



Knowledge Systems and Technological Dynamism in Industrial Clusters in Developing Countries

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Summary. — Research on industrial clusters in developing countries is increasingly concerned with how their competitiveness evolves and changes over time. This article shows what analytical shifts are needed to unravel the technological underpinnings of clusters' longer-term competitiveness. Building upon an understanding of technological learning in large-scale firms, we stress the need to focus on systems of knowledge accumulation, rather than just production systems. With this in mind, future research should investigate clusters' active capabilities for generating and diffusing knowledge, and their openness to external sources of knowledge. A conceptual framework to guide investigation of these aspects of cluster knowledge-systems is presented. © 1999 Elsevier Science Ltd. All rights reserved.

1. INTRODUCTION

For those with interests in the technological and organizational underpinnings of the long-term process of industrialization, research on industrial clusters in developing countries has moved into an intriguing transition phase. For several years this field of research has concentrated on various aspects of the comparative morphology of clusters, but recently it has become increasingly concerned with questions about the dynamism of clusters and their longer-term competitiveness. Rabellotti (1995, p. 229), for instance, has stressed the importance of "...comparing trajectories and stages of development instead of snap-shots." Humphrey (1995) has emphasized the importance of moving "from models to trajectories" in the analysis of clusters; and indeed Schmitz (1995, p. 9) found that "the most interesting conclusions emerge from tracing changes over time"—a view recently well illustrated by Meyer-Stamer's (1998) exploration of path dependency in industrial clusters in Brazil.

Research on clusters has also begun to give explicit attention to the "technological" aspects of dynamism. Although they might not use that term, authors have turned at least some of their attention to questions about the rates and sources of change in the designs and quality levels of the products produced by clusters and in the characteristics of the materials, processes and organizational arrangements used to produce and market them. Growing interest in these aspects of technological change does not mean however that there is general agreement about the importance of the technological dimension of cluster dynamism. Nor is there any consensus around either the key issues to explore or the conceptual basis for any such exploration. A broad aim of this paper is therefore to stimulate and guide interest in this

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technological dimension, by highlighting some of the most important questions that are as yet unanswered and by suggesting a conceptual basis for further research.

The current situation is reminiscent of a very similar phase of transition in the closely related field of research on technological change and dynamic competitiveness in the large-scale sector of industry in developing countries. Many of the uncertainties, limitations and difficulties currently confronting research on the technological dynamism of clustered industrial production were evident about 25 years ago in what was then an emerging field of research on technological change and learning in individual large-scale enterprises in developing countries.

Research since then built up a body of understanding which fundamentally altered the previously dominant perspective on technological change and industrialization. We suggest that research on clustered small-scale production in developing countries is part way through a similar conceptual transition. So far however it has shown few explicit links with research on the technological dynamism of the large-scale industrial sector in developing countries.¹ In this paper we specifically try to strengthen those links, hoping to contribute to the development of understanding about the technological dimension of the longer-term evolution and competitiveness of industrial clusters.

In Section 2 of the paper we compare the two bodies of research, attempting to locate the perspectives which are currently dominant in research on clusters on the spectrum of shifting perspectives about technological change in large-scale industry which has developed since the 1970s. Then in Section 3 we outline several conceptual issues about knowledge systems and technological capabilities which seem important in developing a deeper understanding about the technological dynamism of industrial clusters in developing countries. In doing so, we draw initially on the previous body of research about technological change in large-scale industry, but that is only a starting point. We then try to move beyond that to address some of the more specific characteristics of technological change in clusters. Finally in Section 4 we build on that conceptual discussion to outline a taxonomy of key features of the organizational basis of technological dynamism in clustered industrial production, and we illustrate how this might be developed as a basis for comparative analysis of change in cluster "knowledge systems" and its relationship to the

long-term sustainability of cluster competitiveness.

2. TECHNOLOGY AND INDUSTRIALISATION: CHANGING PERSPECTIVES

(a) *Technology, dynamism and large-scale industry in developing countries: an earlier transition*

Until the late 1960s there was little interest in understanding industrial technological change in developing countries. This was partly because the process of technological change was presumed to be largely absent, occurring almost entirely in the industrialized world. It was also because, in the tenets of "mainstream" growth economics, technology was embodied in fixed capital and technological progress was therefore achieved by the fairly straightforward process of capital accumulation. Consequently, since the industrially advanced countries were the producers of most of the capital goods needed for industrialization, any problem about achieving long term technological progress in industry was largely a problem about generating the savings and international capital flows needed to acquire externally sourced capital goods.

From that perspective, the technological role of local industry was essentially passive, involving merely the adoption and routine operation of externally supplied technologies. Curiously, this view was also held by the "dependency" school of thought which described the reliance of "peripheral" developing countries on imported capital goods as "technological dependence," correspondingly emphasizing the virtual absence of any significant innovative activity in Third World industry. These views about the irrelevance of any significantly creative industrial technological activities in developing countries rested on several presumptions about the nature of technology and technological change.

—Technology was identified almost exclusively with machinery (capital goods). Technological change was therefore seen either as development of new kinds of machinery (technological "innovation") or as acquisition and installation of new machinery which had already been developed elsewhere (the "diffusion" of technology).

—A sharp distinction was drawn between technological innovation and technology diffusion. One was considered technologically creative; the other was seen as involving merely the passive “adoption” of innovations created by others.

—“Modern” industry in developing countries was seen as typically acquiring almost all its capital goods from suppliers in the industrialized world. If there was any production of industrial capital goods in developing countries, that involved merely the technologically passive replication of machinery designs originating in the industrialized world.

From this stylized “1960s” perspective, any locally generated industrial technological change in developing countries was seen as essentially minor and adaptive, involving little or no technological creativity. The main technological tasks were merely to acquire, and learn how to use, available technologies, and the only “technological capabilities” needed were those for undertaking such routine investment and production activities.

For any social scientist interested in creative aspects of the process of industrial technological change, this perspective suggested that there was little significant to observe. Thus, concerns about policy relating to technological change tended to focus on financial and informational “gaps” that obstructed or distorted the flows of capital-embodied technology. Fortunately, not all social scientists accepted that perspective and, starting from the early 1970s, a growing number began to explore the realities of technological change in large-scale industry in several developing countries, especially in the larger and more industrialized countries such as Brazil, Argentina, Mexico, Korea and India. Twenty-five years later this research has accumulated a large body of understanding which suggests a very different stylized picture from that outlined above.

First, analysis of change in a firm’s production technology must encompass much more than just its machinery-embodied technology. Technology is a much more complex bundle of knowledge, with much of it embodied in a wide range of different artifacts, people, procedures and organizational arrangements. These embodiments of knowledge include at least: product specifications and designs; materials and component specifications and properties; machinery and its range of operating characteristics; together with the various kinds of

know-how, operating procedure and organizational arrangement needed to integrate these elements in an enormously variable range of different production systems. Moreover, as these elements of technology are highly interconnected, improvement in something as “simple” as product quality may require changes to be made across several linked elements of the bundle, e.g., in machine hardware or operating procedures, the organization of production flows, or the specification and treatment of materials.

