Agglomeration Advantages and Capability Building in Industrial Clusters: The Missing Link

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Accumulation of technological capability is crucial for industrial growth and competitiveness of firms, particularly in the context of liberalisation and increasing international economic integration. The article sheds new light on the forces driving capability-building by complementing a micro-economic perspective on learning with a meso-economic perspective that takes account of interaction effects arising from firms' embeddedness in regional networks. The missing link at the interface between the two levels is explored by means of a taxonomy linking various agglomeration advantages to investments in technological effort. The framework results in new policy-relevant insights about the factors underpinning the acquisition of capabilities in comparison to conventional studies. A case study about farm equipment manufacturing in Pakistan's Punjab province is used as an empirical illustration.

1. INTRODUCTION

Since the early 1980s, a large number of studies have documented the importance of firm-level acquisition of technological capability for long-term competitiveness and growth of firms and nations.[1] Technological capability comprises the skills, knowledge and organisation needed to absorb, reproduce, adapt and improve new technologies. It cannot be

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transferred quickly and costlessly along with equipment, blueprints, and user manuals. Rather, it has to be built up through purposeful 'technological efforts': investment in time and resources aimed at assimilating, adapting and improving known technologies, and (ultimately) creating new technologies in-house.

So far, capabilities were seen to emanate predominantly from learning efforts undertaken by firms that operate as individual entities. This micro-economic approach has come up with valuable academic and policy insights. However, in the course of the 1990s regional industrial networks began to gain an increasingly prominent role in fostering competitiveness and growth [e.g., *Piore and Sabel, 1984; Best, 1990; Pyke and Sengenberger, 1992; Schmitz, 1995; Schmitz and Nadvi, 1999*]. There is mounting evidence that embeddedness in a strong regional innovation support structure bolsters firms' competitive position in the context of globalising markets, where competitive pressure for continuous innovation is intense [*Porter, 1990; Simmie, 1997*]. In this constellation, firms' individual learning efforts are complemented by those of others through interaction in local and regional systems.

Hence, studying firm learning as a purely micro-economic process is nowadays bound to lead to incomplete insights of the technological underpinnings of long-term competitiveness and growth. A new approach is needed – one which complements the study of micro-economic learning with a meso-economic perspective that takes account of interaction effects arising from firms' embeddedness in regional networks. This new approach should explore how the accumulation of firms' technological capabilities may be enhanced by agglomeration advantages associated with being part of a regional system.

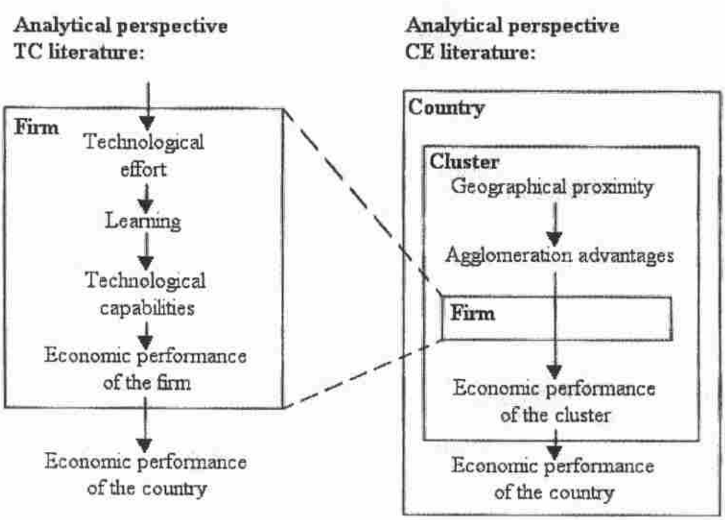
The objective of this article is to contribute to the establishment of a missing link between the two separate levels of analysis. We begin by briefly highlighting relevant insights from the technological capability (TC) literature, spelling out its main limitations in the current economic context (section II). We then develop the line of argument linking clustering, technological learning and economic growth. First, we identify and classify the main agglomeration advantages that are known to exist in the literature (section III). Following this, we use received economic theories as conceptual tools to spell out how these advantages may enhance the technological improvement efforts of the individual firms that constitute a cluster (section IV). Subsequently, we outline the likely implications on the accumulation of firm-level capabilities and economic performance, and show the added value from superimposing the meso-economic perspective on the micro-economic capability approach (section V). We complete our discussion by illustrating our framework with partly new empirical case material (section VI). Conclusions and an agenda for further work make up the final section (section VII).

II. CONCEPTUAL STARTING POINT

The technological capability (TC) literature emphasises that skills, knowledge and organisation are needed to select, adopt, implement and adapt new technologies. These capabilities have to be built up through purposive investments in activities aimed at technological improvement. Bell [*1984*] distinguished five main types of such efforts: staff training, staff hiring, in-house technological improvement (including R&D), external search for information about new technologies and markets, and gathering of internal feedback about performance.

Many studies have drawn attention to the importance of being part of larger 'innovation systems' [*Lall, 1992; Lundvall, 1988, 1993; Cassiolata and Lastres, 2000; Edquist, 1997; Freeman, 1995; Maskell and Malmberg, 1999; Nelson, 1993*] or 'cluster knowledge systems' [*Bell and Albu, 1999*]. However, a systematic conceptual treatment of how and why regional networks could contribute to intra-firm learning processes is lacking.[2] The conceptual toolkit of the micro-economic TC literature is not well suited to explaining why 'the whole is sometimes more than the sum of the parts', and under which circumstances this is likely to be the case. As a result, studies

FIGURE 1
LINKING THE MICRO- AND MESO-ECONOMIC PERSPECTIVES



that have attempted to explain technological dynamism of countries or regions (for example, the ones mentioned above) have not been able to do much more than point towards the general importance of synergy and complementarity between activities of individual firms, the functioning of technology institutions and the thrust of industrial and technology policies in innovation systems. This is usually too general and descriptive to enable the design of well-targeted industrial and innovation policies. Grafting insights from regional approaches to competitiveness on to the micro perspective in a more rigorous conceptual manner can therefore be expected to lead to more detailed insights into the driving forces underlying competitiveness, and provide more specific guidelines for policy intervention.

