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Industrial Dynamics: A Review of the Literature 1990-2009

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Abstract

This paper reviews the literature in the field of Industrial Dynamics as it has emerged since I first introduced the term in 1985. Nearly 8,000 articles in 12 major journals have been reviewed and classified under five broad themes that constitute the basic questions in industrial dynamics:

1. The causes of industrial development and economic growth, including the dynamics and evolution of industries and the role of entrepreneurship
2. The nature of economic activity in the firm and the dynamics of supply, particularly the role of knowledge.
3. How the boundaries and interdependence of firms change over time and contribute to economic transformation.
4. Technological change and its institutional framework, especially systems of innovation.
5. The role of public policy in facilitating adjustment of the economy to changing circumstances at both micro and macro levels.

Under each theme, the main findings and their implications for theory and policy are summarized.

JEL codes: D00, D2, L00, O30

Keywords: Industrial dynamics, literature review, knowledge, technological change, institutions, growth

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INDUSTRIAL DYNAMICS: A REVIEW OF THE LITERATURE 1990-2009

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ABSTRACT

This paper reviews the literature in the field of Industrial Dynamics as it has emerged since I first introduced the term in 1985. Nearly 8,000 articles in 12 major journals have been reviewed and classified under five broad themes that constitute the basic questions in industrial dynamics:

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INDUSTRIAL DYNAMICS: A REVIEW OF THE LITERATURE 1990-2009*

INTRODUCTION

Industrial Dynamics (ID) is a new and rapidly growing field of research. Its theoretical roots are similar to those of Industrial Organization (IO), but the questions addressed are different. IO is based on equilibrium (static or comparative static) analysis; there is no causal analysis. In ID the emphasis is on dynamics: seeking to identify and understand the reasons *why* things are as they are. ID focuses on the *causes* (driving forces) of economic transformation and growth, and on understanding the underlying *processes* of transformation, not just the outcomes. The transformation is viewed in its wider historical, institutional, technological, social, political, and geographic context. This means that the analysis often has to transcend disciplinary boundaries and involve multiple dimensions and levels.

Economic growth can be described at the macro level, but it can never be explained at that level; it is inherently a micro-based phenomenon involving transformation. Economic transformation is a matter of experimental creation of a variety of technologies that are confronted with potential buyers in dynamic markets and hierarchies. Economic growth results from the interaction of a variety of actors who create and use technology, including demanding customers. The interaction takes place in an evolving institutional setting. Understanding economic growth requires causal analysis (Carlsson & Eliasson, 2003).

There are five main themes in Industrial Dynamics:

1. The causes of industrial development and economic growth - the dynamics and evolution of industries, particularly entrepreneurial activity and institutional change.

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2. The nature of economic activity in the firm and its connection to the dynamics of supply and therefore economic growth, particularly the role of knowledge (competence).
3. How the boundaries of the firm (degree of vertical and horizontal integration) and the degree of interdependence among firms change over time and what role this interdependence plays in economic growth.
4. Technological change and its institutional framework (particularly in the form of 'systems of innovation').
5. The role of public policy in facilitating or obstructing adjustment of the economy to changing circumstances (domestically as well as internationally) at both micro and macro levels (Carlsson, 1989, p. 3).

The purpose of the present paper is to define the field, review its evolution and examine its main contributions over its first two decades. This is done through a review of nearly 8,000 articles published in 12 major journals over the period 1990-2009.

The paper is organized as follows. The next section describes the theoretical roots of Industrial Organization and Industrial Dynamics and outlines the main differences between the two approaches by examining the aims and scope of research in the major journals in each field. This is followed by a discussion of the methodology used in the literature review. The bulk of the paper is devoted to a review of the ID research published in the leading IO and ID journals. The paper concludes with some thoughts on the contributions of Industrial Dynamics to a better understanding of industrial transformation and economic growth.