Second, there is no sharp distinction between innovation and diffusion. Very few components of production technology are simply acquired “ready-made” and then brought into use according to standard “recipes” which are identical to, and replicated from, previous applications. Even in cases where the introduction of some element of new technology involves a fairly close approximation to such noncreative technology “adoption,” the interactions with other elements of technology in the production system typically requires creative problem-solving and innovative re-configuration of at least some elements in the overall production system. Furthermore, firms do not acquire the capabilities to generate these creative changes spontaneously merely from the experience of doing production, as implied by notions of learning curves. Indeed, studies of infant industries (e.g., Bell, Scott-Kemmis and Satyarakwit, 1982) have demonstrated that the performance of production systems may not increase at all over time, and can easily stagnate or decline over the long-run.

Third, external sources of technology are not limited to machinery suppliers. Customers, for instance, may be much more important sources of technology, providing not just knowledge about product specifications but also a wide range of other elements (e.g., operating procedures and know-how, or knowledge about materials properties).

More positively, research has identified a wide spectrum of technological changes which do not fit the common focus on “step-jumps” based on new knowledge derived from formalized Research and Development (R&D), requiring substantial investment in new facilities for their implementation. This spectrum of *other* kinds of technological change encompasses, for instance, those which involve (a) improvements to *existing production systems*, rather than investment in complete units of new production capacity; and (b) knowledge inputs

drawn largely *from existing stocks* rather than from recent R&D.

These types of change account for a very large proportion of all technological change and, in technologically dynamic firms and industries in both developing and developed countries, continuing streams of such change typically stretch out over long periods throughout the lives of production systems. Their cumulative economic significance over these periods is typically very large. Moreover, they do not emerge spontaneously as a “by-product” of the routine production operations of firms—as in simpler conceptions of “learning-by-doing”. They are generated with very substantial inputs from the change-generating resources of the technology-using firms themselves (Hollander, 1965; Dahlman and Fonseca, 1987; Enos, 1997).

To sum up, from this “1990s” perspective, technological change is not simply something which firms choose and “buy-in” from outside. On the contrary, it is rooted in a specific set of change-generating resources or capabilities which are located *within* the structure of technology-using firms. Consequently, the learning processes which contribute to building and strengthening those capabilities are seen as playing an important role in the long-term dynamism and sustainability of industrial production.

This also means that for those interested in understanding industrial technological dynamism in developing countries, there *is* after all something to observe—apart from the acquisition of externally sourced machinery. Moreover, these processes of technological change and capability accumulation exhibit wide differences between firms, industries and economies, with some of these differences apparently associated with different long-term paths of economic performance.

There is, however, an important issue which until recently was given only limited attention in the literature on technology and large-scale industrial development: the interfirm, network-based nature of the processes of change and technological learning. While the importance of the individual large firm’s own change-generating capabilities has been emphasized, it has also been recognized that technological change usually depends on externally sourced inputs. More recent perspectives have therefore come to emphasize the importance of this dual structure of internal change-generating resources and links to external sources of tech-

nology—both other firms and more specialized knowledge-generating organizations like universities or R&D institutes. Such combinations of internally organized capabilities with external knowledge resources, and the links between them, have come to be described as industrial “*innovation systems*,” “*technology systems*” or “*knowledge systems*”—a profusion of concepts derived largely from research in the industrialized world in the last decade or so.²

While these systemic perspectives have recently been seen as important for understanding the technological dynamics of late industrialization, there has only been limited empirical research about how these networked knowledge systems emerge and evolve in the specific context of large-scale industry in developing countries. On the other hand, of course, understanding the development of networked structures has been the “bread and butter” of research on clustered small-scale industry in developing countries. That is a major reason why the transition of interest in this field of research toward issues about technological dynamism is potentially so fruitful. If future research on industrial clusters can combine a focus on the interfirm networked structures and relationships, with an exploration of the change-generating resources and learning processes occurring *within* technology-using firms and cluster institutions, then we may move closer to understanding the basis of technological dynamism and the sustainability of competitiveness in clusters.³

(b) *Technology, dynamism and industrial clusters in developing countries*

It is difficult to reflect in a short commentary the inevitable heterogeneity of views and perspectives within a “field” of research. Nevertheless, even a sketchy attempt to do so here may be useful in highlighting some of the key issues which we will develop further in Section 3 of the paper. To provide a clear framework for this, we have focused on the recent doctoral research of six authors. While four of them are contributors to this Special Issue, this article refers to their doctoral theses. Key features of these studies are summarized in Table 1.

All these studies are concerned with issues about change and dynamism over relatively long periods. There are, however, wide differences in the key aspects of change given most attention and, at a broader level, there is little

Table 1. *The investigation of technological dynamism in selected cluster case studies*^a

Case study	Main focus of inquiry	Investigation of technological change and its determinants
Nadvi (1996) Surgical Instrument Manufacture Sialkot, Pakistan	Relations between economics of clustering, local social identities and international competitiveness.	Used questionnaire-based survey of 57 firms. A few technology-related questions, but not the main focus (~5% of questionnaire): What new technologies and equipment adopted in past five years? General sources of technical innovations? Changes in the way production is organized and controlled? Sources of information for process innovation and product designs? There is however, limited discussion of the results of these questions. Qualitative evidence from detailed case-studies is ambiguous about technological advantages of clustering relationships. Relates clustering to improving organization and quality standards.
Tewari (1996) Light-engineering Industry Ludhiana, India	Patterns of small-firm growth, including their dynamism and incorporation into national and export markets.	Explored the social and historical origins of the vibrancy of Ludhiana's industry. Interviewed 117 firms, but details of methodology and questionnaire not available. Little quantitative analysis of results. Ample qualitative evidence provided for mechanisms which aid rapid diffusion of technical changes through the cluster, and lower entry barriers. Extols "innovative adaptability of Ludhiana's small firms." Does not address the key question of how new knowledge and skills for managing technical change (innovative adaptability) are acquired.
Sandee (1995) Rural Roof-tile Manufacture Karanggeneng, Indonesia	Longitudinal study, exploring processes of technical change—in particular, how innovations diffuse through a village cluster.	Six-year study of innovation diffusion among 34 producers, distinguishing between early, late and non-adopters. Highlights disadvantages to those excluded from networks of information and credit. Demonstrates advantages of clustering where collaboration is necessary due to scale-economies (indivisibility of capital goods). Comprises a detailed investigation of the closing of a particular "technological gap," but not if and how this is part of a process of deepening technological capabilities (to close future/wider gaps). Sources of technological change (innovation) are treated as exogenous. Concerned with how the use of innovations diffuses, rather than with the capabilities of adopters.
Rabellotti (1995) Footwear Industry Leon/ Guadalajara, Mexico	Analysis of the economic effects arising from the linkages existing among economic agents within clusters.	Structured questionnaire-based survey of 50 firms in Mexico and a similar number in Italy. Supplemented by nine detailed case-studies. Technology-related questions few, along same lines as Nadvi (above), but there is minimal discussion of the results. Technological performance is seen as very poor, but this is associated simply with the lack of a domestic capital goods sector. There is little exploration of why these clustering firms capabilities to manage the opportunities and threats created by technical changes are so weak. Addresses need to study the "system's capability to grow and innovate in" conclusions.
Cawthorne (1990) Cotton Knitwear Industry Tiruppur, India	Labor processes under amoebic capital accumulation in a cluster of mainly small firms.	Intensive research based on detailed case-histories of 25 sample firms, focusing principally on capital accumulation and labor processes. Explicitly rejects technological factors in explaining recent expansion and export success. Argues convincingly that stimuli for technological change are external, but does not investigate factors that influence the cluster's technological capability to respond to market stimuli. Questions whether Tiruppur industry can continue to compensate with cheap labor for what it lacks in technical sophistication. Anecdotal evidence presented suggests it cannot.
Visser (1996) Garment Manufacture Lima, Peru	How clustering helps small firms perform core functions of production, transactions, innovation and risk management.	Carefully conceived and structured questionnaire-based sample survey of 130 firms including (uniquely) two non-clustered control groups. One (of four) research questions is: "do local networks add technological knowledge to the local environment?" The survey analysis dwells however on relationship between productivity performance and static linkage-effects. The kind of linkages which might have dynamic-effects are found to be absent or only incipient. Conceptual emphasis on dynamic functions of the firm, and dynamic linkage-effects of clustering, but no direct attempt is made to measure technological development.

