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Emerging through Technological Capability: An Overview of India's Technological Trajectory

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Foreword

India's emergence as a major economic power over the last decade can be attributed in a significant manner, to its sustained efforts at technological learning and capacity building. Professor Amit Shovon Ray, who recently joined ICRIER as Chair Professor of Trade, Technology and Competitiveness, has been researching on issues of technology and R&D in India for now over a decade. This paper puts together the set of research findings pertaining to India's technology capability acquisition.

The paper presents a comprehensive overview of India's technological development with a view to understanding the role it has played in the process of India's economic progress. It includes a discussion on the process of technological learning and catch-up through appropriate policy designs including a favorable IPR regime pursued by India. The paper argues that India's achievement have by and large remained confined to "minor" as opposed to "major" innovative capabilities. However, India has displayed significant competitive strength in routine (but skill intensive) tasks like coding (in software) or process development (pharmaceuticals), and perhaps less so in product innovation and processes that are at the frontiers of global technology. I am sure the paper would be of interest to both academicians and policy makers.

(Rajiv Kumar)
Director & Chief Executive

November 26, 2008

Abstract

India's emergence in the world economy over the last decade, has often, in popular discourse, been attributed, at least to a large extent, to its sustained efforts towards technological learning and capacity building. In this paper we present an overview of India's technological trajectory with a view to understanding the nuances of India's technological capability and the role it has played in the process of India's economic progress. Our conclusion is that while India has successfully nurtured its high-end human capital for technological learning and is poised for a smooth transition to a knowledge economy, there has been a tragic neglect of low end human capital investment for productivity gains in mass manufacturing. This can not be ignored while carving out an appropriate technological strategy for India for a sustainable and "inclusive" growth process.

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Emerging through Technological Capability: An Overview of India's Technological Trajectory

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I. Technological Progress and Economic Growth

For a very long time, economic theory highlighted capital and labour, the two primary factors of production, as the key driving force behind production and growth. It was only in the 1950s that technological advancement as an important source of growth was brought into the discussion of mainstream economic theory. Solow's (1957) pioneering attempt to estimate the contribution of physical factors to growth, by introducing the technique of growth accounting, revealed that only 1/8th of the growth of the US economy during the first half of the present century could be explained by the growth of its endowments of physical factors, leaving the remaining to a "residual" (termed as technical progress or total factor productivity growth (TFPG)). Focus shifted thereafter from physical factors to the role of technology in production and growth. It is fairly well established now that technological advancement resulting from R&D is the most important factor behind today's productivity growth.

Indeed, the growth experience of most advanced industrial nations has been driven by TFPG rather than by growth in factor endowments. For these nations, operating essentially on the frontiers of global technology, TFP growth necessarily implies an outward shift of the technological frontier. Of course, the contribution of TFPG to their economic growth has not been uniform across all industrialized nations. Hayami (1999), for instance, compared the sources growth in Japan and the USA during their respective high growth periods (1958-70 for Japan and 1929-66 for the USA) and found, not surprisingly, that Japan's growth was attributable to both capital input growth as well as technical progress as opposed to the US experience of predominantly technology driven growth – TFP contribution being 53 per cent for Japan's growth and 80 per cent for the USA.

Even, for the late industrializing countries in East Asia (the so-called East Asian Tigers: South Korea, Hong Kong, Singapore and Taiwan), the contribution of TFP has been observed to be much more moderate than the US experience. According to World Bank (1993), approximately two-thirds of the observed growth in these economies may be attributed to accumulation of physical and human capital and the rest came from total factor productivity growth. This is not to deny that productivity growth *did* play a very important role in East Asian success, but it was clearly not the sole (and not even the dominant) factor.

However, equating productivity growth with technological progress a la Solow (1957) can also be somewhat problematic in understanding the growth successes of developing nations. Not all productivity growth is derived "pure" technological advancement. Rather, a large part of productivity growth may arise out of improvements in labor force and human capital accumulation leading to high levels of cognitive skills of the labor force that permit better firm level adoption, adaptation and mastery of "given" technologies. In fact, Young (1995) makes an exemplary attempt to control for all changes in inputs, including improvement of the labor force as well as sustained capital accumulation, and found the residual TFP contribution to the growth of the East Asian Tigers between 1966 and 1990 to be abysmally low. It was 2.3 percent in Hong Kong, 2.1 percent in Taiwan, 1.7 percent in South Korea and 0.2 percent in Singapore. Hence "technological improvement" in the neoclassical sense was perhaps not *that* important in facilitating the East Asian Miracle.

II. Beyond Neoclassical Perspectives: Technological Capability of LDCs

In the neoclassical theoretical tradition, technological progress is identified with major breakthroughs in science and technology resulting in a shift of the frontier.[1] As a result, the important contribution to technical progress made in diffusion, adaptation and application of new technologies, which are particularly important in the context of LDCs, has remained under-emphasized. However, the evolutionary models of technological progress (Nelson & Winter, 1982; Mowery & Rosenberg, 1989) are perhaps the only theoretical constructs that consider minor, as opposed to major, innovations to be the more likely and more conventional research output of any R&D programme. These models have a broader perspective on technology defined as a set of linked capabilities based on different types of knowledge: formal and informal (i.e. tacit or experimental). Indeed, the evolutionary models' characterization of technical change as a "tacit", "path-dependent" and "non-linear" movement makes technological progress similar to the process of technological catch-up commonly observed in many LDCs.

Lall (1987) observed that "*considering technological progress only as a movement of the frontier is a highly simplified neo-classical view because 'major technological innovations' are not the only, perhaps not even the main, source of productivity improvement in the history of industrial development … and … minor changes to given technologies—to equipment, materials, processes and designs—are vital and continuous source of productivity gain in practically every industry*". Therefore, one can argue in line with Bell (1984) that technological effort should ideally be viewed as "conscious use of technological information and the accumulation of technological knowledge, together with other resources, to *choose*, *assimilate* and *adapt* existing technology and/or to *create* new technology". This is what reflects *technological capability of an LDC, defined as the capacity to select, absorb, assimilate, adapt, imitate and perhaps improve given (imported) technologies*. Several case studies (country level, industry level and firm level) confirm that the creation of such indigenous technological capabilities requires conscious technological effort and risky investments in R&D.

