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Technological Capability and Development

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1. Introduction

The most important issue for development centres on the debate about the centrality of knowledge, technology and innovation to the process of economic development. While this much is broadly agreed, what is at issue is the precise mechanics of overcoming economic development challenges in different *contexts*. At the heart of it all is about how economies at different levels deploy the unending streams of information and knowledge to developmental ends. In time, the notion of income convergence between the poorer *South* and the wealthy *North* has proved a mirage, while a new economic divide has in fact occurred within the South itself, and as well, between regions and within regions. The debate relating to latecomers is thus framed in discussions about regions and countries that arrive late to mastering industrialization in achieving economic prosperity through the use of knowledge. In other words, a new divide has emerged among the latecomers themselves, and with it, greater conceptual complexity in the ways of our understanding of the divergent ways of economic development.

In this paper, we enter this debate acutely aware of the complexity of this process; we are equally persuaded that economic development is largely driven by innovation - by this we do not mean R&D or frontier science - but ways and dynamics of process, product and organizational changes is embedded within specific and varied contextual institutions.

Technological change is a cumulative and path-dependent process, in order words, national or firm level actions taken in previous times condition the current state of capabilities. The literature is replete with different taxonomies of capabilities that adopt different definitions, terms, deepness and focus, but all of them have in common the description of different levels of complexity of technological effort for the recipient or related actors; and, the functions/actions of the firm(s) are seen as the focus. The one important common denominator in all these definitions is that they refer *to knowledge, skills and experience as core elements of the concept of technological capability.*

In taking this debate forward, we explore in this paper, the implications of the differences in technological capabilities for the innovative performance of countries. What kinds of capabilities are required to boost the transition from the lower domains of knowledge (that are purely informal and traditional production-oriented) to highly skilled science-based knowledge domain (at the frontier), and what role does the physical and technological infrastructure of countries play in this transition?

2. Technological Capabilities in a Latecomer Context

We develop a framework to understand the processes by which firms and countries move from one level of knowledge domain through other, by building technological capabilities. A firm needs external knowledge on a continual basis to regenerate itself failing which it might well stagnate or regress. A firm's connection to its external partners (buyers, suppliers, etc) is essential for building capabilities because as we noted earlier capability acquisition is largely driven by interactive learning conducted with a multiplicity of firms, and non-firm organizations. We show that the stage-wise gradation of firm/country from one level/domain to the other over time involves several heuristic feedback loops. Catching–up is both a mountain climbing metaphor as it is a marathon challenge where firms and countries practically run the gauntlet and whereby failure is costly. The notion of latecomer therefore signifies the fact that the entity (country or firm) is late to meeting up certain key capabilities compared with both the forerunners as well as competitors. We elaborate upon the different domains of knowledge and how each of these domains are inevitably related to levels of technological capabilities and differential modes of learning.

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A number of useful taxonomies have been elaborated by several scholars including Lall (1992), Ernst et al, (1998) and Bell and Pavitt (1992) among others. The authors defined and classified technological capabilities in six types of functions with the great variety of knowledge and skills positioned as the core elements, which firms need for them to acquire, assimilate, use, adapt, change and create technology.

The taxonomies are functional categories, which follow a roughly sequential order of complexity. On this we provide a slightly modified version, which is:

1. *Production and Manufacturing Capabilities*: refer to the knowledge and skills used in plant operation. It is divided into three broad types of activities: a) production management; b) production engineering, and c) repair and maintenance of physical capital.
2. *Investment capabilities*: knowledge and skills needed to undertake the functions of identification, preparation, design, setting up and commissioning of new industrial projects, or the expansion and/or modernization of existing ones. This category has two main elements: a) pre-investment capabilities and b) project execution capabilities.
3. *Re-Design and Product Modification capabilities*: are the firm's ability to adapt and improve continuously its products and processes. It includes: a) reverse engineering; b) analytical design, and c) system engineering capabilities. This is what is found in most latecomer countries and to a considerable degree in advanced latecomers as well as frontier countries.
4. *Marketing and Network capabilities*: includes the knowledge and skills required for collecting market intelligence the development of new markets, the establishment of distribution channels and the provision of customer services. Firms also possess the ability and organizational competence to transfer technologies within the firm, among firms and between firms and the domestic scientific and technological infrastructure.
5. *Design and New Products and Process Capabilities*: knowledge and skills required for the creation of new technology, design new features of products and processes, and the ability to spread out scientific knowledge in developing patentable ideas.