Figure 1 shows how we intend to approach this task. The left-hand side presents the analytical perspective of the TC literature, namely intra-firm knowledge accumulation processes. Various stimuli, not necessarily induced by proximity, enter the firm and are somehow translated into efforts aimed at technological improvement. These efforts induce learning, which results in technological capabilities, in turn enhancing the economic performance of the firm and therefore (by assumption) the country.

The right-hand side of the figure represents the meso-economic perspective. Studies in this line strongly emphasise advantages for firms that accrue from being part of an industrial cluster. An important stream of literature in this line is the so-called collective efficiency (CE) approach.[3] Studies that shed light on inter-actor relations have formed its main sources of inspiration, including transaction cost theory, socio-geographical studies dealing with regional dynamics, sociological approaches, and most recently Gary Gereffi's work on global commodity chains [*Humphrey and Schmitz, 2000*]. Most CE studies address some aspects of 'upgrading', but this concept is not rooted in an analytical framework in which firm-level technological change takes central stage.[4] Thus, the functioning of firms remains largely a black box (see Figure 1).

The dotted lines connecting the left-hand side to the right-hand side of Figure 1 indicate how we connect the micro- with the meso-economic perspective. From left to right we look towards the regional level, which is not explicitly analysed in the TC approach. Thereby we are led to explore what happens at the interface between micro and meso. Specifically, we ask what are the mechanisms by which technological efforts within firms in an industrial cluster may be enhanced by different agglomeration advantages that commonly occur there.[5] In order to answer this question we need information about the nature of technological efforts (already discussed above) on the one hand, and the main types of agglomeration advantages emanating from clustering on the other (section III).

III. GEOGRAPHICAL CLUSTERING AND AGGLOMERATION ADVANTAGES

Richardson defines the term *agglomeration economies* as everything that induces people and economic activities to cluster together [*1978a and 1978b*]. The general idea behind the concept is that the environment of the firm has a positive influence on its output. What exactly are these advantages that comprise the overall concept of agglomeration economies? Firms expect to realise various benefits when they settle into a cluster. In this respect, reference is often made to the three Marshallian reasons for geographic localisation [*Marshall, 1920*], which are:

(1) the presence of a labour pool with specialised skills;

(2) the phenomenon that 'an industrial center allows the provision of nontraded inputs specific to an industry in a greater variety and at lower cost' [*Krugman, 1991: 37*]. To these, we should add market access provided by specialised buyers [*McCormick, 1999*];

(3) technology spillovers, which are defined as intellectual gains through exchange of information for which a direct compensation to the producer of the knowledge is not given, or for which less compensation is given than the value of the knowledge.

As firms expect these various benefits to be generated through co-location, they are induced to locate in a cluster. In this way, a cluster grows and the expectations materialise, leading to the emergence of a 'growth pole' [*Perroux, 1955*].

For an individual firm, Marshall's reasons for localisation within a cluster come down to the expectation (and ultimately the realisation) of three different types of advantages, namely (i) economies of scale and scope; (ii) transaction economies; and (iii) knowledge spillovers. Marshall's first reason, the presence of a labour pool with specialised skills, points to transaction cost advantages for firms. Obviously, a cluster will attract workers with specialised skills, which is advantageous for new firms locating in a cluster. Marshall's second reason, the provision of non-traded inputs specific to an industry in greater variety and at lower cost, points to scale and scope economies as well as transaction economies. Marshall's third reason, technology spillovers, is equivalent to the currently accepted concept of knowledge spillovers [*Caniëls, 2000*].

For individual firms, economies of scale, scope and transaction point to cost advantages (pecuniary gains) accruing from being close to each other, while knowledge spillovers point to benefits arising from real information or knowledge inputs emanating from other actors in the cluster. In this regard, Stewart and Ghani speak of *real dynamic externalities* (a concept which appears to be more or less identical to Marshall's knowledge spillovers) to indicate that these particular advantages are fundamentally important to economic development, especially through their effects on activities that foster technological change [*Stewart and Ghani, 1991: 573*]. They also argue that these externalities are widely prevalent and potentially substantial in magnitude.

While the existence of a positive link between clustering and the incidence of economies of scale, scope and transaction is obvious, the same does not hold for knowledge spillovers. Why would information flow more easily across short distances? Economic geographers identify several reasons why this would be so [*Audretsch and Feldman, 1996; Feldman and Florida, 1994*].[6] These stem from the nature of the innovative process, which can be summarised in five 'stylised facts' (Dosi [*1988*]; further developed by Feldman [*1994a, 1994b*]; and Baptista and Swann [*1998*]), namely uncertainty, complexity, reliance on basic research, importance of learning-by-doing, and cumulativeness [*Caniëls, 2000: 3–5*]. Even though these stylised facts were formulated on the basis of experience in countries at the world's technological frontier, most of them appear to be equally relevant to the situation in poorer countries, the only exception being the importance of basic scientific knowledge generated in universities and research laboratories.

IV. LINKING AGGLOMERATION ADVANTAGES TO TECHNOLOGICAL EFFORTS: A TAXONOMY

In this section we use relevant literature on clustering to distil a taxonomy of mechanisms through which the agglomeration advantages identified above may enhance technological effort (summarised in Table 1). We distinguish five main mechanisms. The first one (I) runs through economies of scale, scope and transaction *in the production of goods and services*; the second (II) works through economies of scale, scope and transaction *in undertaking R&D (and thus technological effort) itself*; while the third, fourth and fifth are associated with *knowledge spillovers*. These are spillovers emanating from: (III) changing attitudes and motivations; (IV) informal learning-by doing; and (V) transfer of technological information. The four columns in the table represent four main types of technological effort identified by Bell [*1984*], namely: (A) hiring of staff with new skills and knowledge; (B) training of existing staff; (C) search for information about new technologies and markets; and (D) formal and informal R&D.[7] The contents of the cells describe the (sub-)mechanisms through which the agglomeration advantages affect these technological efforts.[8]