^a Source: Abstracted from Albu (1997).

consensus about the phenomena described as “dynamic”. Nevertheless, all six studies are concerned with issues about “innovativeness” in some form or other. None of them is centrally focused on questions about technological change, but *all* of them *do* address such questions in some form: in other words, their interest in “innovativeness” is concerned in some degree with change in the characteristics of the products, processes and production organization of the clusters examined, and all the studies make more than just incidental reference to these kinds of change.

This does not, of course, mean that all the authors identified the presence of significant technological change in the clusters they examined. It was apparently weak, intermittent or absent in some; and in the case of the knitwear cluster in Tiruppur, for instance, Cawthorne (1990) explicitly rejects the idea that technological factors could explain the rapid expansion of output and the considerable export success.

Independent of how much they emphasize technological change in their studies, some aspects of the authors’ underlying perspectives on technological dynamism can be roughly located on the stylized “1960s–1990s” transition outlined above. None of them is consistently and clearly located at the 1960s end, although, some of them in some respects are nearer that end than the other. This can be illustrated with reference to three issues: a common emphasis on the introduction of machinery within a relatively narrow perspective on what constitutes “technological change”; a preoccupation with technology “diffusion” as the main intracluster process contributing to technological change; and limited interest in the nature of intracluster capabilities for generating innovation or in the factors which may influence whether and how those capabilities are accumulated.

(i) *Technology as machinery, and the limited scope of “technological change”*

An emphasis on technology as machinery is quite pervasive in the studies. This is probably most evident in Sandee’s research on tile making in Indonesia and least evident in Visser’s study of garment-manufacturing in Lima. Others are more ambiguous. For instance, with reference to the products produced by the textile industry in Tiruppur, Cawthorne (1995) notes that “...the quality of such garments has improved beyond recognition over a 10-year period...” (p. 46). But she then also notes that

there is relatively little technological change or improvement in the industry as a whole in Tiruppur (p. 49). This apparent contradiction seems to arise because the author’s comments about technological change were almost entirely concerned with machinery, while the improvement in product quality was not identified as “technological.”

Ambiguity is also shown in Nadvi’s fascinating study of the long-term evolution of the surgical instrument cluster in Sialkot (1996). A large part of the study is concerned with issues of product quality, and the manifold forms of technological change underlying quality. In particular, Nadvi emphasizes the importance of what he calls “soft technologies”—aspects of the procedures and organizational arrangements used in production. When questions about technology and technological change are directly addressed, however, machinery and its acquisition tend to occupy center-stage. This emphasis is continued in a subsequent paper based on the research: “In an industry reliant on traditional knowledge and metalworking expertise, the adoption of new technologies has been relatively simple in that the logic of new machinery can be easily understood” (Nadvi, 1997, p. 6).

Rabellotti also is concerned at one level with different kinds of technological change, but a large part of her treatment of this issue focuses on machine-centered changes. Indeed, she seems to identify capital goods production as the heart of the technological change process and its absence as a major reason for the observation of limited technological innovation: “...the lack of a domestic industry specialized in the production of machinery for the shoe sector is probably the main drawback to increasing technological co-operation and introducing innovations” (Rabellotti, 1995, p. 144).

Our emphasis on this type of ambiguity is not just definitional nit-picking. The issue has important implications for the conclusions one can draw from these studies about the nature of technological change in clusters. If it were unambiguously evident that the researchers had explicitly sought to assess technological change on the basis of a consistent and broad concept their conclusions would carry considerable interest and weight. In particular, observations about technological change in clusters being limited to machine-centered forms of change would highlight important aspects of the “narrowness” of the technological change process taking place. For instance, if Cawt-

horne's conclusions about the limited significance of technological change and improvement in Tiruppur do reflect a careful demonstration that rapid growth in output and exports had little or nothing to do with change in the specifications of products, processes, materials or production organization, it would be an important and revealing finding about the nature of the dynamism underlying the development of at least this particular cluster. On the other hand, the ambiguous conceptual and methodological basis of the result leaves one wondering whether the conclusions merely reflect the approach taken in observing "technological change and improvement."

(ii) *The role of extracuster innovation and intracuster diffusion*

Several of the studies reviewed here throw interesting light on aspects of technological change generated by firms inside the cluster. Indeed, this descriptive material seems to allow comparison across the studies, suggesting for instance that there is considerable variation in the relative importance of sources of technology inside and outside the clusters.

In some cases, external sources appear to have played a large or even dominant role. For instance, in Nadvi's (1996) study of the Sialkot surgical instrument cluster, links with foreign buyers were important sources of technological change, as illustrated by the case of German firms which "sent out metallurgical engineers for periods of up to three months to train the Sialkot partner firm in quality control and production engineering" (p. 117). More strikingly, US consultants played a major role in enabling firms in the cluster to raise product quality and overcome the threat to their continued existence posed by a US embargo on Sialkot instruments on account of their poor quality. External buyers were also critically important in the initial introduction of new hand-press machinery in the tile-making cluster studied by Sandee (1995).

In other cases, extracuster sources of new technology seem to have been much less important. For instance, Rabellotti's study of Mexican shoe manufacturers suggests that buyers played a much less significant technological role, though this seems to have reflected a limited implementation of change derived from *any* source rather than a different relative importance of technology sources within and outside the cluster. In other cases however, internally generated change seems to have been

the main driving force behind continuing improvements to products and processes. For instance, Tewari emphasizes that the key reason for the successful growth of the Ludhiana metalworking cluster was the innovative adaptability of the small firms themselves. In particular, their cost-cutting process improvements and low-cost adaptation and replication of machinery allows small firms to upgrade their production processes at a relatively rapid rate and low cost.

Thus, the studies appear to have observed different types of technological change. In several cases the observations were made through a research lens with a high enough level of resolution to detect at least some of the fine details of locally generated incremental innovation. In this respect they are far removed from the 1960s perspective on technological change which, presuming that locally generated innovation would be absent, emphasized the role of technology diffusion as the dominant technological change process.

On the other hand, one cannot be totally confident in using these observations to draw conclusions about intercluster variation in the relative importance of different sources and processes of technological change. One wonders again about the extent to which the apparent differences are more a reflection of different approaches used in the research. With the methodologies still in a rather opaque and idiosyncratic phase of development, such questions are not easily answered by the reader, and the potential insights from cumulating comparative analysis must be largely forgone for the time being.