We seek to explore the implications of the differences in technological capabilities and innovative performance of countries. What kinds of capabilities are required to boost the transition to knowledge-based sectors and supporting that what role physical and technological infrastructure plays in this regard?

2.1. Levels of Capabilities, Learning and Development

Technological learning is the way firms accumulate capabilities (Malerba, 1992). It involves not just technical learning but learning to build the right kinds of organizations and to foster the institutional forms within which policies would make the expected impact. In the last three decades we have learnt a great deal about the nature and processes by which latecomer countries acquire capabilities but we also have a long way to go in constructing a framework that systematically takes account of the diverse and increasingly differentiated paths of development being taken by latecomers. Much has been learnt through firm-level studies (Lall, 1992; Bell and Pavitt, 1995; Hobday, 1995) but there is a growing level of dis-aggregation among latecomers that we need to begin to address them on this basis (see Figure 1). For instance most of the current work focus on the success cases of East Asia "advanced" latecomers to understand the reasons and different pathways to success while much less has been done on the lagging ("falling behind") firms and countries. With these countries learning has come to be conceptualized on the strength of R&D carried out and patents taken just as in the case of industrialized countries. In the lagging latecomers, learning is difficult to quantify, measure or even observe because much of the activity, including incremental technical change is experiential and tacit in nature. At a conceptual level, R&D is not equal to innovation as it is as an instrument of learning. Non-R&D activities (prototype building, design and quality testing for instance) tend to consume a much higher proportion of firm-level level investment in new products and processes and this is highly disconnected from the limited R&D taking place in the local contexts. In essence, orthodox measures create a misleading impression of the learning processes in latecomer countries.

Essentially, technical change or innovation is largely incremental but nonetheless useful in advancing productivity growth and has been classified into three different categories (Bell, 1984). First we have technical change that involves the introduction of new techniques (products and processes) into the economy through new investments in plants and machinery. This type of technical change broadens the industrial base of the economy. The second form of technological change involves evolutionary (incremental) improvement to existing techniques by effecting technical change to existing products and third, the generation of new knowledge through research within the firms or within separate R&D institutions.

So how and what explains the process by which countries and firms move from one level or knowledge domain to the other? The observed structure of knowledge or sets of capabilities that one finds in an economy is a result of cumulative technological mastery and investment efforts made over a long time. In other words, technological change is a cumulative and path-dependent process, in order words, national or firm level actions taken in previous times condition the current state of capabilities. In short technological capabilities acquisition processes are not just strongly cumulative in nature they have elements of strong path dependence (Dosi, Nelson et al. 1997). The conceptual and empirical literature on technological capabilities (TC) blossomed in the late 1980s received considerable attention from the mid-1980s through and early 1990s (Westphal, Kim and Dahlman 1985; Ross-Larson et al,1987; Lall,1990, 1992; Mowery, 1993; Bell and Pavitt, 1993, 1995). Several authors refined the typologies and elaborated upon them but essentially the key ideas revolve around the same concepts[1]. The essential elements of

[1] Authors Nelson and Winter (1982) developed the notions of "routines". Bell (1984), Scott-Kemmis

the framework are as follows:

1. TC focuses on efforts to “make effective use of technological knowledge in production, investment and innovation Westphal, Kim and Dahlman (1985) [p. 171]’.

2. The process has strong heuristic elements of feedback from previous experiences to current states and as such skills and knowledge gained in previous domain becomes part of the organizational memory of firms and nations that create a new capability domain resulting in more efficient techniques and systems[2].

3. The build up of capabilities therefore entails individual and organizational “learning” (Lall, 1987, 1990, 1992; Dahlman and Westphal 1982; Katz 1984, 1987; Dahlman, Ross-Larson et al., 1987). The process is re-conceptualized as essentially efforts by organizations to master technological functions though learning driven by explicit investment.

4. Firms and nations require explicit investment capabilities in order to identify, prepare, design, set up and commission a new industrial project (or an expansion of it). In other words if the processes of capability build up must continue, this set of skills and experience will be built in a co-evolutionary process with technical capacity.

5. As technical change and innovation do not take place in isolation and is only possible within a network of other actors, firms and countries require a systemic framework. This has been conceptualized as “linkage capabilities” which knowledge and experience required to foster interactive learning (see point 3 above).[3]

2.2. Knowledge Domains as they relate to technological capabilities and development

A firm needs external knowledge on a continual basis to regenerate itself failing which it might well stagnate or regress. A firm’s connection to its external partners (buyers, suppliers, etc) is essential for building capabilities because as we noted earlier capability acquisition is largely driven by interactive learning conducted with a multiplicity of firms,

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and Bell (1988), Katz (1987), used “technological capacity” to described the learning processes involved in building up a minimum base of essential knowledge to engage in innovative activity.