TABLE 1
DIRECT EFFECTS OF AGGLOMERATION ADVANTAGES ON THE TECHNOLOGICAL EFFORTS (TE) OF THE FIRM

<table>
<tr><th>Agglomeration advantages</th><th>A. Hiring</th><th>B. Training</th><th>C. Information search</th><th>D. R&D</th></tr>
<tr><td>I. Economies of scale, scope and transaction in production</td><td colspan="4">Lower unit cost due to large market size leaves more resources for technological effort.</td></tr>
<tr><td rowspan="4">II. Economies of scale, scope and transaction in knowledge accumulation</td><td colspan="4">a) Large local market gives rise to critical minimum demand for innovations, inducing technological efforts to develop them.</td></tr>
<tr><td colspan="4">b) Presence of specialised suppliers lowers transaction costs, which facilitates easy and cheap access to specialised inputs needed for technological effort.</td></tr>
<tr><td></td><td colspan="3">c) Low transaction costs facilitate joint undertaking of technological efforts, thus leading to cost-savings.</td></tr>
<tr><td></td><td colspan="3">d) Low transaction costs stimulate additional technological effort in joint lumpy and complementary projects, which in turn facilitates access to, and leads to generation of new information and knowledge.</td></tr>
<tr><td>III. Knowledge spillovers: Changing motivation and attitudes</td><td colspan="4">Exposure / demonstration effect / contagion stimulate demand for TE.</td></tr>
<tr><td rowspan="2">IV. Knowledge spillovers: Human capital formation through informal learning-by-doing</td><td colspan="4">a) Exposure / demonstration effect / contagion stimulate demand for TE.</td></tr>
<tr><td></td><td colspan="3">b) Direct free input through industry-wide accumulation of skills</td></tr>
<tr><td rowspan="2">V. Knowledge spillovers: Technology transfer</td><td rowspan="2">Direct free input through inter-firm movement of trained labour</td><td rowspan="2"></td><td colspan="2">a) Direct free knowledge input through trade journals, meetings, fairs, etc.</td></tr>
<tr><td colspan="2">b) Direct free input through user-producer interaction.</td></tr>
</table>

The first row (I) indicates a mechanism associated with direct cost advantages in production obtained by clustered firms. One such cost saving emanates from high demand (among others Swann [*1998*]). Clustered firms are thus left with more financial resources to invest in technological effort (columns A to D), because they reap more economies of scale in production compared to non-clustered ones. In addition, clustering may induce more intensive competition among input suppliers, which reduces input costs for user firms [*Nadvi, 1999b*].

Economies of scale, scope and transaction in knowledge accumulation itself may have four significant effects on technological effort (row II). First, clusters can generate a critical minimum demand for new, specialised products or services that cannot be produced profitably elsewhere. In turn, this stimulates investment in efforts to master the production of these new items (IIa) [*Stewart and Ghani, 1991*]. This effect may apply to all kinds of technological effort (columns A to D).

A second important link deals with the local presence of suppliers of specialised inputs who are attracted by large local demand. This may lower transaction costs associated with procurement of specialised inputs. Thereby, clusters act to reduce costs of specialised inputs needed to undertake investments in technological effort (IIb) [*Tewari, 1999*]. This mechanism may influence all kinds of efforts, because there are manifold actors offering specialised services, including workers with specialised skills and technical consultants (A), institutions providing training courses (B), government extension services (C and D), sourcing agents looking for suitable suppliers (C), suppliers of machinery, materials and components (C and D), and so on.

A third important link in row II operates by offering possibilities for firms to join networks of innovators because of low transaction costs associated with local interaction (IIc) [*Freeman, 1991; DeBresson and Amesse, 1991*]. This leads to cost-advantages from sharing costs and risks. In the literature, the focus is primarily on R&D-type efforts (D), but the mechanism is also likely to work in respect of other activities with scope for collective investment, such as training (B) and search (C).

Fourthly, pooling R&D resources will induce *more* R&D investment as well, as it becomes feasible to embark on large, costly projects that are beyond the capacity of individual investors [*Baptista, 1998*]. A related case is where proximity allows parties to invest in technological effort that requires mutual commitment, since they need to supply complementary inputs for it (IId). As in the case of row IIc, this mechanism might operate not only in respect of R&D (D), but also for other efforts where collective investment is feasible, that is, training (B) and search (C).

Rows III, IV and V indicate that knowledge spillovers from other firms may complement a firm's own efforts and thereby increase the efficiency of those efforts. Implementing knowledge from outside the firm increases its chances of success [*Nelson, 1993; Feldman, 1994a; Von Hippel, 1988; Baptista, 1998*]. Firms might benefit from complementarity and synergy effects that arise from the R&D of other firms in the cluster. Spillovers are facilitated by opportunities for firms to establish direct contact with each other in a cluster, such as through inter-firm labour mobility and formal and informal exchange of information and ideas [*ibid*].

The rows in our table follow the classification of spillovers adopted by Stewart and Ghani [*1991*]: Changing attitudes and motivations (row III), human capital formation through informal learning-by-doing (row IV), and technology transfer (row V).

Changing attitudes and motivation (III) primarily work by exposing people to new ideas and artefacts in a particular environment. These act on people's mental predisposition in such a way that they will begin to favour change over stability, and thereby stimulate investment in the technological efforts needed to bring it about. These advantages affect firms' efforts in a broad manner. For example, changing attitudes happen through exposure to new information, ideas and products, which generally stimulates demand for technological improvement efforts of all kinds (A to D).

Human capital formation through informal learning-by-doing (IV) likewise acts through changing attitudes, in this case attitudes towards work (IVa). Like mechanism III, it is a broad effort-inducing mechanism (A to D). In addition, learning-by-doing entails assimilation of a basic body of more specific production-related technical knowledge and skills that are common in a local industrial environment (IVb). This constitutes a direct free input complementing a firm's own investments in staff training (B). Thus, this spillover not only affects the demand for technological effort, but also the supply of inputs for it.