This doubt is reinforced by a curious contrast within this body of research. On the one hand, as summarized above, several studies identify internally generated change as important in at least some of the clusters and externally acquired technology as a major source of change in most of them. Yet, when analysis shifts to draw more general conclusions, for example, about the influence of clustered production on the process of change, little attention is given to either of those processes, and interest is focused almost exclusively on the diffusion of existing technology among firms within the cluster. For instance, despite the evident importance of external linkages as sources of technology in most of the clusters studied, only Nadvi investigates how these actually assist industrial clusters in developing the means to effect technological change. We explore this issue further in the

discussion of “open” and “closed” knowledge systems in Section 3(c).

(iii) *Intracluster technological capabilities*

Perhaps the most important contribution made by research on technological change in the large-scale industrial sector in developing countries has been its clarification of the central role of specific resources (people, knowledge and organizational arrangements) as the drivers of technological change. In particular, the pervasive significance of these resources has been emphasized. They are not merely concentrated in a few supply centers for innovations but, blurring the boundary between innovation and diffusion, they are widespread and deeply rooted across the whole spectrum of firms in technologically dynamic industries and supply chains.

Given the apparent importance of these resources, considerable efforts have been made to understand how they are accumulated and, especially important, how key characteristics of these resources change as technology-following firms and industries in developing countries evolve along trajectories of increasingly complex technology to “catch up” with international technological frontiers—for instance, Hobday (1995) on the electronics industry in several Asian countries, or Kim (1997) on large *chaebol* operating in several industries in Korean. To a lesser extent, efforts have been made to understand why these innovative technological capabilities are accumulated in different ways and at different rates across firms and industries (Katz, 1987; Bell and Pavitt, 1993).

It is in this area where research on industrial clusters in developing countries is still perhaps closest to the “1960s” perspective. As summarized in the right-hand column of Table 1, most of the studies reviewed here gave no attention to the nature of the knowledge-resources and other capabilities underlying the technical change observed in the clusters. None raised questions about how such change-generating capabilities were acquired and accumulated. This neglect of the resource base for technological dynamism seems to arise partly because research on clusters has emphasized the importance of interfirm links within spatially concentrated groupings. Intrafirm issues have attracted much less attention, inevitably involving only limited efforts to identify and understand the specific resources underlying technological change. This trend has been reinforced by perceptions of passive technology

diffusion, rather than creative technical change, as the dominant intracluster process contributing to technological dynamism.

3. KNOWLEDGE SYSTEMS AND TECHNOLOGICAL CAPABILITIES

In this section we explore a number of conceptual issues which seem important in moving forward to build a deeper understanding of the technological dynamism of industrial clusters in developing countries. These issues hinge around three important distinctions: between “production systems” and “knowledge systems” involved in clustered industry; between “knowledge-using” and “knowledge-changing/creating” elements within knowledge systems; and between “open” and “closed” knowledge systems.

(a) *Production systems and knowledge systems*

Leaving aside their spatial structure, the key characteristics of industrial clusters have usually been defined in terms of the materials they use and the goods they produce. For instance, “horizontal” clusters are typically defined by the similarity of the firms products; and in “vertically” linked clusters it is the flows of materials and goods which constitute the key linkages. When attention has turned to technological change in clusters in developing countries, these materials-centered structures and flows have usually remained at the center of the analysis, both defining the system to be observed and describing its key characteristics. For example, it is not uncommon to consider how the density of linkages concerned with goods and materials might influence the diffusion of technology.

Yet technological change is essentially a knowledge-centered process. It is knowledge stocks within firms and knowledge flows to them, between them and within them which underlie change in the types of goods they produce and the methods they use to produce them. We will call these stocks and flows of knowledge the “knowledge system,” and assert that it is the structure and functioning of that knowledge system which generates technological change at particular rates and with particular degrees of continuity and persistence. Consequently, an important initial step in trying to understand the varying technological dynamism of industrial clusters is to develop a

“map” of what seem to be the key knowledge flows and processes.

This kind of knowledge-centered perspective has been emphasized in other related strands of research, for instance by those who have tried to examine technological change in “innovative milieux” in Europe. As noted by Lawson (1997, p. 11), this body of research has sought to “emphasize the importance of linkages between firms—linkages which are not simply concerned with material transfers.” This perspective is developed furthest in Camagni’s (1991) exploration of learning processes underlying innovation among networks of firms in innovative milieux.⁴ It is also central in a totally different research tradition which has focused on interactions among firms and associated knowledge institutions constituting “technology systems”—the institutional basis for industrial technology diffusion and innovation (Carlsson, 1995; Carlsson and Jacobsson, 1997).

These various perspectives all seek to distinguish knowledge systems from the associated materials-centered systems of production and trade—what one might call “production systems”. This distinction is so fundamental to our argument that it is worth explicating our model here in more detail.

The production system can be understood to encompass the product designs, materials, machines, labor inputs, and transaction linkages involved in production of goods to a given specification. In this sense the concept is very broad. For example, to describe the machinery component it might be necessary to specify the type of equipment, but also the particular operating settings and maintenance procedures involved in its use. Materials specifications and purchasing systems, detailed product designs and blue-prints, particular labor skills and operating routines, specific quality assurance standards, distribution arrangements etc. all form elements of a production system. The existence and nature of trading linkages and contractual arrangements with suppliers, buyers, subcontractors are also included in the concept, as might be details of the physical, social and legal infrastructure which supports the industry in its current state.

In another sense, the production system concept is purposely shallow. It defines only the *status quo*. A description of the production system in this sense tells us nothing about the evolution of the firm or cluster it describes: its history, current trajectory or capacity for future

technological change. Although every workshop, factory or industrial cluster is to some extent an expression of past and present knowledge embedded in people, organizations and social institutions, that knowledge stock is not revealed in a mere description of the production system as defined above.

The knowledge system concept on the other hand, encompasses those flows of knowledge, stocks of knowledge and organizational systems involved in generating and managing changes in the products, processes or organization of production. Knowledge flows (in a cluster context) can occur into firms from outside the system, between firms (and other institutions) within the system or indeed internally within firms themselves. All of these various kinds of knowledge flows may contribute to the accumulation of those knowledge stocks and resources often labeled “technological capabilities.”⁵ At one end of a complexity spectrum these include the most routine production capabilities required simply to maintain the efficiency of an established production system given inevitable variations in the characteristics of materials, labor and customer requirements. At the other extreme are the most innovative capabilities required to specify and design new products, develop novel machines and install new processes, establish new channels of supply and distribution.

Knowledge systems and production systems obviously overlap, but they are not identical. Actors in one may not be actors in the other. Similarly, knowledge flows may be carried along the same channels as those concerned with market transactions over goods—as for instance in the common case of flows of new technology into clusters from external buyers of their products. But it is also very clear that in some situations goods-centered linkages play little or no role in creating or diffusing knowledge—as, for instance, in the case of the links between external buyers and the Mexican shoe clusters examined by Rabelotti (1995).

Thus although knowledge and production systems interact with each other, the nature of this interaction is highly variable. For instance, in reviewing learning and innovation systems in technology districts in France, Italy and the United States, Storper (1993, p. 450) notes that the mere existence of cluster-type production systems does not provide an explanation for their technological dynamism. Instead, he suggests that dynamism emerges from the interaction between learning processes and

production systems. He illustrates how social processes and institutional structures mediate that interaction, describing industrial districts which exhibit greater technological dynamism as “learning-rich production systems” (p. 435).

Understanding why some industrial clusters in developing countries are “learning-rich” and others “learning-poor” would make an important contribution to understanding the technological dimension of their long-term dynamism. As we have described, an initial step in that direction is to distinguish knowledge systems from production systems.