Accordingly, one must broaden the definition of technological output in the context of a so-called *research production function* of an LDC. R&D units in LDCs need not

[1] See, for instance Schumpeter (1934, 1939). Note that Rosenberg (1976) has strongly criticized the Schumpeterian usage of the term "innovation" on four grounds: "(1) We confine our thinking about innovations to characteristics which are likely to be true only of major innovations, (2) we focus disproportionately upon discontinuities and neglect continuities in the innovative process, (3) we attach excessive importance to the role of scientific knowledge and insufficient importance to engineering and other 'lower' forms of knowledge, and (4) we attach excessive significance to early stages in the process of invention and neglect the crucial later stages".

come up with very different products or processes but may still be acknowledged as an innovator, albeit of "minor" rather than "major" innovations. The distinction between minor and major innovations proves to be extremely important in understanding technological progress in developing countries.[2]

The stages of technological capability acquisition can be described as a process of *path dependent evolution*.[3] It begins with *learning by doing* followed by *learning by adapting*, aiming at augmenting productivity through efficient utilisation and adaptation of technologies at the shop floor. We call this the stage of *production engineering*. Next comes *learning by design* and *learning by improved design*, aiming at replicating processes and designs for better understanding and further improvement of given technologies. This stage is described as *reverse engineering*. All this culminates into *learning by setting up complete production systems* and *learning by designing new processes* which ultimately sets the stage for *basic (frontier) R&D capabilities.*

Following Lall (1985), it is useful to categorise technological capability as "***know-how***" and "***know-why***". *Know-how* is acquired through "not only the assimilation of imported techniques (which itself can be a lengthy and active learning process) but also quality control (which also involves active technical effort), improved plant layout and production practices, slight modifications to equipment and tooling, troubleshooting, the use of different raw materials and so on",[4] all of which can be summarised as production engineering. *Know-why* is the next stage of technological development, which involves the understanding of the nature of the process and product technologies leading to the development of new improved designs. Applied research and frontier R&D leading to major innovations follow this stage.

Broadly speaking, *know-how* is expected to bring about rapid and immediate productivity growth in LDCs. *Know-why*, on the other hand, is absolutely necessary (but by no means sufficient) to create and strengthen the technological foundation of LDCs. Without going through this phase of *know-why* oriented technological learning, LDCs can never aspire to reach the global technology frontier to catch up with the levels of technological advancement of developed countries in the long run. However, there may not be any immediate pay-off of *know-why* oriented technological effort in terms of immediate productivity gains in the short and medium terms.

What then are the technological options available to LDCs? In very broad and simple terms, there are two alternatives, not necessarily mutually exclusive:

1. Bring in latest imported technology (exploit the global frontier) and focus on *know-how* to reap maximum productivity gains.

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[2] Indeed, instead of recognising the key role played by the capability to invent around (minor innovations), the rise in competitiveness of Japanese industries in the mid-1960s was initially wrongly attributed to low labour cost advantage (along the lines of the product cycle paradigm). See, Rosenberg and Steinmuller (1988).

[3] Lall (1978)

[4] Lall (1985), page 116.

2. Concentrate on *know-why* and applied research to create capabilities to generate new technology and attempt to catch up with the advanced nations on their own footing.

Historically, LDCs have usually opted for different combinations of the above two, depending on their initial conditions and policy focus. Accordingly we may find inter-country variations in the levels of technological capability acquired by LDCs. Evenson and Johnson (1998) have classified developing countries into six levels of technological capability. Countries belonging to the lowest three levels of technological capability generally do not undertake any R&D work. Though a little bit of R&D work is visible in the third level, it is mostly directed towards pirating of trade marks and design. In these three levels production technology is essentially purchased in an "inter-linked" contractual form. In the fourth and fifth levels of technological capability, the dominant objective of firm level R&D is to facilitate technology purchase, directly (licensing) or indirectly. Here the role of R&D is to create absorptive capacity to understand and adapt and implement the purchased technology successfully. Some adaptive invention is undertaken, usually stimulated by domestic intellectual property rights. The technological competence developed through R&D in these countries is instrumental in initiating activities of reverse engineering or imitation. In the sixth level of technological infrastructure, imitation is generally taken up as a conscious policy of technology generation through a more structured "buy-then-imitate" strategy. According to this classification by Evenson and Johnson (1998), India falls into the fifth level of technological capability while Korea belonged to the sixth level.

III. India's Technology Policy Framework[5]

India is among very few, but perhaps not unique, less developed countries (LDCs) that have pursued a well-articulated technology policy providing the broad guidelines for technological development within the country. India's technology policies included both direct policies for indigenous technological development as well as indirect policies for restricting and regulating technology imports and technology transfer. The first *Scientific Policy Resolution* was published as early as 1958 and the latest *Technology Policy Statement* appeared in 2003. Over this half a century, there has been a major shift in India's policy stance towards technology development, roughly coinciding with India's economic reforms and trade liberalisation in the 1990s. Accordingly, India's technology policy environment has been distinctly different in the pre and post-reforms period.

III.1 Technology Policy in the Pre-Reforms Period (pre-1991)

The basic objective of India's post independence technology policy was "the development of indigenous technology and efficient absorption and adaptation of imported technology appropriate to national priorities and resources."[6] Attainment of technological competence and self reliance was placed at the heart of India's technological development. The aim was to achieve breakthroughs in indigenous technological development "appropriate to national priorities and resources" (i.e.,

[5] This section draws heavily on my earlier paper, Ray (2004).
[6] *Technology Policy Statement of 1983*, Govt of India (1983), page 3.

maximum utilisation of human resources, efficient use of energy, increasing productivity, maintenance of ecological balance).

In fact, prior to 1990, the Indian economy operated within the broad framework of an inward looking policy regime of protection and interventions. Restrictions and regulations on trade and industrial production were pervasive. Against this backdrop of the overall policy framework, the main focus of India's technology policy was not only to build up *search*-, *selection*-, *implementation*- and *absorptive*- capability, but also to acquire technological capabilities of *adaptation* and *minor innovation* through reverse engineering.