Technological transfer (V) acts entirely on the supply side. It operates through three channels: inter-firm movement of trained labour (A); trade journals, meetings, trade fairs and various other fora for inter-personal exchange (C and D); and user-producer interactions which often occur in the course of implementing and perfecting innovations in iterative fashion (also C and D) [*Johnston and Kilby, 1975; Ahmad et al., 1984; Nowshirwani, 1977; Fransman, 1982; Cortes, 1979; Basant and Subrahmamian, 1990*].[9] Inter-firm movement of trained labour boosts skill levels through hiring of new staff; while communication fora and user-producer interactions are primarily sources of free new information and knowledge about technologies and markets, which complement the firm's own search and research efforts.

Technology transfer spillovers often interact with economies of scale, scope and transaction. Low transaction costs in clusters directly facilitate (horizontal and vertical) business interaction, joint projects, and labour mobility, which are the main vehicles through which skills, knowledge and ideas travel across firms. Furthermore, we have seen that economies of scale, scope and transaction boost the amount of intra-firm technological effort in various ways. Clearly, the more actively firms are engaged in learning, the more spillovers to neighbouring firms are likely to result. The recipients essentially receive free inputs that complement their own technological efforts and in this way increase the effectiveness of their learning processes. In sum, when economies of scale, scope and transaction work in tandem with knowledge spillovers, both the amount and effectiveness of intra-firm technological effort will receive a boost.

V. EFFORTS, LEARNING, CAPABILITIES AND ECONOMIC GROWTH

Having established the various ways in which agglomerations can boost firm-level technological effort, we now turn to the implications for capability accumulation and economic performance of firms, regions and countries.

Firms in less-developed countries devote their efforts mainly to acquiring, using, adapting and perhaps improving existing technologies developed by others. This is reflected in the nature of their learning processes and the capabilities that they build up. Many writers classify capabilities in a way that closely reflects the main direction of the efforts undertaken.[10] First, there are *investment capabilities*, which refer to the firm's skills and knowledge needed to acquire and assimilate new technologies from outside.[11] Then there are *production capabilities*, which consist of the skills and knowledge to use and reproduce existing technologies. And finally, there are *innovation capabilities*, the skills and knowledge required to make independent adaptations and improvements to existing technologies, and ultimately to create entirely new technologies.[12]

It has often been pointed out that a certain sequence is involved in the accumulation of these three types of capabilities [e.g., *Chudnovsky and Nagao, 1983; Lall, 1992*]. Initially, learning tends to focus on accumulating basic skills for assimilation, use and unmodified reproduction of given knowledge. These skills are a prerequisite for entering the intermediate stage of creative adaptation, in which basic design skills are developed along with more advanced investment- and production capabilities. The third stage centres on the accumulation of advanced capabilities for making substantial improvements to existing technologies and creating new knowledge proper, along with developing advanced investment capabilities and process engineering capabilities.

Most of the industrial clusters in less-developed countries are made up of small firms which are still predominantly at the first stage, relying mainly on absorption, use and copying of technologies developed elsewhere

[*Romijn, 1999*]. In the absence of internal design skills, they are highly dependent for further learning on new information, skills and knowledge emanating from outside their local cluster. At this early stage, therefore, regular inputs from actors such as non-local buyers, suppliers, skilled migrant labour, developmental agencies and so on, are particularly crucial. In the absence of regular external stimuli, primitive clusters will stagnate, since their participants do not possess indigenous capacity for generating new knowledge internally or even for extracting and absorbing substantial new knowledge actively from extra-cluster sources.[13]

However, primitive clusters which are exposed to regular external inputs, for example by becoming part of a global production chain, could have the potential of becoming technologically quite dynamic due to the mechanisms for rapid and easy diffusion of new information, skills and knowledge present within the locality. By affording ample learning opportunities, such clusters can help firms to accumulate relevant technical experience, enabling them to move up the learning ladder from basic assimilation and copying skills to internal adaptive design capability more quickly than they would have been able to do on their own. Having reached that stage, firms begin to make an independent contribution to knowledge accumulation, and fertilising each other with the fruits of their own new ideas. Clusters in which firms have reached this stage have established an internal learning dynamic.[14]

After some time, this dynamic is boosted not only by development of indigenous design capability, but also by an increasing capability to manage the technological learning processes efficiently, in other words the capability to learn. As stated by Stiglitz, 'experience in learning may increase one's productivity in learning. One learns to learn at least party in the process of learning itself' [*1987: 130*]. Similarly, Cohen and Levinthal argue that ' … while R&D obviously generates innovations, it also develops the firm's ability to identify, assimilate, and exploit knowledge from the environment – what we call a firm's "learning" or "absorptive" capacity' [*1989: 569*].

By contributing to capability building in a locality, clustering has the potential of contributing significantly to improved economic performance and the competitive position of firms and, through this, to regional economic growth and eventually catch-up with other countries. There is sufficient circumstantial evidence to suggest that a positive link between the accumulation of capabilities and improved enterprise performance exists [*Bell et al., 1984; King, 1974, 1996; Cortes, 1979; Cortes et al., 1987; Aftab and Rahim, 1986; Child and Kaneda, 1975; Gupta, 1994*]. No hard and fast requirement of minimum firm size or level of technological competence appears to be required for technological accumulation to occur, and its benefits to materialise.

Several additional policy-relevant insights about the technological drivers of competitive performance can be gleaned from the integrated framework presented above. Conventional capability studies have drawn attention to a variety of push and pull factors external to the firm [*Katz, 1987; Lall, 1992; Herbert-Copley, 1990*]. One major set of factors relates to the macro- and sectoral environment, including: the general economic climate; the degree of competition and market structure; the rate of change in the international technological frontier; trade and industrial policies; and fiscal and monetary parameters. These factors point towards the importance of stimulating firm-level technological effort through creating a conducive macroeconomic environment and sectoral regulatory regime. Other factors concern the importance of a supporting science and technology (S&T) infrastructure, which helps to overcome pervasive failure in the market for innovation through public R&D and education of the labour force.