BACKGROUND: THEORETICAL ROOTS

This paper has its origin in the presidential address I delivered to the European Association for Research in Industrial Economics (EARIE) in 1985. The presentation (subsequently published as Carlsson, 1987) focused on the relationship between the two main traditions which together make up Industrial Economics, namely mainstream Industrial Organization (IO) and Industrial Dynamics (ID). While the term Industrial Economics is still used in Europe to refer to both of these branches, the emphasis of scholarly work in the field has clearly shifted to Industrial Organization more narrowly defined. In the United States, mainstream Industrial Organization seems to have become even more dominant than it was three decades ago. As we shall see, what I defined as Industrial Dynamics nearly 30 years ago has also flourished, sometimes, but not always, explicitly recognized as integrated in the tradition of industrial economics.

Both IO and ID have deep roots in microeconomic theory. Both are founded on the works of Adam Smith and Alfred Marshall. IO goes back to Chamberlin (1933), Robinson (1933), Mason (1957), and Bain (1959) in its empirical “Harvard tradition” and to Stigler (1942) in its more theoretical “Chicago” tradition. In the 1970s, as dissatisfaction grew with the limitations of the cross-sectional empirical analysis that had come to dominate industrial organization, game theory came into the picture. While it has roots in Cournot and Bertrand, its modern application can be traced to von Neumann and Morgenstern (1944) and Nash (1950). Game theory had been largely ignored in mainstream economics until the work of Selten (1965), Harsanyi (1967), and others was extended and applied in the 1970s. As a result, Industrial Organization was transformed from a field made up mainly of empirical analyses with a relatively loose theoretical base to a strongly theoretical field with relatively little attention to empirical application.

While Industrial Dynamics can also be traced back to Marshall, its subsequent development came via Wicksell (1898) and Schumpeter (1911, 1942). For a variety of reasons, Schumpeter’s work was largely ignored for several decades. Its revival, further development and current application in Industrial Dynamics owe much to Dahmén (1950 and 1984), Klein (1977 and 1984), and Nelson and Winter (1982). These were the people whose work influenced me to raise questions about the need for a new approach – which I referred to as Industrial Dynamics - to the issues facing industrial economists but not addressed within the IO tradition:

> [W]e need to deal more seriously and systematically with some of the larger questions of the type raised long ago by people like Marshall, Wicksell, Schumpeter, and others. We need to have a substantially improved understanding of the structural changes in the economy and their driving forces. For example, I am convinced that we are at a turning point with respect to the role of manufacturing, the sector to which most of the empirical work of industrial economists has been devoted in the past. But what about the dynamics of the whole economy? What are the implications of the emergence of the new service industries (especially business services) in this regard? I maintain that the ID tradition has to develop a suitable micro-macro framework for addressing macro-questions on the basis of its admirable micro-level depth and detail. (Carlsson, 1987, p. 141)

That there was (and is) indeed a need for a new approach is demonstrated by the founding of several new journals in the late 1980s and early 1990s. *Small Business Economics* was founded in 1989, *Structural Change and Economic Dynamics* (1989), *Economics of Innovation and New Technology* (1990), *Journal* *of Evolutionary Economics* (1991), *Journal of Industry Studies* (1991, re-launched as *Industry and Innovation* in 1997), and *Industrial and Corporate Change* (1992). The International Joseph A. Schumpeter Society was founded in 1986. The Danish Research Unit for Industrial Dynamics (DRUID) was founded in 1996 as one of the first entities incorporating Industrial Dynamics in its name. At the 4th DRUID conference in January 1998, Bengt-Åke Lundvall presented a paper "Defining Industrial Dynamics and Its Research Agenda," followed by a joint paper (Carlsson and Lundvall, 1998) at the 5th DRUID conference in June, 1998. The main concern in the 1998 papers was to distinguish ID from mainstream IO.

Now that nearly 30 years have passed, it is time to take a closer look at what Industrial Dynamics is all about, how the field has evolved, and what it has contributed. This is the task in the current paper.