Considerable resources were allocated for this purpose. Indeed, India's share of national R&D expenditure in gross national product (GNP) had increased steadily from 0.17% in 1958-59 to 0.98% in 1987-88, the major share of which was borne by the Government.[7] The overwhelming majority of government R&D expenditure was allocated to various public sector research laboratories, under the auspices of the CSIR (Council of Scientific and Industrial Research) engaged in applied research in a wide range of fields including areas like aeronautics, experimental medicine, environment, oceanography and structural engineering.

Apart from spending on R&D itself, the government also offered specific *R&D incentives* with the objective of building up domestic technological capability for rapid industrialisation. Prior to the 1990s, the main thrust of the R&D incentives was to generate indigenous technologies primarily in the institutional sector (public funded R&D institutions) and facilitate effective commercialisation, transfer and absorption of such technologies in the industrial sector. There were very few incentives at the firm level with the explicit aim of augmenting technology-creating capabilities. In-house R&D was encouraged only to facilitate acquisition of technological capabilities of absorption, adaptation and assimilation. Special incentives were given to firms using indigenous technologies developed by R&D institutions.

Apart from these direct policies to promote indigenous technology development, the Government has also adopted indirect policies for restricting and regulating technology imports and technology transfer. Till 1991, import substitution and technological self-reliance constituted the core of India's technology policy, which was in line with its inward looking overall policy regime. Import of technologies in the form of licensing as well as foreign direct investment (FDI) was severely restricted in order to promote indigenous technology. The importer of technology had to obtain a clearance from appropriate government authorities after a thorough screening to make sure that there are no objections on grounds of high cost, "inappropriateness", availability of local substitutes or even the long term building up of indigenous R&D capability. The onus lay on the prospective importer to show that the technology was necessary (in terms of plan priorities), not available locally and fairly priced (Lall 1984).
Another indirect policy instrument has been the *Intellectual Property Rights* (IPR) Regime adopted by India. The Patent Act of 1970 did promote considerable technological learning and acquisition of technological capability through reverse

[7] Even as late as 1998-99, 75.5% of the national R&D expenditure in India was borne by the Government.

engineering activities. This issue of IPR as a determinant of technological development will be discussed at length in a subsequent section.

Thus, India's technology policy in the pre reforms era was essentially grounded on building up of national level capabilities through the public institutions, while at the same the industry (private and public sector) was encouraged to actively engage in R&D activities to develop absorptive and adaptive capabilities of minor innovations.

III.2 Technology Policy in the Post Reforms Era (post-1991)

The decade of 1990s started with the ongoing thrust of integrating the Indian economy with the global economy in the GATT-WTO framework. From 1991, with the liberalisation of the Indian economy, restrictions on imports, FDI and technology transfer have been progressively removed. The technology policy also had to be moderated, and attuned to meet the new challenges of global competition. In fact, the *Science and Technology Policy 2003* states that, "*It is recognised that these objectives* (of S&T policy 2003) *will be best realised by a dynamic and flexible Science and Technology Policy, which can readily adapt to the rapidly changing world order. This policy, reiterates India's commitment to participate as an equal and vigorous global player….*"

The decade of the 1990s saw a departure in the sense that government attempted to distinguish between fundamental R&D and commercial R&D, both in the private R&D units. It encouraged the creation of the so-called *Scientific and Industrial Research Organisations* (SIRO) in the private sector for undertaking more fundamental R&D in a non-commercial manner. Such private sector R&D institutions might have existed even earlier, but in the late 1980s, they were given renewed attention and emphasis under the new name of SIRO.

One contrasting feature is the shift of focus from national R&D institutions to R&D carried out by the industry either in in-house R&D units or in the SIROs. Industry captured the lion's share of the incentives provided in 1990s compared to the earlier decade, when the majority of the incentives were directed to public R&D institutions. Indeed, post 1991, the thrust of R&D incentives showed a clear shift away from the institutional sector to technology generation by the industrial sector. In the post reforms period, industrial productivity and technological capability in a more market driven (profit maximising) framework have perhaps been given priority over indigenisation (import substitution) of technology and self-reliance. There has also been a move to encourage collaborative R&D between industry and R&D laboratories.

The nature of some of the *non-fiscal incentives* also underwent significant changes in the 1990s, especially with the introduction of the new Patent Act of 2005 (to be discussed later).

Table 1 presents a summary of R&D incentives in India in the 1980s and the 1990s. We notice a clear shift in the structure of R&D incentives in India and its underlying guiding principles over the period under study.

Table 1: A Summary of R&D Incentives in India

Incentives in the 1980S		Incentives in the 1990S	
To Promote Institutional R&D	*To Promote In-house R&D in Industry*	*To Promote Institutional R&D*	*To Promote In-house R&D in Industry and SIROs*
• Customs Duty Exemption • Depreciation Allowance* • Investment Allowance* • Weighted Tax Deduction* *: granted to firms for using and commercialising technologies developed by institutes	• Income Tax benefits (100% tax deduction)	• Duty free Imports • Depreciation Allowance* *: granted to firms for commercialising technology developed by institutes	• Income Tax deduction • Weighted Tax Deduction on Sponsored Research • Tax Holiday • Excise Duty Exemption • Weighted Tax Deduction, industry specific • Customs Duty Exemption to SIROs • Excise Duty Exemption on Purchases made by SIROs • Income Tax Exemption for donation to SIROs • Excise and customs duty benefits to Biotech & Pharmaceutical

IV. India's Trajectory of Technological Capability Acquisition

Against this backdrop of a well articulated technology policy over the last half a century, India's share of national R&D expenditure in gross national product (GNP) had increased steadily from 0.17% in 1958-59 to 0.91% in 1988-89. Thereafter it started declining reaching a low of 0.71% in 1995-96 and finally it has settled around 0.8% as per the latest available information.[8] This is rather alarming, especially in the context of the new economic policy regime of reforms and globalisation. In spite of a clear mandate of the *Science and Technology Policy of 2003* to strengthen India's in-house industrial R&D in the post "liberalisation" period by raising the above share to at least 2% of India's GNP by the end of the Tenth Plan, India has not even been able to reach the 1% target. It is worth noting that among the newly industrialised Asian countries, South Korea spends as much as 2.8% of its GNP on R&D, which is at par with industrialised nations, like US, Japan, UK and Germany.