Our integrated approach draws attention to various effort-enhancing mechanisms in clusters that strengthen the impact of the policies that have been conventionally identified in the TC approach. Thus, conventional TC measures are likely to be more effective when supplemented by policies to induce firms engaged in similar and complementary activities to co-locate on industrial parks. Moreover, the framework provides specific handles for enhancing capability accumulation in firms within existing clusters that are not explicitly evident from TC studies.

While not all mechanisms in Table 1 are equally amenable to policy stimulation, several can be leveraged through targeted interventions. For example, policies may foster the operation of mechanisms IIc and d, by building mutual trust through collective institution-building initiatives. This is likely to foster collaboration in knowledge-accumulation investments. In addition to realising cost-savings and inducing new large knowledge-building projects that are beyond the scope of individual firms, these collaborations may also indirectly trigger various inter-firm knowledge spillovers (III, IV and V). Other policies could aim at stimulating spillovers directly, by concentrating new technological and market information, training, and extension services locally in clusters. The framework further suggests that such interventions do not need to aim at directly targeting all potential beneficiaries in a locality, as the TC approach has sometimes appeared to advocate. Even if the facilities only reach a few dynamic firms, geographical proximity will ensure quick diffusion to others through easy demonstration effects (III and IVa), industry-wide accumulation of skills (IVb, B); inter-firm movement of labour (V, A); and circulation of information and knowledge (Va and b, C and D).

VI. AN EMPIRICAL ILLUSTRATION

In this section we apply the integrated framework to an empirical case. It is set in Pakistan's Punjab Province, the industrially most advanced region in the country. The focus is on small-scale farm equipment manufacturing, an industry that plays an important role in the acquisition of national technological capability. In low-income countries like Pakistan it tends to be the core segment of the capital goods sector, which is the main locus for the accumulation of skills and knowledge required for assimilating, replicating, adapting and improving technology [*Rosenberg, 1963*]. The farm equipment industry serves as a springboard for the subsequent development of more complex branches of engineering through diffusion of knowledge and skills relating to generic mechanical engineering principles [*Johnston and Kilby, 1975*].

The Punjab is a fertile agricultural region known for its widespread adoption of modern cultivation practices from the late 1950s. Agricultural modernisation has been supported by a sizeable small-scale farm equipment industry. Manufacturing is concentrated in about eight major regional towns, each with its own agricultural hinterland.[15] One cluster consists of roughly 50 to 60 firms, which employ approximately five to fifty workers each. The largest workshops expand to about 100 workers during peak seasons.

The industry emerged in the early 1960s in response to rapidly growing demand for irrigation equipment by farmers. Local manufacture of centrifugal pumps and slow-speed diesel engines had begun in the late 1950s in a few large engineering firms with colonial origins, using older imported designs. Quite soon, ex-employees of these firms began to set up their own small workshops in which they replicated the equipment. They competed on low prices and quick repair due to proximity to customers, even though product quality was typically lower than that of the large companies [*Child and Kaneda, 1975*].

A second growth wave occurred in the 1970s, this time induced by farm mechanisation. Tractors soon began to be assembled in Pakistan by subsidiaries of large foreign tractor plants, such as Massey Ferguson and Ford (USA) and Belarus (former USSR). These firms also began to offer a range of equipment that could be used in combination with tractors, such as ploughs, seed drills, land levellers, rear and front blades, cultivators, and border formers. While tractor-assembly was beyond the capacity of the small-scale workshops, they did begin to copy a growing assortment of subsidiary equipment [*Aftab and Rahim, 1986; Nabi, 1988*].

Diversification and increasing complexity of the manufactured products occurred in the following years [*Government of Pakistan, 1984*]. In the most recent survey of the industry in 1994, well over fifty different farm equipment items were counted [*Romijn, 1999: 280–1*]. The simple rigid structures of the early days were still being made in large numbers, but several firms had also mastered more complex machinery with internal transmission mechanisms, such as rotary cultivators, wheat and rice threshers and maize shellers. Incremental improvements to designs had also been made to increase capacity, safety, sturdiness and efficiency. Thus, it is evident that technological capabilities had accumulated in the clusters to some extent [*ibid.*].

These capabilities had accumulated as a result of a range of technological efforts, including: internal experimentation to improve designs based on customers' feedback; hiring technically qualified consultants; training of staff; grooming junior family members by sponsoring their education at a polytechnic; searching for new designs by visiting trade fairs, contacting foreign farm equipment producers, or travelling to other regions to study the farm equipment in use there; and seeking interaction with local institutions concerned with research and development to adapt imported farm equipment to local conditions [*ibid.*].

The ways in which geographical agglomeration has affected this process of knowledge accumulation has not been studied. Some salient observations can nevertheless be teased out from existing studies that have documented the growth and development of the industry. The framework presented in Table 1 is used to structure the findings.

A useful starting point is the strong conducive market environment in the form of demand-pull arising from agricultural modernisation [*Child and Kaneda, 1975*]. The industry emerged in the proximity of agricultural areas with fast-increasing crop yields. Rising purchasing power of farmers combined with increasing seasonal labour shortages fuelled massive investments in mechanisation, which in turn induced a critical minimum local demand for many new types of farm equipment. There was an obvious impetus for producers to introduce new product technologies by reverse engineering prototypes imported by large engineering firms and wealthy farmers.

The demand-pull effects began to be relayed up the production chain. Specialist 'vendors' began to supply parts, components and machining services, investing in processes that require a critical minimum production scale to be economically viable (mechanism IIa in Table 1). Investments took place in 'heavy' machinery such as power cutting units, cylinder-boring machines, large furnaces (cuploads), honing and milling machines and power presses. What distinguishes these machines from the 'light' equipment conventionally used in farm equipment workshops is ' ... that they are more expensive and *require considerable expertise in handling.*

Also there are economies of scale in their use' [*Nabi, 1988: 59;* emphasis added]. These specialised investments extended and deepened the range of local manufacturing abilities, as vendors began to master the production of parts and components that had been hitherto imported or that had only been produced in Pakistan by one or two large engineering firms that were not part of the local clusters. A survey by the Punjab Small Industries Corporation in 1977-8 estimated the number of iron casting units at 419, employing well over 2,000 workers. It also reported 2,141 light engineering services units employing 10,500 workers [*Aftab and Rahim, 1986: 68*].

