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INTRODUCTION

The post-independence technology trajectory for India had two broad objectives. First, it aimed at building up strategic technological capability, and secondly, it strived to acquire industrial technological capability through learning and catch-up. Achievements on these fronts are quite often judged by contrasting the first with the second. If we analyse India’s technological progress in terms of its achievements on the strategic technology front in comparison with its technological effort towards industrial competitiveness and economic growth, we get somewhat mixed and conflicting signals about India’s technological accomplishments.

The national level endeavour to build up strategic technological capability turned out to be successful on several counts. We get to see significant achievements in Space Research, Atomic Energy and Defence – evidently all under government patronage. *Aryabhatta,* India’s first satellite was launched way back in 1975 and an indigenously fabricated satellite launch vehicle was ready by 1980. India exploded its first underground nuclear device in 1974 and could set up nuclear power plants at Trombay and Kalapakkam. Later in 1985, the installation of a fast-breeder test reactor at Kalapakkam indeed marked a big step forward. These milestones, in a way, became the brightest examples that were cited quite often in support of a larger policy framework aimed at self-reliance adopted by India after independence. These milestones indeed deserve special mention because achievements of this order were somewhat unthinkable in the context of any other LDCs with similarly low levels of GDP *per capita* in those years. However, apart from these indicative achievements, it remains to be established how far India’s success in strategic technology can be compared with the existing global frontiers in these fields, generally benchmarked by the achievements of the West. But there is no denial that India’s achievements commanded a lot of awe and admiration from the entire world, especially given the fact that India was still a poor developing economy with very limited material capability.

On the industrial front, the Soviet model of a planned economy for India, especially from the Second Five Year plan onwards, did aspire to mimic the development trajectories of the advanced industrialised nations. Accordingly, India adopted an inward looking development strategy and meticulously planned out a diversified industrial production base ranging from simple consumer items to sophisticated capital goods and heavy machinery. Therefore building up of indigenous technological capabilities as well as *technological learning* for catch-up became extremely important for its industrial and economic aspirations.

However, the flipside of the protectionist trade policy regime revealed itself in the form of inefficiencies of various kinds. India's low but steady rate of growth during the initial years suffered a serious blow during the years of industrial deceleration, the saviour *green revolution* in agriculture notwithstanding. There was practically no incentive to keep pace with the fast changing global technology frontier in many of the manufacturing sectors, which resulted in Indian industry becoming technologically backward and inefficient with respect to global standards of costs and quality. Prolonged practice of inward-looking development policies discouraged competition and therefore killed the prospects for innovations and competitiveness at all levels of production. The public sector used technologies in a most cost-inefficient manner, while the private sector lacked both the initiative and the competence to advance technologies for greater efficiency in production and quality. Therefore perceived capabilities that the *planners* had in mind could not be transformed into actual competitive advantage. The Indian industry failed to keep pace with the fast moving frontiers of global technology and protectionist policy environment fostered such an incentive structure whereby there was no attempt to upgrade technologies or acquire new technologies from the global frontier. The form of technological capability building by the Indian industry during the first three decades post-independence remained by and large confined to routine activities of production and trouble shooting.

Accordingly, India's experience with technological progress has been varied and contrasting. During the first few decades of India's development experience, the level of its industrial technology was in no way comparable with its achievements on the strategic technology front, however isolated and sporadic. Contrasts persisted even during the later decades of the nineties and beyond when India could actually showcase some of its technological capabilities in the *high-tech* sectors like Information Technology (IT) and subsequently was directly catering the world market, although its IT infrastructure back home remained seriously deficient.

In this paper we focus only on India's experience with innovations and technology generation for competitiveness and economic growth. However, India's experiments with strategic technology demand a separate analysis and shall not be covered here.

THE ROLE OF TECHNOLOGY IN GLOBAL ECONOMIC EMERGENCE

The Productivity Story

Economic theory, for long, highlighted *capital* and *labour* as the two primary factors of production and recognised them to be 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 last 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 (TFP) growth). Such breakthrough revelation thereafter shifted the focus from physical factors to the role of technology in economic progress. It is fairly well established now that technological advancement resulting from R&D is the most important factor behind today's productivity growth in most industrialised countries across the globe.

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 labour force and human capital accumulation leading to high levels of cognitive skills of the labour 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 labour 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.