[8] R&D Statistics, Dept of Science & Technology, Government of India.

The Government's R&D expenditure takes two forms: institutional R&D in Central and State Government laboratories and industrial in-house R&D in public sector enterprises, accounting for 62.6%, 8.5% and 4.5% of total (national) R&D expenditure respectively. There is small portion (4.1%) going to higher education, bringing the total share of the government in India's R&D expenditure to 79.7%. The share of private sector R&D remains around 20%. Industrial R&D (public + private sector) constitute only 24.8% of total R&D.[9] This share is remarkably low compared to some of the East Asian countries, e.g. Singapore (60% in 1992), Korea (around 80% in 1992) and Taiwan (50% in 1993).

IV.1 Technological Achievements: Outputs, Expenditure in the Institutional and Industrial Sectors

India's post-independence inward looking policy regime did manage to generate a considerable amount of technological effort and development. To understand India's trajectory of technological learning and technological capability acquisition, let us first take a quick look at the technological achievements in terms of R&D output. As already noted, public sector (institutional R&D) played the dominant role, especially during the pre-reforms period (pre-1990). In this phase, much of the technological effort went into creating technologies first time in the country rather than breakthroughs first time in the world and that too pre-dominantly in the public sector institutions.[10] This is perhaps expected as it conformed to the broad objective of creating technological self reliance in the pre-reforms period. However, it is doubtful whether these efforts of the public research laboratories have had "much impact on technological development in large scale organised industry, though it claims to have provided hundreds of technologies for use to small scale enterprises".[11] More importantly, it is doubtful how efficient these indigenously developed "new" technologies were by international standards of costs and quality.

As far as in-house industrial R&D is concerned, this import substituting policy regime typically fostered several conditions – no direct need to keep up with the global frontiers of technology, small size of operations, various input scarcities, and lack of adequate competitive pressures with respect to cost and quality – all of which dampened the effort to build up sustained technological capability at the frontiers. The absence of competition in any of the three key dimensions (domestic or internal competition, import competition, export rivalry) encouraged conservative technological behaviour on the part of the Indian firms preventing technological upgrading, let alone major innovations and breakthroughs. Moreover, restrictions on technology imports resulted in failure to promote effective transfer and absorption (know-how) of latest global technologies. Although, many Indian firms did manage to assimilate a lot of basic technology and even improved upon it, they remained far behind the global frontiers of technology.

We have already seen that fiscal incentives for R&D have taken a new turn in the era of globalisation with the focus shifting from institutional to industrial R&D. Ray

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[9] See R&D Statistics 2004-05, Department of Science &Technology, Government of India.

[10] In very few cases in which "pioneering" technologies were created were those using typically Indianised raw materials, e.g. Amul Spray – a baby food technology from buffalo milk).

[11] Lall (1984), page 233.

(2004) takes a closer look at the profile and composition of R&D expenditure and outputs in terms of institutional versus industrial R&D over the period 1986-2000 and attempts to relate this with the structural changes in incentives.

DST identifies various technological outputs and publishes it in their biennial R&D Statistics volumes. We have categorized these outputs in two groups: **Type-1** output includes R&D outcomes like patents, product development, process development, development of new designs and import substitutes, which directly *augment firm-level productivity and profitability*. **Type-2** output consists of R&D outputs like consultancy services rendered and publication of books, papers and reports, which reflect technological capability through augmenting knowledge-base, but do not directly enter the firm's production function, at least, in the short run. Table 2 reports the profile of R&D output.

Table 2: Type-1 and Type-2 outputs by Institutes and Industry

Year	Institute Type-1	Institute Type-2	Industry Type-1	Industry Type-2	Ratio Inst : Indy Type -1	Ratio Inst : Indy Type -2	Ratio Type1: Type2 Industry	Ratio Type1: Type2 Institute
1987	951	42083	16273	5916	0.06	7.11	2.75	0.02
1991	3670	23527	13430	5609	0.27	4.19	2.39	0.16
1993	2111	29778	11933	8342	0.18	3.57	1.43	0.07
1995	1335	22290	9687	4283	0.14	5.20	2.26	0.06
1997	2172	70849	13783	10690	0.16	6.63	1.29	0.03

While the institutional sector puts more emphasis on type-2 output, industry puts more emphasis on type-1 output. The industry is more concerned with type-1 output for immediate gains in profitability and productivity. But the institutional sector during the 1980s perhaps followed a social mandate of enriching the public domain of R&D knowledge by producing and disseminating type-2 output. The situation has somewhat changed in the last decade. We find that industry's share of type-2 output in total R&D output is increasing. This increase can be attributed to the changes in the R&D incentive structure, which does not intend to portray the public sector R&D institutes as the sole source of indigenous technologies and knowledge-base. Industry, in the changed scenario, has to appreciate the complementarities between the two types of R&D outputs – instant productivity gains through type-1 and augmenting knowledge base through type-2.

Table 3: Share of Import Substitutes in Type-1 Output

Year	R&D Inst	Industry
1987	0.81	0.22
1991	0.21	0.25
1993	0.40	0.24
1995	0.26	0.34
1997	0.39	0.24

Source: R&D Statistics, DST (Various Years)

One interesting finding relates to the relative importance of import substitutes developed by the institutional and industrial sectors as revealed in table 3. The share of import substitutes in Type-1 output produced by the institutional sector declined from around 0.81 in the 1980s to around 0.3-0.4 in the 1990s. The industry, however, has maintained its share of import substitutes (perhaps a marginal increase) in Type-1 output at 0.2. Note that the decade of 1980s had a clear mandate to develop import substitutes in both sectors which has been removed in the 1990s. We, however, conclude that the scope of cost effective import substitution by industry, especially in a profit maximizing framework, continues even with globalization and economic reforms.