(b) *Knowledge-using and knowledge-changing elements*

Most of the issues which are discussed in this article relate to the processes by which knowledge stocks or technological capabilities are acquired and accumulated. Before addressing these however, we must also recognize that in a cluster context different kinds of technological capability play different (and possibly unequal) roles in sustaining long-term competitiveness.

(i) *Different categories of technological capabilities*

Following Dahlman, Ross-Larson and Westphal (1987) it has been usual to place technological capabilities in functional categories related to the kind of activities which they facilitate, for instance: production capabilities, investment capabilities and linkage capabilities; but often with “innovation capabilities” identified separately from these functional categories. As Lall (1992, p. 167) illustrated, however, it is conceptually helpful to locate capabilities not only horizontally in functional categories but also vertically according to the degree of innovativeness of those activities. Lall recognized that for most functions, capability may lie somewhere on a scale ranging from doing simple routine activities, through adaptive and duplicative activities, to more original innovative activities. In this sense “innovativeness” is not a separate functional category of capabilities, but a quality or depth which may be achieved to different extents in all functional areas.

When we leave aside the functional categorization, and concentrate on the depth or innovativeness of technological capabilities, an important distinction becomes apparent: some elements of the knowledge system tend to be more concerned with using, replicating and re-

circulating knowledge that is already established within the production system, whereas other elements are more involved in acquiring, creating, processing and accumulating new knowledge, so that it can be brought into play in the system. The *knowledge-using* elements are involved, for example, in maintaining or expanding capacity using given modes of production; training workers in established operating procedures, or within a cluster context, the imitation of production techniques used by neighboring firms. The *knowledge-changing* elements are involved, for example, in the management of innovation processes; in product design and development; or in the search for, selection, adaptation and assimilation of new product or process technology (from outside the cluster).

Although the concepts of knowledge-use and knowledge-change illustrate different ends of the same spectrum, the distinction is important in analyzing clustered knowledge systems as a whole. For instance, one firm’s search for and adoption of new technology copied entirely from *within* the cluster, while indicating some innovativeness on the part of the individual firm, may add little or nothing to the knowledge stock of the cluster as a whole. A great deal of knowledge exchange, use and replication can occur within a rather inward-looking cluster system—creating the impression of dynamism at the individual firm level—but nevertheless leaving the cluster as a whole technologically static.

(ii) *Acquisition of technological capabilities*

There are a wide range of processes by which firms may add to their knowledge stock. Following Romijn’s (1998a) review of studies describing the acquisition of capabilities, we can collapse most of these into three general mechanisms.

First, they may be acquired through various internal technological activities. These may include the observation of routine production activities; the acquisition of knowledge from undertaking the repair, maintenance or reconditioning of equipment; more systematic reverse engineering or experimentation; or more formally organized technology development or even applied research.

Second, knowledge may be acquired from external sources, either relatively passively as a by-product from various kinds of interaction with the outside world or from a range of more deliberate and active search efforts—though the

deliberation and activity may sometimes be more evident on the part of the knowledge source than the recipient.

Finally, capabilities may be augmented through various kinds of human capital formation at the firm level—either via formal and informal training activities or simply by hiring people who already embody the knowledge being sought.

However one classifies learning mechanisms and channels, it is important to recognize the distinction between strengthening the knowledge-using-and-replicating elements and strengthening the knowledge-changing elements of the system. For instance, at one level, internal technological learning in firms may involve simply the transmission of existing knowledge and skills—as, for instance, in the observation of production operations by new employees in order to learn routines and procedures. This “multiplication” of existing knowledge may be used, for instance, to expand existing levels of knowledge-using capability in order to support a larger scale of production. At another level, however, the efforts of firms to learn from production, or from the repair, maintenance and reconditioning of equipment, may add to their deeper innovative capabilities. This may be extended into more systematic

efforts to learn from observation, reverse engineering and practical experimentation in order to enhance capabilities for generating change.

These various sources of skill and knowledge that contribute to both kinds of learning are summarized in Table 2, and an important step in developing deeper understanding about learning in industrial clusters in developing countries will be to generate descriptive and comparative material within frameworks along these or similar lines. Equally important, research needs to take into account that the relative importance of different learning mechanisms changes over time.

(c) “Open” and “closed” knowledge systems

In seeking to explain the economic and technological performance of clustered production, much analysis has focused on the importance of the internal characteristics of clusters—for instance, the characteristics of the production/market links between firms in the cluster;⁶ various aspects of the organization and control of production; the intensity of active co-operation among firms and the particular form it takes; or the organizational mechanisms for the diffusion of knowledge and skills among firms. Considerable attention has

Table 2. Illustrative sources of increased capability in cluster knowledge systems

	Sources of increase in knowledge-using capabilities	Sources of increase in knowledge-changing capabilities
Intrafirm sources	Passive experience of production (“learning by doing production”) Active efforts to adopt or improve specific technologies Improved practices derived from trial and error experimentation on specific tasks	Generally applicable technological understanding gained from undertaking investment activities (“learning by doing investment”) Generic technological insights gained from adapting and improving existing technology in use (“learning by changing”)
Intracluster sources	Intracluster mobility of skilled labor Cluster mediated training in operating skills and procedures Know-how diffusion between intracluster producers and users of machinery or production-related services	Cluster-sourced training in planning, design and technology management Creative collaboration between firms and cluster-based technology institutions Intracluster collaboration in tests and experiments to adapt machinery or develop product designs
Sources outside the cluster	Customers and traders knowledge, specifications and product/process advice Machinery and other input suppliers operational knowledge, advice and training Externally linked technical advice and consultancy services Externally linked trade and marketing information services	Externally sourced training in planning, design and technology management On-the-job experience in design and engineering with machinery and other input suppliers Collaborative testing or technology development with technology institutions or firms outside the cluster

also been given to more deeply rooted institutional variables underlying such organizational aspects of clusters,⁷ for instance, cultural coherence and social identity; the extent and nature of trust relationships; and political structures and processes. These features of the *internal* structure and institutional basis of clusters are evidently important. But this internal orientation of analysis may seriously inhibit efforts to explain the longer-term technological dynamism of clustered production.

We have suggested that the characteristics of knowledge systems associated with clustered production may be a centrally important influence on its longer-term dynamism, and we have noted how frequently sources of knowledge located *outside* clusters have been identified as major contributors to their technical change and dynamism. In particular, among the case studies described in Table 1, Nadvi (1996), Visser (1996) and Sandee (1995) all emphasize the importance of such external knowledge flows.

This suggests that key features of the knowledge systems of clusters include not just their internal mechanisms for circulating the knowledge already available and for acquiring new knowledge from the experience of various kinds of "doing." Possibly more important is their openness to knowledge flows from outside. A scattering of empirical material about these external flows suggests that relatively "closed" knowledge systems may be associated with an inability to sustain competitiveness in the longer term. For instance, the weak performance of Mexican footwear producers described by Rabelotti (1995) might be interpreted in these terms, as might the deepening crisis of the Sialkot surgical instrument producers until rescued by a large inflow of new knowledge from outside (Nadvi, 1996). Moreover, it is interesting that Tewari (1996), having given considerable emphasis to the internal knowledge-circulating and knowledge-accumulating processes among Ludhiana metalworkers, speculated that it would not be possible for the cluster to sustain innovation only on the basis of endogenous incremental change. At some point it would be necessary to acquire much more substantial inflows of external knowledge—to turn outward as she put it. The importance of this distinction between relatively "open" and "closed" knowledge systems has been stressed in different language, by Visser (1996, p. 67): "if both data and

preferences have local origins, path and context dependence may produce lock-in, cognitive inbreeding or 'entropic death' Camagni (1991, p. 140). External sources of data and experience are more likely to challenge the receiver, trigger learning and enhance creativity."