TFP Calculations for the Indian Economy

Against the backdrop of India's technological effort, we 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.[1] Using a panel of 29 industries over 1975-76 to 1994-95, it 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. From the estimates we see an overall TFP growth of 0.024 (2.4%) during this period. However, the study also registers 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. 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. 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, wide variations in TFP growth experience of different industries in our 29 classification structure, are also observed. Only 8 out of 29 industries recorded

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

positive TFP growth. Among these, E&E (Electrical and Electronics) 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).

These calculations show that technological progress (a la Solow) did not contribute significantly to India's industrial growth. However, this does not mean that technology had no role in India's development experience. It is this context that we attempt to technological progress taking it beyond neo-classical perspectives.

Beyond Neo-Classical Perspectives

Neoclassical theory identifies technological progress with major breakthroughs in science and technology resulting in a shift of the frontier.[2] 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 therefore remained under-emphasized in the neoclassical tradition. 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

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[2] 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".

[3] Lall (1978)

[4] Lall (1985), page 116.

development of new improved designs. Applied research and frontier R&D leading to major innovations follow this stage.

Following such notions that takes us beyond neo-classical conceptualisation to appropriately understand the process of technological capability acquisition of the LDCs, it can broadly be summarised that *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. By-passing this phase of *know-why* oriented technological learning, LDCs can never possibly aspire to reach the global frontiers of technology 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.
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.

INDIA’S TRYST WITH TECHNOLOGY: ROLE OF THE GOVERNMENT

While strategic technology remained exclusively with the government to be developed and used, the government did also play a proactive role in the domain of industrial technology. It is in this context that one finds it extremely important to understand the role of the Indian government in defining national strategies for technology generation, in terms of its objectives, magnitude and channels in areas other than strategic technology.

India’s Technology Policy: A Brief Overview

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.”[5] 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., 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.

Apart from the direct policies to promote indigenous technology development, the Government had 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).

As far as in-house industrial R&D is concerned, the 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,

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[5] *Technology Policy Statement of 1983*, Govt of India (1983), page 3.

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.

India's technology policies have included both direct policies for indigenous technological development as well as indirect policies for restricting and regulating technology imports and technology transfer. 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 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.

Channels of Technology Generation in India

We can primarily identify four channels through which the government intended to advance the cause of technology generation (R&D) in India: (1) investing in applied industrial research, (2) promoting science education and fundamental academic research, (3) public-sector production and (4) offering fiscal and non-fiscal R&D incentives to the private sector.

Applied Industrial Research

If we look at the R&D expenditure incurred in India before 1990s we find that the 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.[6] 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.

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

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

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.[7] This is perhaps expected as it conformed to the broad objective of creating technological self reliance in the pre-reform 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".[8] More importantly, it is doubtful how efficient these indigenously developed "new" technologies were, by international standards of costs and quality.

Science Education and Fundamental Research

The grand vision of building up indigenous capabilities in India was thought could be achieved not only by imparting science education to the coming generations to constitute a large pool of highly skilled workforce but by also improving the conditions for fundamental research in the country. The higher education policy post-independence envisaged setting up of several Indian Institutes of Technology, Regional Engineering Colleges and Central Universities across the country. The IITs went a long way in providing the country with highly-skilled technical manpower over the next decades, so much so that India's relatively recent transition to a global economic power based on some of the high-tech sectors like the IT is often attributed to the indirect role of these institutions.

However, it remains debatable whether the above mentioned publicly funded institutions were equally focussed on fundamental research. It is agreed that these establishments were mandated to conduct fundamental research, but for long these institutions failed to live up to such research aspirations. Although the newly modelled 'technology' education institutes along with the traditional university system did succeed enormously in their endeavour to generate high skilled human resources, they lacked appropriate initiative to take forward fundamental or cutting-edge research.

Public Sector Production

As mentioned in the introduction, public-sector production inspired by the Soviet model of a planned economy was seriously considered in India post-independence, especially from the Second Five Year plan onwards. The Indian government perhaps aspired to mimic the development trajectories of the advanced industrialised nations. Accordingly, inward looking development strategy and a meticulously planned out diversified industrial production base ranging from simple consumer items to sophisticated capital goods and heavy machinery was adopted in India. This implied heavy investments on import substituting industries across the board on the part of the government. Indeed, it is through such a process that building up of indigenous technological capabilities as well as *technological learning* for catch-up became extremely important for India's industrial and economic aspirations.