MAINSTREAM INDUSTRIAL ORGANIZATION AND INDUSTRIAL DYNAMICS DEAL WITH DIFFERENT QUESTIONS

The differences between the two traditions within Industrial Economics become apparent if we examine the aims and coverage of some of the leading journals in each tradition. The *Journal of Industrial Economics*, founded in Britain and first published in 1952, is the oldest journal in the field. It "covers all areas of industrial economics including: organization of industry and applied oligopoly theory; product differentiation and technical change; theory of the firm and internal organization; and regulation, monopoly, merger and technology policy."

This coverage of topics represents a good summary of the prevalent view of what Industrial Organization is all about. The coverage is similar in other leading journals, such as the *International Journal of Industrial Organization* and the *Review of Industrial Organization*. The emphasis in these journals is on static analysis of a fairly narrow set of microeconomic issues. Linkages to other fields are largely restricted to adjacent fields within economics (primarily international and labor economics and macroeconomics). Only rarely are other disciplines involved. Empirical evidence is primarily presented in the form of econometric analyses of secondary data but sometimes in the form of case studies based at least in part on primary data.

The aims and scope of the Industrial Organization journals can be contrasted with those of journals more closely representing Industrial Dynamics. As mentioned already, most of these journals did not even exist in 1987. The journal that comes closest to covering the entire range of issues in Industrial Dynamics is the *Journal of Industry Studies/ Industry & Innovation.* The *Journal of Industry Studies* was first published 1993 as a cross-disciplinary journal devoted to understanding the dynamics of industrial vitality, whether at the firm, sectoral or national level. In 1997 it was re-launched as *Industry & Innovation* “to provide a balance... between general issues, devoted to industry studies in general.” Another journal whose main focus is on Industrial Dynamics is *Industrial and Corporate Change*. Its mission statement captures most of what I consider to be the core questions of ID: “The journal is committed to present and interpret the evidence on corporate and industrial change, drawing from an interdisciplinary set of approaches and theories from e.g. economics, sociology of organization, organization theory, political science, and social psychology.” The role of public policy is not a primary focus, reflecting the positive (as distinct from normative) orientation of ID.

Another journal with a broad coverage and emphasis on dynamics is the *Journal of Evolutionary Economics*. It is even broader in its interdisciplinary approach and is also more theoretically (modeling) oriented than ICC. It is also broader than ID, i.e., ID is considered a sub-field within evolutionary economics. *Research Policy* is another major journal that publishes articles in the ID tradition. It was founded much earlier (1971) than the journals just mentioned, with the expressed intent of bridging the gap between academic research and its policy application.
Economics of Innovation and New Technology (EINT) is somewhat more mainstream in its orientation but may be considered as fitting within Industrial Dynamics by virtue of its focus on innovation.

Small Business Economics, founded in 1989, focuses on the particular problems of small business which often inherently involve dynamics and cut across disciplines. Its original statement of aims and scope stated that *SBE* “provides the central forum for the economic analysis of the role of small business.” It is noteworthy that the word “entrepreneurship” does not appear in the original statement, reflecting the difficulty of integrating entrepreneurial activity into economic analysis and resulting in slow acceptance of the term in economics generally (see Carlsson *et al.*, 2013). However, the current statement of aims and scope states that the Journal focuses “on the role of entrepreneurship and small business… and on multiple dimensions of entrepreneurship, including entrepreneurs' characteristics, new ventures and innovation, firms' life cycles; as well as the role played by institutions and public policies within local, regional, national and international contexts.“

Structural Change and Economic Dynamics "publishes articles about theoretical, applied and methodological aspects of structural change in economic systems. An important aim is to facilitate communication among researchers engaged in the study of structural change. *Economic Geography* was founded in 1925 as a disciplinary journal in the field "to publish the best theoretically-based empirical articles that deepen the understanding of significant economic geography issues around the world." *The Journal of Economic Geography* is of much more recent origin. It was first published in 2001. Its aims "are to redefine and reinvigorate the intersection between economics and geography."