All this suggests the need to give greater attention to the openness of the knowledge systems supporting the technological dynamism of clusters.⁸ But questions then arise about the organizational basis for this technological openness. One of these questions concerns the size of firms which play the role of technological "gatekeepers" in clusters. Although small firms may play this role, it is evident that many play no part at all in the technological openness of their clusters. On the other hand, large firms within clusters may be critically important in providing new knowledge inputs for smaller clustered firms. This certainly seems to have been the case in several industrial clusters in Europe—for instance, in Baden Wurttemberg (Cooke and Morgan, 1998; Schmitz, 1992). Scott (1992) has also highlighted this role in the case of large systems houses in industrial districts in southern California. With reference to developing countries, Rabelotti (1995) and Nadvi (1996) stress that large firms may come to play an important role in the *production-systems* of industrial clusters, but whether they play a similarly important role as "gatekeepers" in the clusters' *knowledge-systems* is not clear.

Technology support organizations may also play important knowledge "gatekeeper" roles at the boundary of cluster knowledge-systems. Some of these may be public sector institutes, with varying degrees of support from local firms, which carry out research, or provide technical or training services—for instance, the Metal Industries Development Center in Sialkot Nadvi (1996, p. 132), or SITRA in the Tiruppur knitwear cluster (Cawthorne, 1995). Others may be collectively created organizations acting on behalf of associations of firms. Yet others may be commercial organizations providing services for fees and so virtually indistinguishable from industrial firms operating within the cluster system - for instance, the reconditioning teams described by Tewari (1996, p. 176) in Ludhiana. As with large firms, however, variability in their effectiveness within cluster knowledge systems seems to be common. Some institutes seem to have been highly successful in bringing new knowledge into clusters—for instance, CITER in the textile

district in Carpi, Italy (Murray, 1996). Others have evidently been much less effective.

Understanding the roles played by large firms, technological “institutes” or other organizations as technological “gatekeepers” in open knowledge systems therefore seems to be important. Efforts to build that understanding are likely however to be inhibited by cluster models which overemphasize the importance of spatial proximity. Humphrey (1995), for instance, has noted such constraints and suggested setting research on clusters in the framework of commodity chains, as developed by Gereffi and others. Important elements of knowledge systems are likely to run through such chains and may therefore span far more than “local” distances. Indeed, the spatial dimensions of the knowledge systems associated with clustered production may radically change as the clusters evolve, and research that is too tightly bounded by concepts of spatial proximity may be unable to reveal such patterns of geographical re-structuring.

4. THE ORGANIZATIONAL BASIS OF TECHNOLOGICAL DYNAMISM: A FRAMEWORK FOR EXPLORATION

This section seeks to provide a framework for future research. As stressed by Schmitz (1995, p. 24) future research on industrial clusters needs an approach which is dynamic, comparative, and includes external linkages. Our key point in Section 3 was that if research is to reveal technological dynamism, a re-focusing is also needed from production systems to knowledge systems.

In seeking to explain differing paths of technological dynamism, it is not clustering *per se* that seems to be the most relevant issue. Rather it is the properties of what we have called the knowledge systems associated with clustered production that are likely to be most relevant, and more specifically the kinds of organizational and structural characteristics of knowledge systems we have discussed. These may well be influenced by various aspects of clustering, but they may also vary widely across clusters which are very similar in other respects. Consequently, exploration of the relationship between clustering and technological dynamism needs to center on the mediating role of these organizational characteristics of knowledge systems. In this last section of the paper we therefore take a few tentative steps toward the

development of a framework for comparative analysis of the organizational basis of the technological dynamism of clustered industrial production in developing countries.

(a) *Key organizational characteristics of cluster knowledge systems*

We outline here a framework of organizational characteristics⁹ which may provide at least some of the elements of a taxonomic framework for comparative analysis. As indicated in Table 3, this framework deals separately with the two different processes distinguished earlier: the diffusion and replication of knowledge within clusters, and the acquisition and generation of knowledge which is new to the cluster. Important organizational characteristics of these two processes are listed under column A.

Drawing on fragments of empirical material scattered through the literature on industrial clusters and knowledge networks, we then indicate under column B how each of these organizational characteristics may take different forms in specific situations, suggesting in each case a continuous dimension of variation. For instance, with respect to the main basis for knowledge diffusion within a cluster—Row (1) in Table 3—we identify two ends of a spectrum as follows.

—At one extreme, spatial proximity, rather than any actively structured organizational mechanism, is the main basis for diffusion, and knowledge flows between organizations in a cluster, largely as an unintended “by-product” of other activities. Similarly, knowledge flows between people within firms largely through unstructured learning mechanisms (“by watching,” etc.). In other words, knowledge diffusion arises as a “passive” externality derived from the spatial clustering of production activities and their technological similarity. Visser’s clothing cluster in Lima seems to have many of these characteristics.

—At the other extreme, the movement of knowledge between agents is to a large extent managed purposefully as an activity in its own right, and organizational structures have been deliberately created to achieve that diffusion. These may include both arrangements and activities *within* firms (e.g., formally organized training schemes which acquire knowledge from outside the firm

Table 3. *Differences in the organizational basis of clusters' knowledge systems*

A. Organizational characteristics	B. How the characteristics vary		
(1) The basis for diffusion among small firms	With respect to intra-cluster knowledge diffusion and replication Spatial proximity and "passive" externalities	←————→	Structured and "active" co-operation
(2) The dominant "direction" of knowledge flows	Horizontal: between firms producing similar goods	←————→	Vertical: through user-producer links and production chains
(3) The role of technology/training Institutes	Non-existent or crisis-driven/intermittent	←————→	Pervasively and consistently important
(4) The role of large firms Composite of 1-4 above	Unimportant Unstructured and "passive"	←————→ ←————→	Pervasively important Structured, cooperative and "active"
(5) Knowledge sources internal/external to cluster	With respect to acquiring or generating new knowledge Within a low total of new knowledge acquisition: High proportion originating outside the cluster	←————→	Within a high total of new knowledge acquisition: high proportion originating inside the cluster
(6) Channels for external sourcing	Limited and informal channels	←————→	Pervasive informal channels plus organized "gatekeepers"
(7) Role of firms in learning	Firms' role relatively small	←————→	Firms' role relatively large
(8) Type of "learning"	High proportion as a "by-product" from doing	←————→	High proportion generated by purposeful search
Composite of 5-8 above	Unstructured, undirected and "closed"	←————→	Structured, purposeful and "open"

and diffuse it among employees), and arrangements which act as diffusion channels *between* firms (e.g., training institutes or design/market intelligence organizations). Thus, knowledge diffusion is "actively" sought and managed, and part of this active management is likely to rest on deliberate cooperation among actors (e.g., in creating and supporting a design/market intelligence organization). Some of the Third Italy clusters demonstrate this form of organization (see, for instance, Murray, 1996).