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[7] 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.

[8] Lall (1984), page 233.

However, through direct intervention in industrial production on the basis of *a priori* planning, the government seemed to ignore the notion of natural comparative advantage. The protectionist trade policy regime practically left no incentive to keep pace with the fast changing global technology frontier in many of the manufacturing sectors most of them in the public sector, which resulted in Indian industry becoming technologically backward and inefficient with respect to global standards of costs and quality.

R&D incentives to the private sector

The above three channels clearly indicate that India's technology policy in the pre reforms era was essentially grounded on building up of national level capabilities through the public institutions. But, at the same time, industry (private and public sector) was encouraged to actively engage in R&D activities to develop absorptive and adaptive capabilities. To this end, the government also offered specific *R&D incentives* with the objective of building up domestic technological capability for rapid industrialisation going beyond spending directly on R&D. 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.

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. One contrasting feature is the shift of focus of fiscal incentives from national R&D institutions to R&D carried out by the industry either in in-house R&D units or in the SIROs (Scientific and Industrial Research Organization). 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.

R&D Expenditure and R&D Outcomes in India: Macro Trends

Against the 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.[9] 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

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

much as 2.8% of its GNP on R&D, which is at par with industrialised nations, like US, Japan, UK and Germany.

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.[10] 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).

A comparison of aggregate nominal R&D expenditure also reveals some interesting turnarounds. 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.

However, 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. However, it 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.

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 take a quick look at the technological achievements in terms of R&D output.

Fiscal incentives for R&D took a new turn in the era of globalisation with the focus shifting from institutional to industrial R&D. Ray (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. The Department of Science and Technology (DST), Government of India identifies various technological outputs and publishes it in their biennial R&D Statistics volumes. The study on the basis of the mentioned database have categorized

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

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.

It is quite understandable that the institutional sector puts more emphasis on type-2 output while 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. The study finds 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.

One interesting finding relates to the relative importance of import substitutes developed by the institutional and industrial sectors. 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.

IPR Policy and Technological Learning in India

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. 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. [11]

The *Intellectual Property Rights* (IPR) Regime adopted by India has acted as an indirect policy for the Indian industry. The Patent Act of 1970 did promote considerable technological learning and acquisition of technological capability through reverse engineering activities. However, the technological trajectory of sectors like the E&E was 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).

UNDERSTANDING THE PROCESS OF TECHNOLOGICAL CAPABILITY ACQUISITION BY THE INDIAN INDUSTRY

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. They 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 sought to explain the variations in research output, none of these factors, not even research effort on its own, appears 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.

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[11] 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. See Ray and Bhaduri (2008).

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.

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.[12] 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.[13] It will be more learning by doing and learning through experience in this sector.

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[12] Ray (2005)

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

Implications for Export Competitiveness

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",[14] 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.

However, 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*. Sustained effort towards *know-why* activities may eventually lead to technology creating capabilities to *invent around* cost-effective processes or designs.[15] 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.

Econometric results in Bhaduri and Ray (2004), capturing the impact of these various facets of *technological capability* on export performance, revealed striking inter-industry differences 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

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[14] Lall (1985), page 116.

[15] Dore (1984).

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.

CONCLUDING REMARKS: THE WAY FORWARD

To conclude our paper, we note that India missed the opportunity to join the other labour surplus Asian economies in the so-called Asian miracle of the 1970s and 1980s that was essentially a growth process spearheaded by massive expansion of labour intensive manufactured exports. Despite India's vast pool of labour resources, India was left behind, when the rest of labour surplus Asia was getting integrated with the world economy based on low labour cost advantages. Fortunately, however, the advantage conferred by low labour costs in India has been pervasive, extending well beyond the realm of traditional labour-intensive goods into new industries and services, like software and IT, biotechnology, pharmaceuticals and long-distance communication-based services, where skills and technological capability play a vital role in shaping competitive advantage. India's strength in quite a few industries within the manufacturing sector which requires process, product and capital engineering skills is now well demonstrated.