[2] Dahlman, Ross-Larson et al., (1987) conceived TC as the ways to use existing technology to produce more efficiently and to use the experience gained in production and investment to adapt and improve the technology in use.

[3] Linkage capabilities are defined as “…the capacity of forging co-operation between managers and workers within the firm, for securing co-operation between firms in the supply chain, and for crafting co-operative interfaces between firms and the wider institutional milieu, be it local, regional, or international” (Cooke and Morgan 2000).

and non-firm organizations. The inter-relationships between knowledge, learning and technological capabilities are not necessarily captured by functional dimensions of knowledge commonly discussed in the literature that focus specifically on systematic work related to new knowledge creation. This constitutes but one dimension of the science, engineering and technology (SET) domain that makes up a large part of the national knowledge systems. But in a more holistic perspective, a national knowledge system consists of four such domains:

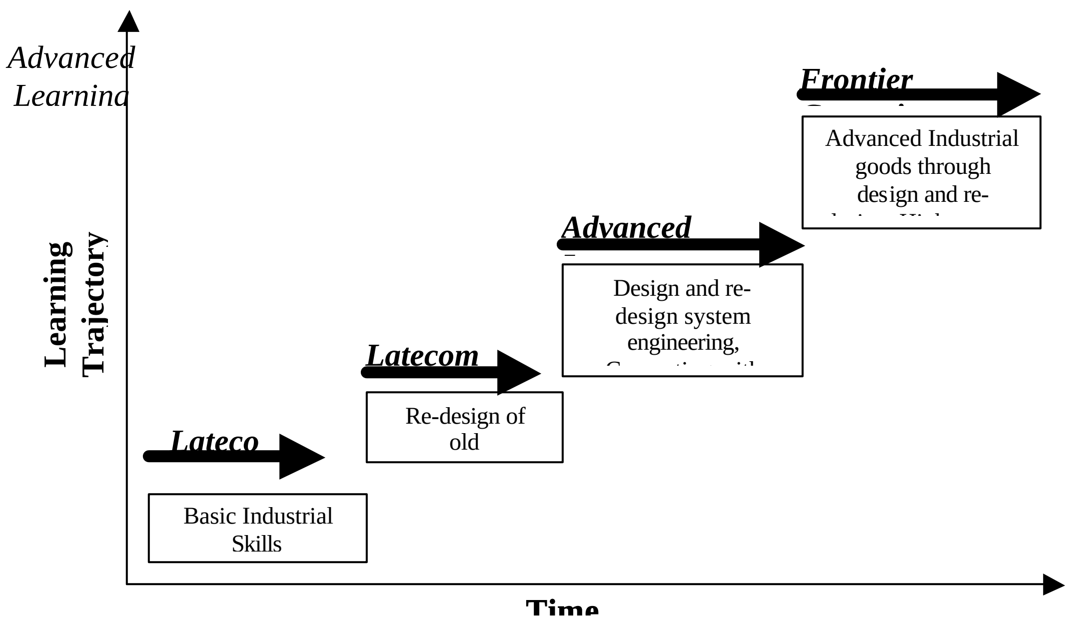
1. The largely science-based domain with scientists and engineering research and development (R&D) as the dominant activity. The actors are mainly research scientists and engineers working in these private and government research laboratories. Contrary to what conventional wisdom and popular indicators suggest, this knowledge domain employs only 10% of science and engineering (S&E) manpower in the most research-intensive country, USA. According to the NSF (2006), of the approximately 15.7 million individuals have a first degree in S&E in 2003, and a smaller 11.9 million has an S&E as its highest degree. 90% of these S&E professionals are non-R&D workers.
2. The second domain is the Design and Engineering component which involves systematic engineering and scientific specification of products, processes, systems including computer hardware and software. In this category, 13% of S&E manpower is employed in the US, while close to 20% work in non-S&E fields of project management and related areas. Notably, 66% of the total US S&E professionals work in what is termed non-S&E occupations, many of which are in management and marketing. This component is linked more directly to knowledge domain 3 below, which is the manufacturing and production component rather than R&D although outputs of applied research and development feed into this sub-system.
3. The third domain is the modern production and manufacturing establishments with engineers as well as skilled technicians but less so scientists as the dominant actors. The locus of activity here is the factory and manufacturing centres.
4. The fourth level of knowledge domain is the informal or traditional sector, which characterizes developing environments. The main actors are artisans, crafts persons and technicians. The locus of activity is the diverse but structurally homogeneous maintenance and repair garages, clusters of low technology, traditional products and production processes such as indigenous knitwear, leather and footwear making and so on. The mode of knowledge is largely skill-based tacit and experiential. There are three characteristics of this knowledge base. First, the actors are largely low-level skilled workers and apply low-level technologies based on a mix of modern and traditional methods to manufacture. Second, it is largely disconnected from component