Similar spectra of differing organizational forms underlie the acquisition and generation of new knowledge—illustrated in the lower half of Table 3. For instance, with respect to intra-firm learning mechanisms—Row (7)—we can distinguish between two ends of a spectrum as follows.

—At one extreme, firms play a very limited role in either acquiring new knowledge from outside the cluster or generating such new knowledge themselves. If they do acquire new knowledge from outside the cluster, they do so "passively"—for instance, acquiring it as a "by-product" from transactions such as selling products to customers. Similarly any new knowledge generation within the firm is likely to consist of limited extensions of existing knowledge arising "passively" as a result of learning-by-doing routine production tasks. Corresponding to these passive learning processes, there are few specific organizational arrangements within firms designed explicitly to acquire or generate knowledge. Several of the clusters in traditional industries in developing countries appear to demonstrate this form of organizational arrangement.

—Toward the other extreme, “active” learning processes based on specific organizational structures within firms account for a relatively large proportion of the total flow of new knowledge that is either acquired by, or generated within, a cluster. For instance, at least in some degree, firms develop and create their own designs (rather than copying wholesale the existing specifications of other firms products), and they do so on the basis of some degree of organizational specialization within the firm (e.g., there exists a person or even a “department” which has the specialized role of “designing”). Several of the Third Italy clusters seem to exhibit this form of organizational arrangement for acquiring and generating new knowledge.

We suggest that these kinds of difference in organizational form are likely to be highly correlated, and this permits the construction of more aggregated composite categories of organizational difference. For instance, with respect to knowledge diffusion (upper half of Table 3), clusters in which knowledge is diffused primarily in the form of passive externalities are also likely to be clusters in which a large proportion of those externalities arise in the form of “horizontal” knowledge flows between firms producing similar goods, while the diffusion role of technology/training institutes and large firms is limited. A composite synthesis of these forms of organizational arrangement for diffusion might be described as organizationally “unstructured and passive.” In contrast, in other clusters which have developed more specialized organizational structures, the organizational form might be described as organizationally “structured, cooperative and active.”

Similarly, there is likely to be a close correlation between differences in the organizational characteristics underlying the acquisition of new knowledge (lower half of Table 3). Some clusters will acquire and generate relatively low total flows of new knowledge in any period, and a large proportion of this flow is likely to be acquired from outside the cluster via relatively few channels which are mainly informally organized. At the same time, in such clusters little new knowledge will be acquired or generated by learning within firms, with most of that arising “passively” as a by-product from various kinds of doing. A composite characterization of this combination of organizational

forms might be described as organizationally “unstructured, undirected and closed.”

Conversely, a cluster in which a relatively large proportion of a large total flow of new knowledge originates internally, is also likely to be a cluster where there are pervasive informal processes for acquiring knowledge from outside the cluster, together with more formally structured “gatekeeper” arrangements for doing so. This combination is likely to be associated with a large proportion of the internally generated new knowledge being produced within firms, with much of that arising from purposeful search activities undertaken in relatively specialized organizational structures. This combination of organizational forms might be described as organizationally “structured, purposeful and open.”

(b) *Knowledge systems and the long-run evolution of clusters*

The taxonomic propositions summarized in Table 3 provide a framework for cross-sectional comparative analysis of the knowledge systems underlying technological dynamism in industry clusters in developing countries. This framework is summarized in a different way in Figure 1 where the vertical and horizontal axes reflect respectively difference in the organizational basis for (i) intracluster knowledge diffusion and (ii) the acquisition/generation of new knowledge.

We suggest that comparative analysis within this framework would confirm two broad empirical propositions about clusters in more “traditional” industries—the kinds of cluster which have been the subject of most research so far. First, the organizational bases of the knowledge systems could be relatively unstructured and passive with respect to knowledge diffusion, and undirected and closed with respect to creating and acquiring new knowledge. Second, however, there could nevertheless be considerable differences between clusters within that southeast quadrant of the figure.

It is tempting to argue that these differences are associated with differences in the long term technological dynamism and sustainability of clusters. That might be so, but might also be too simplistic. The effectiveness of different kinds of knowledge system is contingent on basic characteristics of the particular industries and technologies involved. The importance of such contingent variables has been noted in research on industry clusters and innovation

networks in the industrialized countries—for instance, the importance of the stage of the life cycle of a cluster’s product/technology (Audretsch and Feldman, 1996). In the context of developing countries, two other kinds of contingent variable seem especially important—the complexity of technology involved in that product sector and the cluster’s distance from the international technological frontier.

—The underlying “complexity” of technology in any product sector is likely to have a significant influence on the kind of knowledge system needed to support high rates of technological dynamism. For instance, the technological dynamism needed to sustain the competitiveness of a spatially clustered network of firms supplying components and services to the automobile industry or the oil industry will depend on a knowledge system that is much more organizationally structured and active than the system needed to sustain the competitiveness of a cluster of rattan furniture producers.

—Within any particular product sector, the distance behind the international technological frontier at which the cluster is operating will also have an important influence on the organizational form of a cluster’s knowledge

system. When a cluster is operating far behind the frontier, there will exist a large body of existing knowledge which can be acquired and diffused to contribute to rapid technological dynamism. This will depend on a knowledge system with organizational characteristics which are very different from those needed to generate, acquire and diffuse knowledge when firms are closer to the international frontier. For instance, as firms in the electronics industry in Korea and Taiwan closed up on the international technological frontier, they developed knowledge systems with increasingly structured organizational mechanisms to support increasingly active processes for knowledge acquisition and diffusion, with those systems involving both greater internal knowledge generation *and* greater openness to external knowledge sources (Kim and Tunzelmann, 1998). In effect, they moved in a northeasterly direction across Figure 1.

Consequently, as illustrated in Figure 2, one must disaggregate observed intercluster differences in knowledge systems into three components:

- (i) knowledge system differences arising from differences in the complexity of technologies

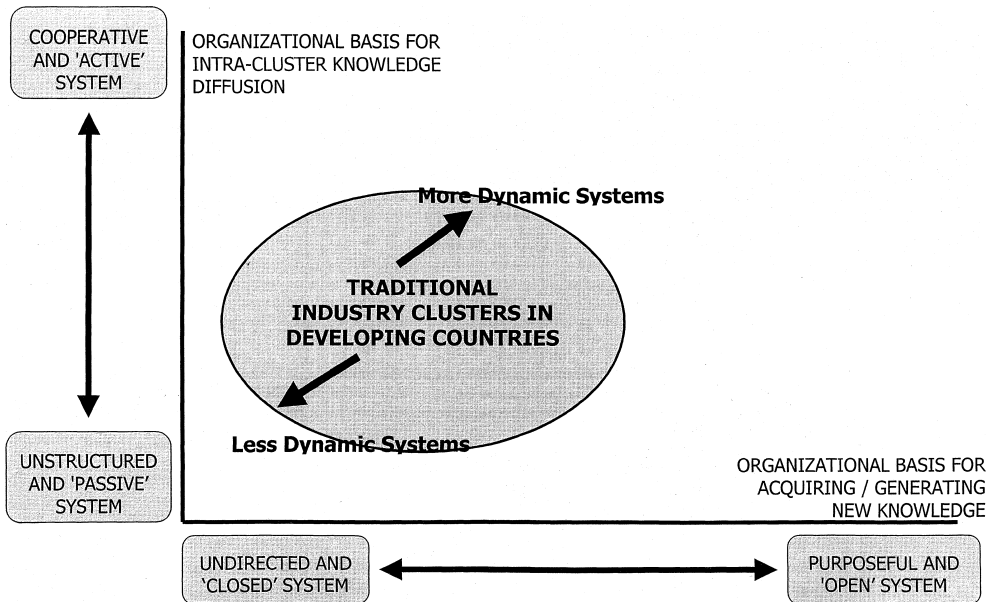


Figure 1. Differing organizational forms of knowledge systems in industrial clusters: traditional industries in developing countries.