If we look at the Indian manufacturing experience we find that India has several advantages in skill-intensive industries, such as auto-components, pharmaceuticals, forgings (both for automotive and non-automotive sectors), power and transport machinery, high-end electrical and electronics and specialty chemicals. Apart from the abundance of skills, these advantages include *technological capability* (process, product and capital engineering) plus established raw material bases, a mature supply base and a growing domestic demand. This has lead to India being considered as a design house, a tooling centre, a components base, and a manufacturing hub by many MNEs. Indeed, from the experience of 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.

However, India's technological advantages in these skill intensive 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. At this critical juncture when India is imminently poised for a successful transition to a knowledge economy, it becomes all the more important to revitalise India's technological capability building through the most appropriate coupling of creative pursuits (especially through public funded research) with applications for industrial R&D. It is in this context, we need to take a fresh look at the role of universities and other institutions of higher learning.

While India's advantage in high end human capital may be primarily attributed to its persistent policy thrust on higher education (especially technical and scientific) creating an extensive network of universities and institutions of higher learning (IITs and IIMs), the Indian university system has failed to contribute adequately to the process of technological learning and catch up. Even though the universities and institutions have been quite active in their research pursuits, university-industry interface in this regard has remained sub-optimum (Ray 2003). It has often been felt that India's transition to a knowledge driven economy would be much easier if the "rich" research potential of its huge pool of premier universities and institutions could be harnessed for effective commercial application and industrial development.

Having said so, we suggest that while carving 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 in the skill intensive sectors, 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.[16] 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.

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

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Indiaï¿½s Tryst With Technology: The Way Forward. Prof. Amit Shovon Ray,Chair Professor of Trade, Technology and Competitiveness, ICRIER and. Sabyasachi Saha , Researcher, ICRIER. [Download Presentation].Â Vacancy: Research & Policy Analyst for Telecom and Technology programme"Apply here". 05 Aug. Growth and Development in India â€“ A Webinar Series"for more details Click here. "27 Jul. Vacancy: 6 motivated researchers for its large Agri-programme"led by Dr. Ashok Gulati, Chair Professor Agriculture, ICRIER Apply here". The MiG-27 fighters of the Indian Air Force will be retired at a ceremony at the Jodhpur airbase on December 27. The event marks not just the retirement of another aircraft type from the Indian Air Force, but the end of the use of a technology, that, for about a decade, dominated military aviation. This technology was â€˜variable sweepâ€™ wing design, more commonly known as â€˜swing wingâ€™. Aircraft with swing wing technology could sweep their wings forward or backward to optimise performance at take-off and landing and for high-speed flight. At the height of the Cold War in the 1960s, swing wing tec... Leadership. Newsmaker of the month: Indiaâ€™s brutal second wave â€“ and the way forward. May 2021: The impact of India's second wave is felt across the world. From impact on the global economy to a new virus strain, there are many repercussions. As leaders around the world prepare to end the pandemic, India's response will be critical. The brutal second wave of COVID-19 in India has left a trail of lasting devastation. It caught the country completely off-guard and pushed back the progress over the past year on the pandemic. For over fifteen days, citizens in the national capital, New Delhi faced Discussion Papers in Economics. Indiaâ€™s Tryst with Technology: The Way Forward. Amit Shovon Ray and Sabyasachi Saha June, 2009. Discussion Paper 09-11.Â If we analyse Indiaâ€™s technological progress in terms of its achievements on the strategic technology front in comparison with its technological effort towards industrial competitiveness and economic growth, we get somewhat mixed and conflicting signals about Indiaâ€™s technological accomplishments. The national level endeavour to build up strategic technological capability turned out to be successful on several counts. We get to see significant achievements in Space Research, Atomic Energy and Defence â€“ evidently all under government patronage. India signed the TRIPs agreement (Trade Related Aspect of Intellectual Property Rights) after becoming a member of the World Intellectual Property Organisation (WIPO) in the year 1995. All the countries that were signatories had to restructure the laws guiding Intellectual Property in their nation to the tune of the terms mentioned in the TRIPs agreement.Â Artificial Intelligence and its Tryst with Intellectual Property Rights. Artificial Intelligence (AI) has been considered to be a revolution in the field of technological developments.Â In the case of AI driven technologies and ideas and other streams of thought, the basic guiding force is a constant string of binaries, data, programmed information and multiple algorithms.