3 (of modern manufacture and production) although it is not unusual that it draws raw materials such as for instance scrap metals, manufacturing rejects and so forth as inputs. Third, its disembodied (human) knowledge is equally disconnected from formal educational centres and laboratories although it is a large part of the economies of developing countries.

There are a wide range of capabilities that are required to match the four broad knowledge domains as they all demand different skills, and policy frameworks to create and sustain the knowledge bases. The observed structure of knowledge or sets of capabilities that one finds in an economy is a result of cumulative technological mastery and investment efforts made over a long time, and it determines the learning curves of firms, sectors and countries over time.

Figure 1 shows the stage-wise gradation of firm/country from one level/domain to the other over time reflecting the heuristic feedback loops involved. Catching–up is both a mountain climbing metaphor as it is a marathon challenge where firms and countries practically run the gauntlet and whereby failure is costly. The notion of latecomer therefore signifies the fact that the entity (country or firm) is late to meeting up certain key capabilities compared with both the forerunners as well as competitors. The four different domains of knowledge and these domains are evidently related to levels of technological capabilities. Furthermore, the mode of learning is also related to the level of capability that a firm or country has accumulated, as figure 1 shows the learning and capability ladder.

Figure 1: Learning to Catch-up



Source: Authors

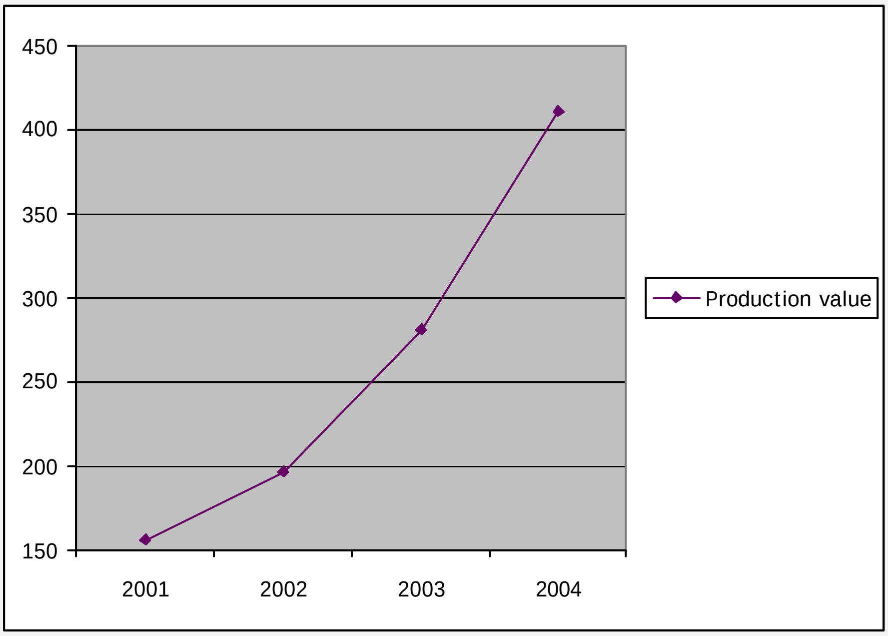
The figure presents the inter-play between the different knowledge domains, the levels of technological capabilities involved to operate in each knowledge domain and the learning process in transgressing from one domain to the next higher one. The amount of learning and skills required to move from the lowest domain of artisanal and indigenous manufacturing to the second lowest knowledge domain of modern manufacturing are embedded in primary and secondary schooling capacities, apprenticeship training, training to read engineering designs and blueprints and organisation of production. Several of these aspects are missing in developing countries – foundary making, metal cutting, and so on – are essential skills to move to the next higher level but a hiatus in several most developing countries since they constitute "nodes of learning" (Rosenberg, 1976). To move from here to the next higher knowledge domain to design and re-engineer products and innovate, one needs not only primary and secondary schooling but tertiary education that equips individuals with technical and analytical skills and public sector investments into building basic R&D capabilities for standards, metrology and other infrastructure. To operate in this domain, a country also requires significant entrepreneurial capabilities which act on the 'demand side' of the market, and act to stimulate demand for certain kinds of products (Rodrik, 2007). The learning associated with transitioning to this knowledge domain is more systematic and systemic, rigorous and has to be sustained over a long period of time and capable of being replicated across several sectors. It also requires an unlearning of several of the conventional ways of conducting the innovation business in these countries. This means new perspectives on collaboration, public-private partnerships, education system design and administering of courses as well as new entrepreneurship models. For a country to move from here to the final knowledge domain, learning becomes concentrated in R&D activities and can be measured using conventional indicators, such as patents, skilled employees, and so on. At this level, the absorptive capacity of firms/entities relies on concentrated efforts in key facilities by highly specialised individuals who conduct research and design activities (Cohen and Levinthal, 1990). This is the level where orthodox measure of R&D as a source of national knowledge begins to apply.