Even though economies of scale within *individual* small farm equipment workshops were reportedly insubstantial [*Child and Kaneda, 1975*], the clusters as a whole did begin to reap significant scale economies due to the increasing vertical specialisation facilitated by expanding demand, noted above [*Aftab and Rahim, 1986*]. More efficient horizontal division of labour through increased specialisation also occurred [*Stewart and Ghani, 1991: 585*]. These cluster-wide scale economies and interdependencies along firms in the industry helped to entrench the competitive advantages of small-scale production *vis-à-vis* imports and products made by large domestic manufacturers [*Aftab and Rahim, 1986: 66*]. It is not unreasonable to speculate that these economies would also have had the effect of freeing up resources for efforts to master new technologies (mechanism I, A–D).

The emergence of a range of specialised suppliers in the clusters also facilitated cheaper and easier access to specialised inputs needed for technological effort, due to reduced costs of transport, import duties, and so on (IIb, A–D). This benefited existing farm equipment firms as well as aspiring new entrepreneurs, as it enabled people with limited means to establish themselves as tiny units which would basically only perform basic machining, finishing and assembly of purchased parts and components [*Aftab and Rahim, 1986: 66–8*]. In the earliest survey of 100 diesel pump firms in the 1960s, only 36 were found to be fully integrated [*Child and Kaneda, 1975: 257*]. A more recent survey found that many workshops with such humble origins had expanded backwards in due course into technologically more demanding manufacturing, casting and forging operations [*Romijn, 1999: 284–5*]. In short, by attracting specialised suppliers, the clusters facilitated a gradual investment path and incremental technological learning trajectory for farm equipment producers.[16]

Technological-effort related benefits also have been associated with the presence of other types of specialised suppliers. A local market for reconditioned second-hand machinery emerged, bringing essential good-quality foreign machines within financial reach of large numbers of aspiring entrepreneurs [*Nabi, 1988: 157*]. Several clusters also began to attract technology-related support from national, provincial or local institutions. For example, several firms in Daska, one of the biggest clusters, had been approached by extension officers from the Farm Machinery Institute in Islamabad who were looking for suitable partners with whom they could commercialise farm machinery prototypes developed by them. Interested workshops would receive in-house technical training and counselling and would embark on a process of collaborative effort to iron out teething problems of new equipment during the stage of field trials with local farmers (IIb, B–D) [*Romijn, 1999: 243*]. Firms in another major cluster, Mian Channun, had benefited from the establishment of a Dutch-funded training and common facility project on the local industrial estate, run under the aegis of the Punjab Small Industries Corporation. Local firms received short training courses in heat treatment, properties of different metals and their uses, and use of jigs and fixtures. Moreover, they could make use of specialised machining services [*ibid.: 243*]. One of the machines was capable of manufacturing bevel gears, which are needed in rotary cultivators. According to local workshops, they would not have embarked on (and hence: mastered) the manufacture of this complex piece of farm equipment without the local machining service, because the nearest alternative facility was a several hours' drive away in Lahore (IIb, B).[17]

Diffusion of skills was further assisted by technical and vocational training centres set up by the central and provincial governments (IIb, B) [*Aftab and Rahim, 1986*]. Moreover, some reputable firms began to assume the status of training institutes. They issued certificates as evidence that apprentices had completed their training there. Since the authenticity of these documents and the reputation of the firms in question could be verified easily in the local community, this reduced transaction costs for workshops looking to hire labour in the local labour market (IIb, A).[18]

Evidence about learning-effects of inter-firm collaborations induced by clustering (IIc and IId) is mixed. There is no tradition of collaborations of the horizontal kind. The main reason is that transaction costs associated with coordination and bargaining are high, among others due to the lack of an adequate property rights regime [*Nabi, 1988: 123; Stewart and Ghani, 1991: 585*]. There is a fundamental lack of trust of competitors. The phenomena closest to collaboration are occasional machining services and trade credit given by a well-established workshop to a new outfit run by a member of the same 'bradri' (caste).[19] This kind of assistance helps to establish new entrepreneurs in the industry by overcoming indivisibility problems (similar to the mechanism discussed above in respect of parts and components suppliers). Especially the large *lohar* bradri ' ... helps fellow lohars to acquire the technical knowledge that is crucial for them to enter the industry' [*Nabi, 1988: 25*]. However, it falls well short of anything resembling collaborative experimentation between ongoing firms. Competition and associated secrecy is severe, even among people who belong to the same lohar bradri [*ibid.: 123*].

Technological collaborations have worked better across different stages of the production chain, because they are more complementary than competitive. Many firms have had collaborative arrangements with local subcontractors to assist in the innovation of components (IId, D). The description below highlights the learning-benefits of close physical interaction in these 'vertical' projects:

> Parent firms need of course to explain component design to vendor firms, but technical drawings are almost never used for the purpose. Instead, the usual practice is to hand over the prototype, which may have been imported or designed by a rival firm, to the vendor with few requirements for modification. While the component is being manufactured for the first time the parent firm actively supervises the process to ensure that specifications are met. This usually requires frequent visits by skilled machinists of parent firms. … Materials selection, too, actively involves the parent firm with the vendor ... since the quality of the material as much as vendor's craftmanship determines the life and quality of the components [*Nabi, 1988: 121–2*].

Transaction costs in these relationships are kept low through the extension of working-capital credit by the parent firms to the parts suppliers, which 'ties' the latter into a co-operative relationship. Moreover, much collaboration takes place among members of the same bradri because mutual trust is higher between members of the same extended family [*ibid.: 22–3*].