A comparison of aggregate nominal R&D expenditure also reveals some interesting turnarounds (table 4). While every sector has witnessed a growth in the nominal R&D expenditure their growth rates are far from being uniform. Moreover, there is also evidence of contrasting growth rate of a particular sector during the 1980s and 1990s. Overall during the entire period, the growth rate of the private sector R&D expenditure has been the highest followed by the growth of the state sector, central sector and public sector.

Table 4: Rate of Increase in Nominal R&D Expenditure

	Central	State	Inst_Agg	Public	Private	Ind_Agg
Inc 86-98	2.95	5.24	3.12	1.76	7.35	4.75
Inc 90-98	2.05	1.81	2.02	0.57	3.30	2.09
Inc 86-90	0.30	1.22	0.37	0.76	0.94	0.86

Note (1)Inc86-90=(R&D1990–R&D1986)/R&D1986 (2)Inc90-98=(R&D1998–R&D 1990)/R&D1990
Source: R&D Statistics, DST (Various Years)

However, as shown in table 4, during the 1980s, the state sector witnessed the highest rate of increase in R&D expenditure followed by private sector, public sector and central institutes. The decade of 1990s saw a reversal in this trend. Private sector emerges as the fastest growing sector, followed by the central R&D institutes. The rate of increase of public sector R&D expenditure fell from 0.75 in the 1980s to 0.57 in the 1990s. This picture seems to be compatible with the overall decline in the policy attention towards public sector enterprises. On the other hand, co-operative R&D between the private sector and central R&D institutes seems to have taken-off resulting in high growth rates of R&D expenditure in both the sectors. State sector growth rate also increased marginally.

The impact of structural change in the R&D incentive structure is also visible in the pattern of the R&D expenditure by different sectors. The relative share of R&D expenditure by the institutional sector has been steadily declining. Indeed, the government R&D expenditure (especially in the state sector) witnessed high growth in the decade of 1980s, while the private sector R&D expenditure achieved the highest growth rate in the 1990s, perhaps due to the positive encouragement offered to the industrial sector in the new R&D incentive regime. It also appears that central R&D institutes has performed better than the state institutes in the decade of 1990s, may be due to better inflow of sponsored research received by some of them, which has been a key feature of the R&D incentive structure in the 1990s.

IV.2 Total Factor Productivity Growth in Indian Industry

Against the backdrop of India's technological effort as described above, we now explore its experience with total factor productivity growth (TFPG). There have been several attempts to measure TFPG in Indian industry in different time periods. Ahluwalia (1991) summarises the results pertaining to the period up to mid 1980s. Long term TFP growth in this period has been negligible in India. Later studies extended the period and came up with similar pessimistic conclusions. Balakrishnan and Puspangadan (1994), for instance, find TFPG to be 0.33 during 1970-71 to 1988-89. Unfortunately most of these estimates relate to TFPG at the aggregate industry.

In a study undertaken for the Department of Science & Technology, Government of India, we attempted a more disaggregated analysis at the level of 29-industry classification.[12] Using a panel of 29 industries over 1975-76 to 1994-95, we estimated the following robust random effects model of cobb-douglas production function corrected for multicollinearity (using the ratio form) after confirming the hypothesis of constant returns to scale:

$$\text{Log }(Q/L)_{it} = \alpha + \beta \text{ Log }(K/L)_{it} + \lambda t + v_i + u_{it}$$

The estimated values of the coefficients are: α = -5.48, β = 0.26, λ = 0.024, all statistically significant at 1% level. Our estimation thus revealed an overall TFP growth of 0.024 (2.4%) during this period. However, we also noticed substantial variation of TFPG across industries and over time and sought to explain this variation in terms of R&D effort by estimating a panel model of the following form:

$$TFPG_{it} = a + b\ RD_{it} + \gamma t + v_i + u_{it}$$

R&D came up as a significant determinant of TFP growth. The time variable appears negative and significant over this entire period. This is indeed alarming. But we

[12] Ray et. al. (1999), Ray and Bhaduri (2002)

intended to explore whether this reflects a secular decline in TFP throughout the period or has there been any structural break in the growth of TFP. To this end we used time dummy for each year beginning 1978 to estimate the following models:

$$TFPG_{it} = a + b\ RD_{it} + \gamma t + \delta\ t*d + v_i + u_{it}$$

where d=0 if t<x, 1 otherwise. This is to identify possible structural breaks at year x. We find a distinct structural break in the growth of TFP in 1982. After a long period of decline and stagnation, productivity in Indian industry displayed an upward movement. This break coincided with a similar break identified by Ahluwalia (1991) in Cobb-Douglas production function estimation of the Indian industry.

More importantly, we also observed wide variations in TFP growth experience of different industries in our 29 classification structure. Only 8 out of 29 industries recorded positive TFP growth. Among these, E&E achieved a phenomenal 137% growth in TFP during this period. TFP growth in fertiliser and telecom sectors were 73% and 50% respectively. Sugar and fermentation industries displayed moderate TFPG of around 30%. It may be worth noting that almost all sectors constituting the chemical industry experienced negative TFPG with the exception of fertilisers. Interestingly, in the three sectors registering highest TFPG (E&E, fertilisers and telecom), public sector's contribution in total R&D expenditure is fairly high (43%, 82% and 69% respectively).

We then took a closer look at two of the different sectors reported above, namely, Chemicals (including Pharmaceuticals) and Electrical & Electronics (E&E). We selected these two sectors as these are the two of the most R&D intensive sectors in India as composite groups, but having divergent experience in TFP growth during this period. The E&E experienced a consistently high growth in TFP, which has contributed to 96% of output growth of this sector. The chemical sector, on the other hand, had a negative and declining TFPG. Output growth in the chemical has therefore been primarily factor driven and it is observed to be generally lower than that of E&E where output growth has essentially been TFPG driven.