Economic history shows that whereas countries move easily from the lowest knowledge domain to the next higher one, moving further up into knowledge domains that focus on incremental design and innovation and then to frontier innovation is ridden with lack of success. Several countries on a supposedly sound catch-up path often do not move as predicted or regress along this path mainly due to the inability of these countries to manage the coordination efforts required in setting up a sound basis to move to the next knowledge domain. This is not surprising since the efforts required are significant and need to be designed to combat both market failure and government failure simultaneously. Merely focusing on industrial policy that does not take into account the scale effects, thresholds of scientists of engineers and minimal standards of domestic knowledge infrastructure as well as conducive policy environment for domestic innovation are common flaws in latecomer countries. Box 1 below uses the case of learning in Chinese computer industry to illustrate the point further.

Box 1: Learning in Chinese Computer Industry

China has become a significant global player by building a strong production base for both domestic and export markets. In many product categories, it has become the number one producer in the world. The same can be said for the Chinese computer industry though it is still relatively far from the frontier and is located at the end of the industrial value chain. The industry evolved from doing simple imitations, as firms accumulate capabilities through active participation in international computer industrial technology. Firms have adapted and through this process and made huge profits through the integration and development of Chinese characters processing technologies into new models of computers. **One of the keys to their success is mastering the core components, namely, integrated circuits, chips design, and software mould.** The international market played a very important demonstrating role at the initial stage of development. Chinese firms learn by responding to international consumers' needs and making changes to old computer models through supply service and sales of imported computer. During the 1980s, the learning modes of firms did not involve the master of core technology and the knowledge of key fields. Since the 1990s, more and more multinational corporations entered into China, many world-class PC producers like COMPAQ, DELL, HP, and IBM set up factories in China. As the domestic market became more competitive, multinational corporations have gradually accelerated the modes and speed of technology diffusion. The flow of technology increased as more and more multinational computer corporations set up R&D centers in China.

Production Value of Computer Clones 2001-2004 (RMB billion)



Sources: Fieldwork by authors

Policies to foster higher technological capabilities of countries will have to be broadened to include a wider variety of sources and instruments. For countries at lower levels of technological development, R&D is largely made up of activities on the shop floor rather than organized work in formal laboratories. Technological knowledge assimilation, absorption and creation proceeds on the back of imported technologies through learning, and traditional and resource-based sectors still dominate the production landscape. As countries progress to more complex stages of learning to produce, formal R&D becomes important and assumes centre stage in knowledge creation. For example, India and China still have the largest portion of GDP coming from agriculture (15 and 25% respectively), as opposed to other OECD countries which all have less than 3% of their GDP from agricultural trade and a significant percentage of their GDP accrues form RD intensive sectors and activities. If one would broaden the table to include other developing and least developing countries, the percentage of GDP accruing from traditional and resource based sectors such as agriculture will correspond inversely with the stage of development.

3. Constructing a Technological Capability Index

In order to understand, empirically analyse and present these differences, we now consider two indices namely physical infrastructure and technological capability indices to illustrate what countries require in order to move along the catch-up ladder. We have a total of 75 countries according to two indices of physical infrastructure and technological capability. Unlike most other studies, we rank the countries over time, more specifically over the period 1990-2003, in order to identify the dynamics of changes over time in the ways these countries evolve. Furthermore, the ranking over the whole period is tested econometrically using two panel data models of technological capabilities (innovation) and gross domestic product (GDP) per capita. The former examines the relationship between different levels of physical infrastructure and how it differs across technological divides, while the latter studies the relationship between GDP per capita and knowledge generation and how it differs across income and technological divides.

