, 1994).

It was perhaps these examples that led the authors of the 1986 CSIR Review Committee, at the tail end of this period, to re-recognise that the natural location of fundamental research was in the universities (whose talents had been cannibalised in the efforts to staff the CSIR laboratories), while the natural home for R & D was within the corporate sector (India, 1986). CSIR could then have as its rightful role the arena of advanced research in the production sciences. Such a role would have provided scope for CSIR researchers to function as scientists (rather than technicians working to industrial priorities) providing the base for Indian industry's transition to epochal areas of technology. However, the realities of the continuing corporate disinclination to engage with challenging areas of research, together with the imperatives facing a fiscally impaired state undergoing deregulation, pointed the Committee towards recommendations in quite mundane areas (Singh, 1986; Singh, 1987a; Valluri, 1989; Sandhya et al, 1990; Valluri, 1990).

5. The Science Industry Interface 1991-2011

The policy objective of the structural adjustment programme initiated in 1991 was to induce technological consciousness in Indian firms, so as to increase their competitiveness and India's export earnings from manufactured items. A major pillar of the National System of Innovation, the subordination of other elements of macroeconomic policy to the requirements of industrial policy was dismantled: henceforward, monetary and trade policies were to be determined autonomously. The basis for the National Innovation System was thus demolished leaving a residue of discrete and uncoordinated programmes for specific industries, a situation that was clearly apparent even twenty years later (Krishnan, 2010: 109-111). Given the performance of industry thus far, it could have been expected that the roles for university, industry and CSIR would be redefined along the lines contemplated by the 1986 CSIR Review Committee (Bhagavan, 1995). On the contrary, the period has seen, through processes engendered by the market, both the dismantling and the decoupling of the institutional base by which the three elements of the system could interact (Valluri, 1993; Valluri 1997). For a substantial period of time, the universities were squeezed of funds, while scholarships in schools which had often determined the choice in favour of following a scientific career were reduced in volume and scope (Krishnan, 2010: 112-119). Rather than a focussed attempt to ease the transition to the operation of the world economy the corporate sector was left to its own devices, to exit areas where competition was the most intense (or corporate animal spirits were lacking), to collaborate with transnational corporations, trading knowledge of local conditions for access to the Indian market, or to leave the industrial sector entirely, after selling out at a substantial monetary gain (Alam, 1993; Subrahmanian et al, 1996; Alagh, 1997; Aggarwal, 2000; Katrak, 2002; Bowonder and Satish, 2003; Kumar and Aggarwal, 2005). Shortly put, this phase does not exhibit any identifiable coherent conception of the science-industry interface (cf India, 1996). CSIR has itself embarked on a role tangential to the logic of improving on achieved technological capability, providing its expertise on the national and international market irrespective of whether the buyer is an Indian or a transnational firm or organisation (Abrol, 2007).

The two successful cases of the post liberalisation era are the software and pharmaceutical industries, with the biotechnology firms achieving some technological breakthroughs, though not yet achieving substantial commercial success, internally or internationally (Bagchi-Sen and Lawton-Smith, 2008; Mallick and Ejnavarzala, 2010; Soby et al, 2012). The case of the pharmaceutical industry was mentioned earlier as an instance of first phase capability accumulation, combined with second phase administrative support. The performance of the industry after the introduction of the WTO regime in 2005 has been noteworthy, particularly in the recent period when the slowdown in new drug developments has led the transnational section of the industry to identify the area of generic drug production as promising (Dhar, 2003; Abrol, 2004; Ray, 2004; Greene, 2007; *Technology Analysis & Strategic Management,* 2007; Basant, 2011; Chaudhury, 2012; Joseph, 2012)). This enduring expertise seems to be based on a specific niche area of competence with no evidence of a new phase of the science-industry interface accounting for it (Tyabji, 1999; Basant and Chandra, 2002; Krishnan, 2010; Krishnan and Jha, 2011). The software industry, also recognised as an exemplar in terms of its export earning potential is equally a case of identification of niche areas in the international information technology "supply chain" with little technological backing from external institutions (Heeks, 1996). It is recognised that the basis for this expertise is a result of the nurture that key institutions were provided during the small window created by the combination of focussed attempts to regulate both technology imports, and areas of industrial investments, in the first half of the 1970s (Sharma, 2009). In short, the two post globalisation decades have shown no evidence of conceptual developments which might underlie a new logic of the science industry interface, in an era where the prerequisites for a National System of Innovation have been degraded (cf Krishnan, 2003; Mani, 2007; Krishnan, 2010; Abrol, 2010; Mani, 2011).

6 Conclusions

The forty five years between independence and 1991 showed significant and impressive developments in the task of grappling with the multi dimensional task of establishing a modern industrial structure. However, during the twenty years after the introduction of the structural reforms programme, the share of manufacturing has stagnated at about 15 per cent of the gross domestic product. India's contemporary international image is clearly not based on its productive prowess. To the extent that this image has any material base, it rests on the performance of the software services industry and on the generic drug capacities in pharmaceuticals While the drug industry's performance has long been acknowledged to be based on expertise in chemistry and on administrative measures such as the 1970 Patent Act, there is now increasing acceptance that that software industry also owes its success to developments specific to earlier phases. Two recent instances of the vagaries associated with India's flat footed integration with the world economy have recently caused some reconsideration of the market fundamentalism that has characterised policy since 1991: the first is the acquisition of leading pharmaceutical firms by transnational corporations; the second is the fragility of India's software exports due to the after effects of the 2008 recession and the concerns expressed in the United States over job losses due to the relocation of routine business processing operations abroad. However, there is no evidence yet of application of mind to the fundamental problem of reformulating the science industry nexus in the contemporary context.

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