Posing these findings on India's TFP growth experience in these two sectors against the Krugman thesis[13], one may be *tempted* to conclude that the technological experience of the E&E sector has been ideal for sustained growth while the technological effort in chemicals has not been that successful in India. But this completely contradicts the results we obtained from our estimation of production functions for these two sectors with R&D as a third factor of production (apart from labour and capital). R&D appeared to be a significant third input into the production of chemicals but not in the E&E sector. This is perhaps due to the fact that in E&E industry technology is largely embodied in capital equipment and is therefore not significant as a separate input into the production process. This is not the case in chemicals, where technology (R&D) is mainly disembodied and acts as a distinct third input. Indeed, the chemical industry, by its very nature, requires substantial adaptation and modification for making the product/ process suitable to local conditions (tastes, temperature, climate etc.), which calls for a deeper understanding

[13] The so-called Krugman (1994) thesis on *the myth of Asia's miracle* suggests that the East Asian growth experience is bound to slow down as it has been fuelled essentially by mobilizing resources (capital) rather than through productivity growth and efficiency gains.

of the underlying technological process. By contrast, the E&E sector in India is characterised by the so-called 'screw driver' technology. Accordingly its technological effort is primarily geared towards better implementation of given technologies with little or no modification/ adaptation in order to achieve a greater degree of operational efficiency.

Clearly then the process of technological capability acquisition and the trajectories of technological learning have been very different in these two sectors. It is hardly surprising each sector will follow its own distinct ***learning trajectory*** and generate distinct patterns of capability and technological advantages.

IV.3 Technological Learning in Indian Industry: The Case of Pharmaceutical versus Electronics

As discussed in section 2, the literature on technology in LDCs, pioneered by Nelson, Katz, Lall, Bell and others, recognized two principal characteristics of technological activities in LDCs. First, their R&D effort is geared towards "minor" as opposed to "major" innovations. Secondly, technological learning, in some form or other, constitutes an integral part of their research thrust. In an earlier paper (Ray and Bhaduri 2001), we examined the process of technology generation and learning in Indian industry by estimating a comprehensive research production function incorporating the role of learning, using Indian firm-level data for pharmaceutical and electronics sectors.[14]

There has been little explicit theorization of the role of learning in the research production process. Arrow (1962) is perhaps the only theoretical construct introducing the concept of learning by doing in the neoclassical theoretical literature, but "*there is little discussion even in that article regarding the nature of the process involved*."[15] In the context developing countries, Bell (1984) distinguished between two dimensions of the learning process: (1) 'doing based' learning and (2) 'learning by training' or 'learning by hiring' or 'learning by searching' or 'spillover'. Both types of learning are equally important in the research production process in an LDC. Learning by doing, for instance, may not result in a research outcome which is altogether new (major innovation), but it certainly contributes to acquisition of technological capability (absorptive, adaptive) and the consequent minor changes or *inventing around*, which is crucially important in LDCs. We also expect that firms with longer experience will spend more on R&D. The justification comes from an evolutionary framework, where firms, which are successful in research, continue with their research activity and enlarge their R&D outfit. Learning through experience also raises the efficiency with which R&D inputs are converted into outputs. It thus has a positive impact on the *amount* of technological output by raising the marginal productivity of R&D inputs.[16] We, therefore, expect that *ceteris paribus* firms with

[14] Such exercises have produced rich and useful results for developed industrialised nations. See Kamien & Schwartz (1975) and Cohen & Levin (1989) for comprehensive surveys of this empirical literature.

[15] Nelson (1987), pp 81.

[16] This is in line with the time-cost trade-off analysis by Scherer (1967) showing that curtailment of learning period makes the research production process less efficient by reducing the scope of trial and error.

longer history of learning (or with more experience) would produce more research output.

With regard to the role of learning through spillover, the neoclassical literature is less precise as it assumes instantaneous diffusion.[17] However later developments recognized diffusion as a complex process requiring explicit effort and investment.[18] This is true even for acquiring knowledge freely available in the public domain. Spillovers would then enter the research production process in a significant way. It would augment technological output in the same manner as learning by doing, but its impact on research effort is less obvious. We define two distinct sources of spillover: national and international, both of which could act as important inputs into the research production function.[19]

The econometric results obtained by Ray and Bhaduri (2001) presented new and interesting insights into the process of technology generation and learning in the Indian pharmaceutical and electronics sectors. We made a clear distinction between R&D inputs and R&D outputs in a research production function framework to understand the process of technology generation. We found that the conventional determinants of R&D, like firm-size, technology import or ownership, appear significant only in explaining R&D effort in line with existing empirical studies. However, when we sought to explain the variations in research output, none of these factors, not even research effort on its own, appeared to be statistically significant. Here in fact, learning, both experience-based as well as interaction (or spillover) based, proved to be the only important determinant of the research production process. According to Ray and Bhaduri (2001), therefore, technological learning has been the most important determinant of technology generation in Indian industry.

First of all, learning through interaction (spillover) proved to be important in the research production process for both sectors. The effect of spillover on research output appeared to be non-linear. In both industries there was evidence of an optimum level of spillover (national as well as international).

Learning through experience also entered the research production function for both sectors, although the way in which it augments research output differs across the two industries. In the pharmaceutical sector, it entered interactively with research effort, implying that firms with older R&D outfits spend on R&D more efficiently. In other words, experience based learning augments the efficiency of R&D effort in the pharmaceutical sector, which is mainly reverse engineering (through trial and errors). Research experience helps the firm to decode the technology faster, reducing its cost of trial and error and thereby making its R&D effort more efficient. In the electronics sector, on the other hand, learning through experience entered the production function as an independent input. Given that the electronics industry in India is driven by the

[17] If at all, spillover was believed to have an adverse effect on the incentive to innovate. See Spence (1984).

[18] See, for instance, Cohen & Levinthal (1989).

[19] The theoretical literature is less precise about the pattern of learning of both types (through experience or through spillovers). It is evident from several empirical studies (Katz (1987) for Latin American firms, Lall (1984) for Indian firms, Jomo, Felkar and Rasiah (1999) for Malaysian firms) that the learning pattern as well as its importance varies from industry to industry and according to ownership structure.

so-called 'screw-driver' technology, simple experience based knowledge (of assembling) proves to be important in the R&D process.