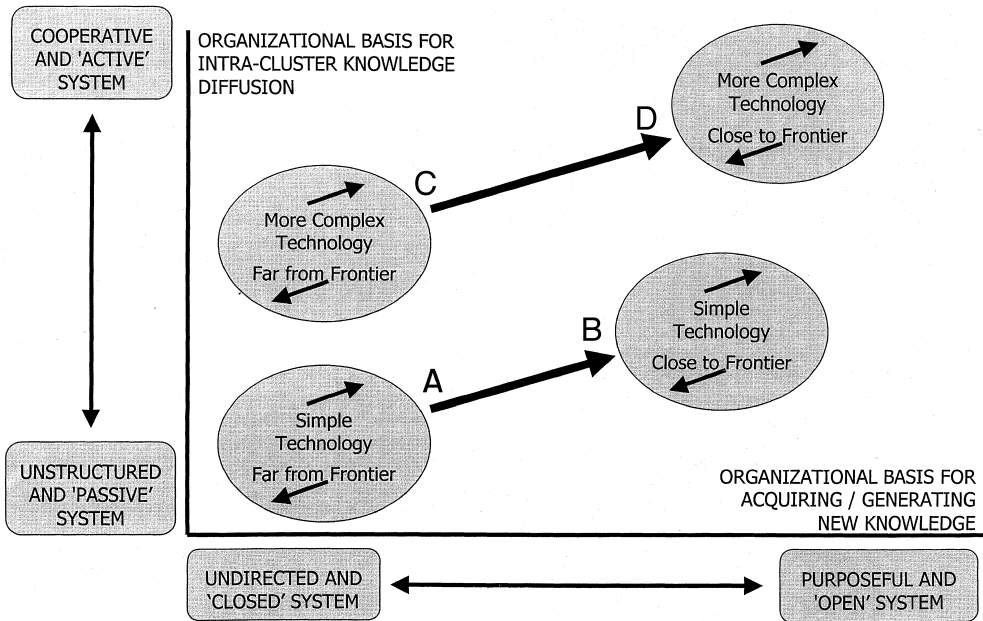


Figure 2. Change in the organizational forms of knowledge systems in industrial clusters: differing technologies and contexts.

in that product sector (i.e. differences between A and C or between B and D in Figure 2)

(ii) knowledge system differences arising from varying distances from the international technological frontier (i.e. differences between A and B or between C and D in Figure 2)

(iii) knowledge system differences that may contribute to differing effectiveness in sustaining the technological dynamism of clusters with similar technologies operating at similar distances from the international frontier (i.e. differences *within* the areas A, B, C and D).

(c) *Concluding questions*

The framework we have presented in this section, illustrated by Table 3 and Figure 2, suggests a number of interesting areas for future research.

Understanding more about the knowledge system differences of clusters with similar technologies operating at similar distances from the international frontier, should yield useful conclusions about policy in the relatively short term. But insights into change over time provided by the framework outlined here may be just as in-

teresting and useful as those derived from cross-sectional differences. In particular, it would be illuminating to be able to answer even simple questions about the paths of change that are sketched as $A \Rightarrow B$ and $C \Rightarrow D$ in Figure 2. These trajectories are likely to underlie Pyke and Sengenberger's "high road" to competitiveness.

In particular, it would be helpful to know whether clusters knowledge systems evolve along the lines suggested in Figure 2 as they move closer to the international frontier in their existing areas of technology. If so, how does this organizational evolution take place, what factors influence it, and does the rate at which it is pursued by clusters significantly affect their rate of technological development and long-term sustainability?

As this evolution takes place, do the characteristics of effective knowledge systems continue to differ between clusters based on more and less complex technologies? If so, what processes of organizational change might be involved if clusters seek to move along "super high roads" such as $A \Rightarrow D$ —simultaneously shifting their production into more complex areas of technology *and* narrowing the distance from the international frontier within those areas?

Finally, the framework outlined in this paper prompts questions about yet longer-term evo-

lution in the organizational basis of local knowledge systems. As clusters move in a northeasterly direction across Figure 2, moving toward increasingly active, organizationally structured and open knowledge systems, does the importance of spatial proximity become progressively less important for the effective

functioning of those systems? In other words, as clusters catch up with the international technological frontier, and as they shift production into increasingly complex areas of technology, does clustering become less important for the effective functioning of their knowledge system?

NOTES

1. One striking exception is Romijn (1998a, b).

2. See, for instance: Camagni (1991), Carlsson (1995), Carlsson and Jacobsson (1997), Coombs *et al.* (1996), Edquist (1997), Freeman (1991), Lundvall (1992) and Nelson (1993).

3. We are deliberately selectively concerned here with micro-level processes behind technological change in industrial production systems. Factors at meso- and macro-level (e.g., the nature of regional and national innovation systems, economic policy and regulatory frameworks) clearly also influence the characteristics of these systems. Our interest here however, lies in understanding the processes of learning and change occurring *within* localized production systems. Specifically we use research on knowledge systems associated with large integrated firms to suggest new approaches to the analysis of these processes in systems comprising clusters of smaller firms.

4. It is striking how much of the work on “innovative milieu” has been concerned with the characteristics of the materials they use and what they produce, rather than with issues about how they acquire and use knowledge in order to innovate. Camagni (1991) is an exception.

5. Technological capabilities can be thought of as bundles of complementary skills and knowledge which, together with the organizational structures in which they are embedded, facilitate particular activities in the production system. They include knowledge which is embodied in people, codified in manuals and blueprints, or embedded in organizational arrangements and procedural routines. Many of the organizational structures in which those resources are located are private to the firm, but they may also be shared or collective in the

sense that they are embodied in creative linkages with and between other firms and institutions.

6. Given the significance of spatial proximity as a core defining feature of industrial clusters, it is surprising how little systematic attention has been given to the spatial characteristics of these links. Does the geographical distance they span have any significant bearing on how effectively clusters function? This issue has been more systematically addressed in a few studies of industrial clusters in the advanced industrial economies (e.g., Lawson *et al.*, 1997).

7. We follow here the kind of distinction between ‘organizational’ and ‘institutional’ dimensions of innovation systems suggested by Edquist and Johnson (1997): institutions refer to things that pattern behavior such as routines, norms, shared expectations, and the ground rules for economic behavior; organizations refer to more specific and concrete formal structures, usually consciously created with explicit purposes (e.g., firms, technical institutes, training centers, business associations).

8. An interesting step in this direction has been taken recently by Kim and Tunzelmann (1998) who suggest that an important feature of the electronics industry in Taiwan was not just the dense patterns of knowledge-centered interaction among local and national networks of predominantly small firms. It was also the fact that this “internal” system of knowledge flows was strongly coupled via specific institutional arrangements into an international knowledge system.

9. We use the term “organizational” here in the same sense as indicated in note 7 above, so distinguishing organizational from “institutional.” But we do not use it in a way which includes the specific “organizational” aspects of industrial production itself—e.g., JIT production methods.

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