This brief review makes it apparent that the agenda in several of these journals is quite a bit broader than in the mainstream IO journals. Key elements in their programmatic presentations are innovation and structural change. Some of them refer explicitly to other disciplines (*The Journal of Evolutionary Economics* and *Industrial and Corporate Change*) while others have economics as only one of several approaches to a common set of problems (*Research Policy*). The mainstream journals put a premium on rigorous (in a formal mathematical sense), precise, quantitative (often econometric) analysis, leaving little room for less formal (but not necessarily less rigorous) analysis of broader, more challenging questions.

The mission statements of the ID-oriented journals provide evidence for the perceived need for analyses of the type referred to here as Industrial Dynamics. The questions that arise are: how has the field evolved, and what is its contribution to knowledge?

In order to answer these questions we need a way to describe the field, i.e., to classify and examine published work in ID. To do so, I go back to the way I defined ID initially.

METHODOLOGY

In order to gather data on publications in Industrial Dynamics, I started with my EARIE presidential address published in IJIO in 1987 (Carlsson, 1987) as the conceptual framework. This framework was fleshed out in an edited volume (Carlsson, 1989) that resulted from a conference I organized in 1987.

Ten years later, in preparing my DRUID presentation (with Bengt-Åke Lundvall) in 1998 (Carlsson and Lundvall, 1998), I added a broader, somewhat more macro-oriented theme to capture the broader issues (Causes of Industrial Development and Economic Growth) that differentiate ID from IO and that tie together the interaction among the four other themes. This resulted in the classification system presented in Table 1.

Working with several graduate students during 1998-2000 I started collecting data on ID publications. Given the vastness of the field and the volume of articles, we decided to examine only abstracts of journal publications.[1] We selected ten journals (treating the *Journal of Industry Studies* and its successor *Industry & Innovation* as one) where we expected to find ID publications. Because of the difficulty at that time of obtaining abstracts prior to 1990, we chose 1990 (or the year of first publication for journals started after 1990) as the starting year. [2] Subsequently the review was extended to include the period 2000-2009 and to also include *Economic Geography* and the *Journal of Economic Geography*. The journals covered in this study are listed in Table 2.[3]

The procedure was to have at least two persons classify each article according to the scheme in Table 1. If differences occurred, we discussed each case and tried to reconcile the coding, on the basis of which I made the final classification. The classification was often quite difficult, either because the abstract did not provide sufficient information (sometimes requiring reading of the full article) or because it was simply difficult to determine which coding category was most appropriate. In many cases articles were classified in more than one category. The resulting classification of articles is summarized in Table 3.

In order to summarize the research findings, I first sorted all the articles by theme (1A, 1B, etc.). After reading all the abstracts in each theme, I grouped the articles according to topic. In most themes I found 10-20 major topics and then selected the topics most heavily represented in each area. I then analyzed the abstracts on these major topics and summarized the findings. The results are presented below.[4]

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[1] The focus on journals only may result in a certain bias against lengthier, more comprehensive works and may therefore also not reflect the true extent of work on certain themes. For example, I am aware from previous surveys on innovation systems (Carlsson, 2006 and 2007) that more than half of the publications in that area have appeared as books or book chapters.

[2] During the period of data collection, some journals did not provide abstracts for all articles, and there was limited availability to abstracts on-line, especially for the early years (SBE and JIS). In some cases (ICC) abstracts were constructed based on the full articles and typed into the database. As a result, data are not available for the early years for all publications.

[3] In addition to those listed, we also collected abstracts from the *Journal of Economic Behavior and Organization* (1990-99, 750 articles), the *Journal of Economics and Management Strategy* (1992-99, 210 articles), and *Technovation* (1990-99, 138 articles). These abstracts have not yet been coded and are not included in the analysis reported here.