Indeed, the two sectors have followed two distinct trajectories of technological learning, resulting in different kinds of technological capability generation. In the electronics industry in India (characterized primarily by "screw-driver" technology), assembly operations, production engineering, shop-floor practices and quality control could prove to be the key elements of technological effort. In-depth technological learning of product designs and processes have perhaps been less important for electronics firms in India. Their technological effort lay primarily in gaining operational efficiency and productivity augmentation through shop-floor practices, day-to-day trouble shooting and customer servicing. Hence, it is *know-how* rather than *know-why* that best describes the learning trajectory of electronics industry in India.

The pharmaceutical industry in India, on the other hand, followed a rather different trajectory of technological learning based on reverse engineering.[20] This essentially implies decoding an original process for producing a bulk drug. This involves a detailed understanding of the chemical properties of the active molecule, the excipients used and the chemical process of conversion from the active molecular compound to the final bulk drug. A chemical process incorporates a complex set of parameters, e.g., solvent conditions, temperature, time, stirring methods, use of various chemical and physical substances with different levels of purity etc., all of which have to be simultaneously optimised in order to arrive at the optimum process specification. It is possible to decode all of these parametric specifications of a process through reverse engineering.

Indeed, from the decade of the 1970s, the industry acquired substantial technological capability of process development through reverse engineering, both infringing processes for off-patented molecules and non-infringing processes for patented molecules. This phenomenon has been often been referred to as the ***process revolution in the Indian pharmaceutical sector***.

Effectively then, the learning process has been largely know-why oriented in the pharmaceutical sector, while in electronics, it has perhaps been simpler and more know how oriented. We may expect a significant role of formal R&D in the learning process of the former. Learning in electronics, on the other hand, is likely to be less dependent on formal R&D.[21] It will be more learning by doing and learning through experience in this sector.

IV. 4 Exporting through Technological Capability[22]

India's technological effort has been primarily directed towards creating assimilative and adaptive capacities rather than generating new technologies. Although at the institutional level, some technology generation took place, but India remained far behind the global frontiers of technology in most industrial areas. The inward looking, protectionist policy environment till 1990 further bolstered India's inability to use the

[20] Ray (2005)

[21] The results of estimated production functions with R&D as third input for the two sectors reported above vindicate this hypothesis.

[22] This subsection draws heavily on an earlier work: Bhaduri and Ray (2004).

latest developments in global technologies though liberal and unrestricted imports. As a result, notwithstanding its impressive track record of technological learning, India continued to be "technologically backward" through out most of the five decades post independence. According to the conventional product-cycle or technology-gap paradigms of international trade, therefore, the technology factor is unlikely to be a key determinant of India's comparative advantage and export competitiveness. In a recent paper (Bhaduri and Ray 2004), however, we have argued that India does enjoy technological advantages in exporting, but these advantages rest on a very different foundation – technological capability as opposed to major technological advancements or breakthroughs.

To explain India's technological advantages in exporting, we again refer to the distinction between know-how and know-why capabilities. *Know-how* is acquired through "not only the assimilation of imported techniques (which itself can be a lengthy and active learning process) but also quality control (which also involves active technical effort), improved plant layout and production practices, slight modifications to equipment and tooling, troubleshooting, the use of different raw materials and so on",[23] all of which can be summarised as production engineering. Hence *know-how* oriented technological effort leads to greater production efficiency and therefore reduced marginal costs. *Know-why* is the next stage of technological development, which involves the understanding of the nature of the process and product technologies, *ultimately*, leading to the development of new *improved* processes and designs. Clearly, reduction of marginal cost may not be the overriding, or even an important consideration for such know-why oriented technological activities, at least initially.

In explaining technological advantages for export success in LDCs, it is *know-how* rather than *know-why*, which has been highlighted in the literature as the key determinant. It is generally argued that *know-how* oriented technological learning (production engineering) enhances firm-level competitive advantage by augmenting production efficiency. But technology creating *know-why* capabilities (reverse engineering) may actually reduce export competitiveness since reverse engineered processes and designs do not usually lead to greater production- and cost-efficiency, *at least in the short run*.

However, sustained effort towards *know-why* activities may eventually lead to technology creating capabilities to *invent around* cost-effective processes or designs.[24] This could then act as a major fillip to the LDC firms' competitive edge in the long run and prove to be a key determinant of their export success. Indeed, international competitive strength of Japan's automobile industry and Korean semi-conductor industry was hidden in its capability to *invent around*, which evolved out of conscious long-term research effort on creating *know-why* capabilities.[25]

According to this conceptual framework, therefore, both *know-how* and *know-why* would act as important determinants of comparative advantage of LDCs. However, the relative importance of these two forces will perhaps vary from industry to industry depending on its technological characteristics and learning trajectory.

[23] Lall (1985), page 116.
[24] Dore (1984).
[25] See Ungsan et al (1997).

To capture the precise nature of the impact of technological capability on export performance, Bhaduri and Ray (2004) introduced quantifiable (measurable) definitions of various facets of technological capability. In particular, we made a distinction between *know-how* and *know-why* oriented capabilities. Our econometric results, capturing the impact of these various facets of *technological capability* on export performance, revealed striking inter-industry differences.

We found that *know-how* (or production engineering) augments export performance in both sectors but *know-why* (or reverse engineering) was important for pharmaceutical exports, not E&E. Indeed, as argued earlier, it is *know-how* oriented capabilities (production engineering, quality control for instance) that augments production efficiency and enables an LDC firm to remain internationally competitive. *Know-why* capabilities, on the other hand, raises export competitiveness only in the long run after a gestation lag of successful learning.

One may of course ask why the E&E firms in India, unlike pharmaceuticals, are unable to augment exports through *know-why* capabilities. The reason perhaps lies in the different characters of the two products. While in both cases the global technological frontier is moving fast, in E&E the rate of product obsolescence is very high, whereas an old drug is never quite pushed out of the market even in the long run when a new "better" replacement arrives. Therefore there is ample scope and incentive to carry out *sustained know-why* activities of inventing around cost efficient processes and designs keeping in mind the off-patent segment of the international pharmaceutical market. Such long run prospects of pay-off from *know-why* do not exist in case of E&E characterized by high rate of product obsolescence.