In addition to stimulating investments in technological effort by the participating parties, these local interactions make learning easier through free exchange of technical information and knowledge (Vb, C and D). One reason why farm equipment producers and vendors tend to co-locate has to do with such knowledge spillovers: 'It gives them the feeling of being in the market and of having easy access to information, whether about demand for their product, or about technological innovation. There is also considerable informal exchange of … engineering advice' [*ibid.: 118*].

User-producer spillovers are also common further downstream in the production chain. Progressive entrepreneurs pay regular visits to farms to field-test their products and get farmers' opinions. Farmers are particularly useful as sources of feedback for design adaptation. Equipment based on foreign designs often needs to be adapted to take account of local soil conditions, land quality and cultivation customs [*ibid.: 141, 150]*). Regular face-to-face communication between manufacturers and farmers ensures that designs are in keeping with farmers' needs [*ibid.: 138*]. Moreover, progressive farmers who buy imported farm equipment are sources of information about new product designs. Manufacturers generally try to reverse engineer foreign prototypes when they are passed on to them for repair and maintenance.[20]

Other types of spillovers have also facilitated diffusion of technological knowledge and skills in the clusters. First, knowledge about new designs spreads rapidly in the industry due to co-location (Va, C and D). Technology transfer appears to result predominantly from informal contact and observation, although marketing leaflets, industry association meetings, and the annual Horse and Cattle Show in Lahore (which features new locally produced farm equipment) may be of some importance as well [*Romijn, 1999*]. However, the advantages of quick diffusion are to some extent outweighed by appropriability problems encountered by the originators of the new knowledge. This affects investments in technological effort by progressive firms. Their reverse engineering and improvement efforts are conducted behind closed doors in the slack season, when seasonal hired labour is absent. This procedure ensures that firms can reap just enough innovation rents from their efforts to make experimentation worthwhile [*Romijn, 1999*]. Local copies usually appear one year after the public launch of the 'original'. This appears to be one reason why only incremental modifications are made to the designs [*Nabi, 1988: 123*]. Vertical spillovers do not suffer from such drawbacks.

Motivational spillovers through demonstration effects have also been widespread (III, A–D). Young apprentices see many local examples of ex-trainees who have made it in business. This feeds entrepreneurial aspirations and attitudes in the industry [*Nabi, 1988*]. Not surprisingly, many ex-apprentices attempt to start their own workshop after completing their training. Thus, skills diffusion has also occurred through inter-firm movement of trained labour (V, A) [*Johnston and Kilby, 1975: 373; Stewart and Ghani, 1991: 585; Child and Kaneda, 1975: 253*]. The process initially started with spin-offs from the large engineering firms in the area, later followed by proliferation of new entrepreneurs trained within the small-scale sector itself [*Aftab and Rahim, 1986: 62; Nabi, 1988: 56,138–9, 152*]. Skills spread more easily through new firm start-ups than through movement of labour between existing companies.[21] Unfortunately, the fission process has been so vigorous that local competition has become a severe problem [*Romijn, 1999: 141–3*].

Recapitulating the evidence, the application of our integrated analytical framework yields several additional insights over those based on the conventional TC perspective. The latter has drawn attention to the importance of a conducive environment (in the form of demand-pull from agriculture), and of various supporting S&T facilities in the region. These factors feature no less importantly in our approach, and it is clear that they have to constitute important areas for stimulating further technological development of the sector.

However, a range of cluster-based mechanisms identified in Table 1 has reinforced the impact of these factors on intra-firm learning. Insights into the operation of these mechanisms can be taken on board in policy-design, thereby achieving more effective targeting. Since the industry is already highly clustered, policies aimed at promoting further agglomeration are not at issue in this case. Potentially more relevant would be interventions aimed at improving or further enhancing the effective functioning of certain effort-inducing mechanisms in clusters that already exist. One obvious example would be to help producers to overcome failures of horizontal collaboration through initiatives aimed at strengthening local collective institutions such as industry associations – the one mechanism in Table 1 that did not appear to work at all well (IIc and d). There is also room for further stimulating mechanisms that already do work well. Many of these do not rely on active co-operation. Examples are direct facilitation of spillovers through improvement of the local infrastructure for dissemination of technical information and new knowledge through local trade fairs, industry journals, and facilitating informal industry meetings (Va and b, C and D).

Furthermore, our findings suggest that targeting technological support to a few specific firms in a cluster could be an efficient approach in some instances. In this case, imparting new production practices to a few advanced firms with formalised apprenticeship schemes is likely to have more impact than a dispersed training effort. The latter can be reached more effectively as a result of indirect dissemination, through spillovers in the labour market (IVb and V, A).

VII. CONCLUSIONS

Accumulation of technological capability is crucial for industrial growth and competitiveness of firms, particularly in the context of liberalisation and increasing international economic integration. The article sheds light on how such capability could be fostered through geographical clustering, by linking the micro-economic technological capability perspective with meso-approaches to the study of regional economic development. The resulting framework provides new policy-relevant insights about the factors driving technological learning as compared to conventional technological capability studies.

Some key observations can be made on the basis of this exercise. First, in order to compile a comprehensive taxonomy of causal linkages between agglomeration advantages and technological effort, a broad array of economic and economic-geography theories relating to developing countries as well as advanced economies were explored. This procedure appears to have generated considerable value added. First, by taking received theory as a starting point, the framework can help to infuse some much-needed conceptual clarity in this field of research. Moreover, it would not have been possible to identify a comprehensive set of contributing factors without casting the net so widely. While the taxonomy includes some mechanisms that have already been pinpointed in earlier studies about cluster dynamics (notably those associated with inter-firm co-operation, commonly highlighted by studies in the collective efficiency tradition), it also threw up others that have received only cursory attention or which appear to have escaped notice altogether. These relate especially to the effects of cost advantages and various spillovers. Possibly, these factors have received less attention because they are intrinsically much harder to observe than inter-firm collaborative mechanisms, and also since researchers did not employ a conceptual toolkit that led them to explore in these particular directions.