[4] There are several biases built into the methodology. In order to manage the massive body of research it was necessary to limit the review to certain journals, not books. This means that some broad topics may not be captured well in the analysis, although I have tried to compensate by referring to seminal works published outside the journals covered here. In particular, there are clearly influential works published prior to the time period (1990-2009)

OVERVIEW OF THE DATA

Distribution of Articles by Theme and by Journal

As shown in Table 3, the database consists of abstracts of 7,871 articles in 12 journals during the 1990s and 2000s.[5] 2,452 of the articles were published in the three IO journals (*JIE, RIO,* and *IJIO*). Of these articles, only 173 were classified as ID articles, representing 3.7 %, 6.8 %, and 9.0 %, respectively, of the total number of articles published in these journals. Thus, there seems to be little or no penetration of ID analysis into the mainstream IO journals. Nor does it appear that there are many IO articles published in the non-IO journals examined here. There seems to be very little cross-communication between the two fields. My interpretation is that this is due to the difference between dynamic and static or comparative static approaches. The questions asked are simply very different, and the answers obtained are perceived differently in the two communities of scholarship due to different absorptive capacities.

We found a total of 535 articles in the 1990s and 2,710 in the 2000s that we classified as ID articles, i.e., 3,445 for the period as a whole.[6] This represents 44 % of all the articles reviewed. If we exclude the articles published in mainstream IO journals (*IJIO, RIO,* and *JIE*), this leaves us with 3,265 ID articles, constituting 60 % of the articles in the non-IO journals. 1,106 of these ID articles (34 %) appeared in *Research Policy*.

It is striking that the percentage of articles that were classified as ID rose dramatically in all the journals, exceeding 85 % during the 2000s in *RP* and *I&I* and 70% or more in *EINT* and *ICC*.

The distribution of ID articles by journal and by theme within each journal appears to conform to what one might expect. There is a great deal of specialization; each journal has its own profile and readership which tend to be stable over time. As a result, when a new field emerges (raising new questions and requiring new analytical methods), new journals have to be created. Indeed, as our analysis shows, with

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reviewed. Also, in some themes there are more topics than I could summarize within reasonable limits in the text. In addition, articles with broad topics may not be captured well in the classification system, even if they are classified in several categories; only 'main topics' are summarized in each category. Further, the analysis is limited to abstracts, not full texts. This may have resulted in mis-classification of articles, particularly those whose abstracts do not accurately represent the content and contribution of the articles. In the course of the analysis, I sometimes found it necessary to reclassify articles under different themes than in the original classification.

[5] As mentioned earlier, another 1390 abstracts were also collected for three additional journals (*Technovation, Journal of Economic Behavior and Organization*, and *Journal of Economics and Management Strategy*), but these have not yet been classified and analyzed. Abstracts have also been collected (but not yet analyzed) for 1,483 articles in *Regional Studies* from 1990 to 2009.

[6] Since numerous articles were classified in more than one category, the column sums in Table 3 exceed the total number of ID articles.

the exception of *Research Policy,* only a small number of ID articles have been published in journals that existed prior to 1990 (i.e., the industrial organization journals).

However, occasionally the thematic emphasis may shift over time. For example, when the *Small Business Economics* journal was founded in 1989, the entrepreneurial function was treated in economics largely under the heading "entry and exit" (the term "entrepreneurship" was seldom used), and the journal was named *Small Business Economics*. There was little or no distinction made between "small business" and "entrepreneurship." Nevertheless, *SBE* was one of the new journals emerging in the late 1980s with a specific emphasis on entrepreneurship (Carlsson *et al.*, 2013).[7] And as mentioned earlier, the aims and scope of the journal were subsequently revised to reflect the change in terminology, reflecting the changing understanding of the underlying phenomena.[8]

ANALYSIS OF ARTICLES BY THEME

In outlining the new field, I thought it would be useful to divide the analysis into several interrelated subfields. There should be room for comprehensive and in-depth analysis of industrial transformation at the meso (industry) level linked to economic growth at the macro level. This is captured under Theme 1A, Dynamics and evolution of industries. Theme 1B, Entry, exit and entrepreneurship, represents the main mechanisms of introducing change into the system at the firm, industry, and macro levels. (The underlying causes, innovation in the form of technological and institutional change, would need a separate subfield - Theme 4, Technological and institutional change.) A dimension would be needed to allow for the analysis of how differences in institutions, culture, endowments, etc., in different geographies influence economic development: Theme 1C, Institutional and regional issues. Even though the domain as a whole clearly needs to be empirically based initially, there is also a need for theory as the field evolves: Theme 1D, Modeling of industrial development and economic growth.