Next we formulate indices of physical infrastructure which lead to the country ranking which is then tested using an econometric model followed by the technological capability index and present the derived country ranking. The yearly rankings according to the two indices are presented graphically in the appendix. Table 1 presents the three categories of countries that is derived from the country ranking, namely frontier countries, fast followers and latecomers. Because of data limitation over the whole period, the following indicators are considered in constructing the technology capability composite index (TCI): high-technology exports (% of manufactured exports), internet users (per 1,000 people), and fixed line and mobile phone subscribers (per 1,000 people) are proxies for technological capabilities (TC); and electric power consumption (kwh per capita), roads (total network in km), and telephone mainlines (per 1,000 people) are proxies for physical infrastructure (PI).

Each technological capacity (TC), institution (I) and physical infrastructure (PI) indicator are normalized according to equation 1,

$$Index_{it} = \frac{X_{it} - \min X_t}{\max X_t - \min X_t} \qquad (1)$$

where X_{it} is either of the TC, I and PI indicators for country *i* at period *t* and min X_t and max X_t are the minimum and the maximum of the indicator at period *t*. We rank our 75 countries according to this composite index of technological capability and physical infrastructure in each year of the period 1990-2003 and (on average) over the whole period. In doing so, we can identify how countries perform over time, i.e. whether they remain the same, if they improved or declined.

Table 1: Group Description of technology capability composite index

Group I **Frontier Countries**	***Group II*** **Fast Followers**	***Group III*** **Latecomers**
1. United States	25. Malaysia	49. Panama
2. Sweden	26. Greece	50. Ukraine
3. Norway	27. Slovenia	51. Turkey
4. Finland	28. Brazil	52. Gabon
5. Canada	29. Estonia	53. Kazakhstan
6. Switzerland	30. Czech Republic	54. Columbia
7. United Kingdom	31. Hungary	55. Tunisia
8. Netherlands	32. Bulgaria	56. Jamaica
9. Australia	33. Phillipines	57. Romania
10. Japan	34. Latvia	58. Peru
11. Denmark	35. South Africa	59. Kyrgyz Republic
12. Hongkong, China	36. Lithuania	60. Indonesia
13. Singapore	37. Slovak Republic	61. Venezuela
14. France	38. Russian Federation	62. Equador
15. New Zealand	39. Croatia	63. Egypt, Arab Republic
16. Germany	40. China	64. Azerbaijan
17. Belgium	41. Thailand	65. India
18. Ireland	42. Costa Rica	66. Maldova
19. Austria	43. Argentina	67. Vietnam
20. Korea, Republic of	44. Poland	68. Guatemala
21. Israel	45. Chile	69. Syria, Arab Republic
22. Portugal	46. Belarus	70. Bangladesh
23. Spain	47. Jordan	71. Nigeria
24. Italy	48. Mexico	72. Congo Republic
		73. Pakistan
		74. Ghana
		75. Benin

Source: Constructed by authors using WDI (2004).

Table 2: Descriptive statistics of the indicator of the technological capability composite index per group of countries in 1990 and 2003

Variables	Mean	(Std. Dev.)	Mean	(Std. Dev)	Mean	(Std. Dev)	Mean	(Std. Dev)
	Group 1		Group 2		Group 3		All Countries	
	1990							
High-technology exports (% of manufactured exports)	15.944	(9.939)	12.372	(15.163)	4.459	(5.521)	10.666	(11.701)
Internet users (per 1,000 people)	2.102	(2.629)	0.000	(0.000)	0.000	(0.000)	0.673	(1.767)
Fixed line and mobile phone subscribers (per 1,000 people)	456.917	(117.373)	128.739	(89.122)	47.331	(42.129)	204.449	(197.263)
Electric power consumption (kwh per capita)	7565.388	(5015.881)	2731.626	(1754.737)	960.652	(983.827)	3640.879	(4123.246)
Roads, total network (in thousands kms)	524.779	(1260.386)	239.231	(414.309)	158.471	(379.121)	301.533	(788.979)
Telephone mainlines (per 1,000 people)	441.017	(105.584)	128.377	(89.338)	47.264	(42.076)	199.221	(188.633)
	2003							
High-technology exports (% of manufactured exports)	21.049	(11.539)	17.089	(18.672)	4.271	(3.495)	13.742	(14.412)
Internet users (per 1,000 people)	460.991	(109.556)	209.517	(115.125)	48.065	(39.215)	231.866	(194.682)
Fixed line and mobile phone subscribers (per 1,000	1369.551	(174.649)	749.495	(322.172)	227.754	(161.009)	760.087	(524.166)

people)								
Electric power consumption (kwh per capita)	9200.987	(4596.097)	3351.826	(1612.994)	1130.696	(938.484)	4423.951	(4406.219)
Roads, total network (in thousands kms)	560.207	(1270.376)	277.394	(471.004)	191.271	(446.526)	336.890	(815.885)
Telephone mainlines (per 1,000 people)	547.040	(103.839)	260.758	107.033	97.269	(73.300)	293.512	(209.871)
Number of countries	24		24		27		75	

Source: Calculated by authors from WDI, 2004.