Important issues for further research can also be derived from the framework. For instance, it suggests factors that may affect the impact of clustering on technological learning and long-run competitiveness of regions, such as inter-industry differences in technology. Industries in which economies of scale and scope are large could be expected to benefit more than industries in which these economies are small. Opportunities to profit from large markets and complementarities arising from an extensive division of labour are greater in the former than in the latter. A somewhat similar argument holds for economies of transaction that can be gained through clustering. These economies are likely to be much larger in industries characterised by fast technological change than in slow-changing industries, because uncertainty and risk tend to be higher and knowledge tends to be less codified in the former than in the latter. As a result, the incentives to engage in joint action could also differ across industries. This could be one reason why attempts at establishing learning-oriented collective institutional arrangements have hardly managed to get off the ground in some places, whereas they have thrived in others.

Another factor is economic in nature. Our framework suggests that geographical clustering of industry cannot be expected to exert much of a positive influence on regional economic prosperity when there is no scope for exploiting opportunities for technological learning. This was also abundantly clear from the case study in the Pakistan Punjab. Firms have to face concrete incentives to invest in technological effort in order to meet a competitive challenge; that is, there must be demand for technical improvement. Only when such incentives are present can firms be expected to develop an active interest in engaging in training, hiring, searching and tinkering on the shop-floor. Only then will the potential learning benefits offered by clustering begin to materialise, because it is only in those circumstances that the various mechanisms set out in our framework can come into play. In this kind of situation, supply-side interventions aimed at overcoming critical missing resources are likely to stand a good chance of success. However, it will be much more difficult to create dynamic clusters by means of this kind of support in a situation of stagnant markets. In the absence of individual capability-building efforts by firms, there can be no cross-fertilisation through new ideas, knowledge and information either. Clustering is no panacea.

These observations suggest the need for empirical work in which these issues can be explored more systematically. The framework developed in this paper is essentially a basic conceptual blueprint that can guide such research. It characterises how the process of technological capability accumulation in an industrial region actually works, providing conceptual focus and helping to pinpoint important factors that are likely to affect the nature and strength of the relationship between regional agglomeration on the one hand, and technological capability accumulation and long-term competitive performance on the other. Understanding the nature of the process is the first step in getting to grips with the long-run industrial dynamism of regions.

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NOTES

1. For example, Katz [*1987*], Bell *et al.* [*1984*], Lall [*1987*], Amsden [*1989*], Westphal *et al.* [*1984*], Fransman and King [*1984*], Stewart *et al.* [*1992*], Hobday [*1995*], Biggs *et al.* [*1995*], Lall *et al.* [*1994*], Dahlman *et al.* [*1987*], UNCTAD [*1996*], and Romijn [*1999*]. Lall [*1992*] and UNCTAD [*1996*] are good reviews of the literature.
2. Bell and Albu [*1999*] make an attempt, but they supply an *ad hoc* list of intra-cluster and extra-cluster mechanisms, and the reasons why the existence of spatial proximity would confer special learning advantages remain unclear.
3. For example, Schmitz [*1995*], Schmitz and Nadvi [*1999*], Humphrey and Schmitz [*2000*], Nadvi [*1996*], Tewari [*1996*], Rabellotti [*1997*], Ceglie and Dini [*1999*], UNCTAD

[*1998*], and the theme issue of *World Development,* Sept.1999.

4. Humphrey and Schmitz define 'upgrading' as improvements in processes and products, and moving into higher-value added operations, specifically in the context of global value chains [*2000: 3*].
5. Clustering may also give rise to some disadvantages, for example due to congestion and excessive competition. In this article the focus is confined to the positive effects.
6. For details, see Caniëls [*2000*].
7. We ignore the fifth main category identified by Bell, internal performance feedback, since it is unlikely to be influenced by factors external to the firm.
8. In order to simplify the discussion we confine the focus to *direct* linkages; that is, effects which occur without intervening third variables which do not constitute technological efforts themselves. An example of an indirect linkage is cost savings in production which provide incentives for firms to expand, which in turn calls forth the need for new capabilities, and thus efforts to build them up.
9. The first two channels are horizontal spillovers; that is, they mainly stimulate diffusion of information, skills and knowledge among firms at the same stage in a production chain. The third is a vertical spillover, involving exchange across consecutive stages in a production chain. This channel is likely to be especially important for firms which are linked to global value chains.
10. The classic reference is Dahlman *et al.* [*1987*].
11. The term appears to relate only to process technologies, but skills and knowledge required to assimilate new *product* technologies are also crucial in developing countries, particularly in engineering industries [e.g., *Romijn, 1999*].
12. Lall [*1992*] uses a slightly different classification of investment, production and linkage capabilities.
13. Several writers on SME clusters in developing countries have indeed noted that relatively 'closed' systems tend to have difficulties in sustaining competitiveness in the longer term [e.g., *Nadvi, 1999a; Rabellotti, 1997; Visser, 1999*].
14. In this connection, Bell and Albu [*1999*] distinguish clusters that are primarily 'knowledge-using' from clusters that have learnt to engage in 'knowledge-changing' activities. The distinction is rather similar to our distinction between the basic phase of assimilation and reproduction and the intermediate phase of creative adaptation. However, we believe that the ability to generate new knowledge internally is ultimately crucial for creating and sustaining indigenous technological dynamism in firms (and by implication also in clusters). Bell and Albu's requirement appears to be less stringent. Their knowledge-changing capabilities encompass elements to do with knowledge absorption alongside internal knowledge-creation.
15. The main locations are Lahore/Sheikhupura, Gujranwala, Hafizabad, Daska, Mian Channun, Okara, Faisalabad and Rahim Yar Khan [*Romijn, 1999*].
16. Already well before the advent of the contemporary studies about collective efficiency and regional industrial development, this feature was referred to as 'structural flexibility' inherent in a network form of organisation [*Aftab and Rahim, 1986: 66–7*].
17. Source: fieldwork by Romijn in 1994.
18. Idem.
19. Idem.
20. Idem.
21. Although there is high labour mobility between ongoing businesses, it concerns mostly unskilled seasonal labour [*Nabi, 1988*].

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