V. The Role of IPR in Technological Capability Building

We have already described technological capability acquisition as a path dependent process, which begins with simple production engineering (*know-how*) capabilities, followed by acquisition of *know-why* or reverse engineering capabilities that sets the stage for a paradigm shift onto *basic research*. The transition from *know-how* to *know-why* capability acquisition entails a trade off between short run gains in term of productivity augmentation (through *know-how*) versus long run benefits of creating a sound foundation for advanced technological capability of basic and frontier innovations (through *know-why*).

It has now been widely recognised in the literature that intellectual property rights (IPR) policy has very significant implications for technological learning and technological capability accumulation in developing countries (Lall 2001, IPR Commission 2002, Dutfield 2005). However, designing an appropriate IPR policy for driving the economy towards an optimum learning trajectory involves a complex public choice problem due to the trade-off between innovation and diffusion that it entails.

Economists belonging to the neo-liberal tradition do not hesitate to endorse the importance of incentives to innovate[26] and believes that a strong IPR regime that

[26] Note, however, that the strength of IPR regime may not always raise the incentive to innovation in a linear fashion, especially if innovation is a cumulative process based on a pioneer invention. See Nordhaus (1969), Scotchmer (1991), Lerner (2001), Gallini (2002).

fosters such incentives for innovation (but restricts diffusion and learning through imitation and reverse engineering) would be the best policy option for a developing or emerging economy to embrace globalisation. Others, however, believe that developing countries are likely to lose out under strong IPR due to shrinking opportunities of imitative R&D and hence a weak IPR, facilitating diffusion and learning, could prove to be most important, for know-why type technological learning and catch-up (Helpman 1993, UNCTAD 1996, Lall 2001, Maskus 2000).

While, the debate on optimum IPR policy continues, one is tempted to conclude that a weak IPR policy would perhaps be preferred over a stronger one in the initial stages of technological learning and economic development. But, once a country reaches technology maturity to achieve major breakthroughs, the benefits of protecting knowledge through strong IPR (incentive to innovate) might outweigh the benefits of diffusion. Hence, a strong IPR policy that encourages innovation may be necessary at a later stage after the country in question acquires innovative capability through learning.

This essentially reflects that IPR policy can not remain static or invariant over time. It needs to be modified, fine-tuned and adjusted at various points in the technological learning trajectory of a nation, according to the nature and level of technological capability already acquired through this learning process. At the same time the nature and extent of technological learning will also definitely be shaped by the IPR policy adopted. In other words, technological learning and IPR policy have a strong mutual interface in the way they evolve. There is significant historical evidence of this phenomenon. Dutfield and Sutharsanan (2005), for instance, documents "numerous instances of how today's developed countries often ensured they had weaker IP regimes than those of the technologically more advanced countries with which they were seeking to catch up".

Ray and Bhaduri (2008) attempt to provide a theoretical understanding of the interface between technological learning and IPR policy, using tools of applied microeconomics. We develop a game theoretic model to explain the optimum IPR policy and the corresponding technological learning in a developing country. Our model identifies the nature and extent of domestic technological learning under different IPR regimes, both being endogenously determined.

Our model, although neo-classical in character based on rational behaviour and optimisation, arrives at a *Nelsonian* conclusion of co-evolution of technology (learning) and institution (IPR regime) with a strong interface between the two in their evolutionary process (Nelson 1994). In this co-evolutionary framework, the technological learning begins with *know-how* oriented production engineering followed by *know-why* oriented reverse engineering (RE) under weak IPR till sufficient innovative capability is acquired for basic research. At this point IPR regime is made stronger to enable firms to adopt *basic research* as a viable (and sustainable) strategic option. Without the introduction of a strong IPR as a negotiated order at this juncture, the transition to *basic research* will perhaps prove to be difficult and unsustainable. [27]

[27] However, a pre-mature imposition of strong IPR, suppressing the evolutionary interface between TC and IPR, will not merely put a halt to the technological catch up process but will actually revert the learning trajectory back to the stage of production engineering.

As already noted above, the technological learning trajectory has not been uniform across all sectors in India. The technological trajectory of the E&E sector has essentially targeted towards achievement of high TFP (based on *know-how* capabilities) with little emphasis on acquisition of adaptive and designing (*know-why*) capabilities and therefore, IPR policy had perhaps little role to play in this regard.

The pharmaceutical industry, on the other hand, focused on building up of *know-why* oriented technological capability, even at the cost of immediate productivity gains in the short or medium terms. Here the IPR regimes did matter. Indeed, the process revolution in the Indian pharmaceutical industry reflecting significant learning and technological catch up can be largely attributed to the Patent Act of 1970 allowing only process (and not product) patents for pharmaceutical substances. One may, of course, further argue that India's transition in 2005 into a stronger IPR regime, compatible with the TRIPS agreement, is perhaps the right moment to leverage its innovative capacity to take a leap towards *basic research* (new drug discovery).

VI. Concluding Remarks

If one looks at India's economic progress in the last decade or so, it is quite evident that knowledge intensive sectors have been driving India's growth, be it IT, Biotech or Pharmaceuticals among many more skill intensive service sectors. India's technological advantages in these areas have still by and large remained confined to the domain of minor as opposed to major innovative capabilities. India has demonstrated significant competitive strength in routine (through skill intensive) tasks like coding (in software) or process development (in pharmaceuticals), and perhaps less so in creativity and innovativeness. Transition to a stronger patent regime raises strong hopes that it will stimulate such creative and innovative technological capability in India's knowledge based industries.

However, to carve out an appropriate (optimum) technology strategy for India, one can not afford to ignore other sectors of the economy, especially the labour intensive mass manufacturing where productivity augmentation through know-how capabilities may prove to be crucially important for sustained TFP growth and industrial development. While India has nurtured and succeeded (to a large extent) with high-end human capital for technological capability, it has been accompanied with a tragic neglect of low end human capital investment (in primary education and health) for productivity gains in mass manufacturing sectors.[28] By stimulating broad based expansion of these sectors through low end human capital and technological capability building, India could bring on board its 300 million poor who have been completely left out of India's prosperity through its emergence as a major economic player in the world economy. Such an "inclusive" technology strategy would be of critical importance for the sustainability of India's growth process.

[28] Guha and Ray (2004), Ray (2006).

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