The overall technological capability composite index is an unweighted average of the technological capacities and physical infrastructure indices. The technological capacities and physical infrastructure indices are themselves unweighted averages of the TC and PI (normalized) indicators, while the I index is the single (normalized) I indicator.

Our rankings help to demonstrate a deep correlation between knowledge accumulation, infrastructure and manufacturing capabilities. Table 2 shows the mean of the different proxy variables, and we observe that some countries such as Malaysia that scored highly on knowledge indices because of their infrastructure fall on the technology composite index (into group 2 countries) due to its relatively lower high manufactured exports when compared to other group 1 countries. Several other countries such as India and China and Latin American countries continue to be in the same country groups for both the knowledge variables as well as the technology capability composite index.[4] At the other end of the spectrum, countries like Nigeria scored very low in both knowledge and technological capability indices due to consistent underinvestment in infrastructure, particularly electrical power.

4. An Econometric Panel Model of Technological Capabilities

The country rankings in table 2 are purely descriptive. In other words, one lets the data

[4] See Oyeyinka and Gehl Sampath, Latecomer Development: Innovation and Knowledge for Economic Catch-up, Forthcoming, 2009, for the construction of a knowledge index that explores these inter-linkages further.

speak and there is no underlying (economic nor econometric) model that explains them. In this section we would like to validate the rankings using an econometric model that explains technological capabilities by proxies of institution and physical infrastructure. The model is described by equation 2,

$$TCIndex_{it} \; ? \; ?_1 IIndex_{it} \; ? \; ?_2 PIIndex_{it} \; ? \; ?_i \; ? \; ?_{it}, \qquad (2)$$

where $TCIndex_{it}$ is the technological capability index, $IIndex_{it}$ is the institution indicator, and $PIIndex_{t}$ is the physical infrastructure index of country *i* at period *t*; a_i denotes the individual effects and e_{it} denotes other unobservables that explain technological capabilities. Equation (2) is estimated for 3 groups of countries, namely group 1 that consists of the first 24 countries (United States-Italy), group 2 that consists of the next 24 countries (Malaysia-Mexico), and group 3 that consists of the next 27 (Panama-Benin). We also estimate the model for all the 75 countries and test for equality of the parameters $ß_1$ and $ß_2$ across the four groups.

We estimate equation (2) using panel data techniques, i.e. the fixed-effects or within estimator, the random-effects using generalized least squares (GLS) estimator, and the random-effects using maximum likelihood estimator (MLE). The results are shown in Table 3 and suggest that the "elasticity" of technological capabilities with respect to the institution indicator is negative and significant for country group 1, positive and significant for country group 2, and positive and insignificant for country group 3 and when all countries are taken together. The "elasticity" with respect to physical infrastructure is similar for the first 2 groups and smaller for group 3, which when compared to groups 1 and 2 has the smallest "elasticity". The last two columns of Table 3 allow us to test the equality of the parameters using a likelihood ratio (LR) test. With a $?^2_{(15)}$ = 261.79, we very strongly reject the null hypothesis of equality of the parameters across the 4 groups (p-value=0.000).

Table 3: Technological capabilities panel data linear regression estimates

Variable	Coefficient	(Std. Err.)	Coefficient	(Std. Err.)	Coefficient	(Std. Err.)
	Fixed-effects		Random-effects GLS		Random-effects MLE	
Country Group 1						
Technology capability index	-0.307**	(0.084)	-0.401**	(0.087)	-0.358**	(0.085)
Physical infrastructure index	2.669**	(0.210)	1.247**	(0.126)	2.033**	(0.263)
Intercept	-	-	0.209**	(0.069)	-0.115	(0.125)
Number of observations	336					
Country Group 2						
Technology capability index	0.099	(0.086)	0.027	(0.084)	0.053	(0.085)
Physical infrastructure index	1.715**	(0.149)	1.411**	(0.138)	1.522**	(0.150)
Intercept	-	-	-0.017	(0.045)	-0.044	(0.049)
Number of observations	336					
Country Group 3						
Technological capability index	0.068†	(0.040)	0.073*	(0.034)	0.072*	(0.034)
Physical infrastructure index	0.762**	(0.126)	0.604**	(0.098)	0.608**	(0.103)
Intercept	-	-	0.012	(0.012)	0.012	(0.012)
Number of observations	378					
All countries						
Technological capability index	-0.102*	(0.045)	-0.147**	(0.041)	-0.155**	(0.041)
Physical infrastructure index	1.956**	(0.102)	1.362**	(0.056)	1.426**	(0.071)
Intercept	-	-	0.038	(0.020)	0.029	(0.022)
Number of observations	1050					
Significance levels: † : 10% * : 5% ** : 1%						

Source: Authors calculations

Again the results validate the hypothesis underlying the framework and the country rankings. For instance, the percentage of high technology export in group one countries is more than 4 times that of group three, infrastructure represented by fixed and mobile line connection in group one is 9 times that of group three and twice that of all the countries mean. The same applies to electrical power, which also has a nine fold factor difference. In the specific cases of the emerging power houses of China and India we again see how underlying knowledge and technological capacity determine their different positions on the groupings ladder. For instance, high technology export from China which was 7.9% of export jumped to 29.9% in 2005 with the concomitant increase in R&D spending per GDP of 1.3% compared with India's which have remained at 0.8%

since the 1990s. In absolute terms, China invests 72 billion US$ on R&D (2005). The number of researchers in China currently matches that of the EU25 (OECD, 2007). While China produces 500,000 engineering graduates, India produces 350,000. Evidently, China has made more explicit investment in builing physical as well as technological infrastructure, which reflects in both manufactured and high technology exports. At the same time, India is not able to sustain its economic growth merely due to its lagging infrastructure (recent estimates are that India loses about 1-2% of its annual growth to weak physical and technological infrastructure).

5. Concluding Remarks

In this paper, we have developed a framework to understand the processes by which firms and countries move from one level of knowledge domain through other, by building technological capabilities. A firm needs external knowledge on a continual basis to regenerate itself failing which it might well stagnate or regress. A firm's connection to its external partners (buyers, suppliers, etc) is essential for building capabilities because as we noted earlier capability acquisition is largely driven by interactive learning conducted with a multiplicity of firms, and non-firm organizations. We show that the stage-wise gradation of firm/country from one level/domain to the other over time involves several heuristic feedback loops. Catching–up is both a mountain climbing metaphor as it is a marathon challenge where firms and countries practically run the gauntlet and whereby failure is costly. The notion of latecomer therefore signifies the fact that the entity (country or firm) is late to meeting up certain key capabilities compared with both the forerunners as well as competitors. We have elaborated upon the different domains of knowledge and how each of these domains are inevitably related to levels of technological capabilities and differential modes of learning.

Using macro data from a total of 75 countries on these indices, over the period 1990-2003, we identify the dynamics of changes over time in the ways these countries evolve and build technological capabilities. The analysis of the 75 countries is conducted by acknowledging that countries reflect acute divisions in physical and technological infrastructure that impacts upon their abilities to catch-up. By grouping the countries into frontier countries, fast followers and latecomers, the paper presents determinants of technological capability in the context of late development. It links knowledge domains for catch-up phenomenon, which concerns the persistent differences in the rates of growth of countries, to the ways and processes firms and nations build up technological capabilities. Both the descriptives and the econometric model developed in this paper advances our understanding of levels of development (domains indicate a country stage in the catch-up ladder) and the processes that links knowledge domains to learning and accumulation of technological capabilities. Modes of learning are different for each stage of technological capabilities building, and these are intricately linked to knowledge domains. The results contain several implications for theory and policy on innovation and development.

The results shown in Table 2 suggest that the “elasticity” of technological capabilities with respect to the institution indicator is negative and significant for frontier countries, positive and significant for fast followers (country group 2), and positive and insignificant for slow learners and laggards (country group 3). The “elasticity” with respect to physical infrastructure is similar. In other words, for these countries to catch-up with fast followers, they need to raise the contributions of these variables significantly.

Our analysis shows that the current domain of latecomer countries, which could be described as developing in relative terms compared with industrialized countries differ in a variety of ways and specifically relating to the three elements reflected in the technological capability analysis in this paper. First, frontier economies belong to the group one domain characterized by high science- intensive and technology-intensive activities, with relatively high levels of domestic investment in R&D. Second, the frontier and fast learning group have developed the design engineering capabilities to relatively high level while late learners are largely engaged in mastering production. Third, the frontier and fast followers have also developed through explicit investment in training high levels of skilled manpower, although a large number of countries classified in the catch-up group are still intensifying investments in building their scientific base.

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