An important dimension of industrial development and economic growth is the analysis of economic activity in the firm and how it links to the industry (meso) level. This means opening up the black box of

[7] Other journals were the *Journal of Business Venturing* (founded in 1985), *Family Business Review* (1988), *Entrepreneurship and Regional Development* (1989), and *Small Business Strategy (*1990).
[8] The distribution by theme is sensitive not only to the classification criteria used but also to the journals included in the analysis. For example, the inclusion of two economic geography journals increased the coverage of geographic dimensions of the literature. And if journals such as *Technovation*, the *Journal of Economic Behavior and Organization*, the *Journal of Economics and Management Strategy*, *Management Science*, and other management-oriented journals such as the Academy of Management journals and *Administrative Science Quarterly* had been included, the distribution by theme would surely be different.

the theory of the firm and examining what firms do (Theme 2A), how they are organized and financed (2B), what capabilities and resources they have (2C), and how they perform (2D). A closely linked set of topics focuses on Firm Boundaries and Interdependence: 3A Firm Boundaries, 3B Spillovers, 3C Cooperation/Alliances/Networking, and 3D Dynamics Related to Firm Size.

The fourth dimension takes a closer look at technological and institutional change: patterns such as technological paradigms, regimes, and trajectories (4B),sources of innovation (4C), as well as adoption and diffusion of technology (4D). The role of institutions influencing and co-evolving with new technologies needs to be analyzed, particularly in the form of innovation systems and industry clusters (4E and 4F). Finally, the role of public policy is examined in a fifth theme.

We turn now to an exploration of the major topics and main findings under each theme. It is practically impossible to summarize while doing justice to the research in so many and diverse articles in so broad an area, but a few observations concerning each theme might at least provide a useful overview. I concentrate on the findings that seem to be most important in advancing the field and tying the elements together. The approach here was to group all the articles under each theme, identify the most important and prevalent topics, and summarize the main findings. Due to space limitations, it is possible to provide references only for major contributions and for a few illustrative examples.

THEME 1: CAUSES OF INDUSTRIAL DEVELOPMENT AND ECONOMIC GROWTH

The ID articles classified under theme 1A (Dynamics and Evolution of Industries) differ markedly from IO primarily by tackling more dynamic issues, focusing on the evolution of industry and industry structures, and examining the causes of such changes (esp. technological change as a driving force). They also tend to be broader and more multidisciplinary in scope. Even when they focus on particular industries, they tend to take a longer historical (evolutionary) perspective. In contrast to IO research, they are much more focused on theory building (inductive) than on theory testing (deductive). The theory is “appreciative” – establishing the salient stylized facts through empirical and often historical analysis and hypothesizing the major underlying driving forces; it is seldom formalized.

1A Dynamics and Evolution of Industries

This area of research comprises several themes. One is the co-evolution of technology, industrial structure, and supporting institutions.[9] The main idea is "to piece together a relatively coherent appreciative theoretical account of economic development at a sectoral level by laying out a story of the growth, and development, of a manufacturing sector, from birth to maturity, and perhaps until death, that seems to fit many cases and which can serve as a target for formalization" (Nelson, 1994b). The analysis should take into account the development of institutions in response to changing economic conditions, incentives, and pressures.

More than 200 articles in this domain were published between 1990 and 2009 in the journals reviewed here. It is a rich literature, ranging from the analysis of the emergence and diffusion of general-purpose technologies (GPTs) to the study of the long-term evolution of various industries. GPTs such as the digitization of information give rise to new arrays of possible combinations. The analysis is more about new activities and products than about higher productivity in an industry, and more about linkages among technologies and firms than about market structure. Studies focus on empirical regularities in the structures and in the patterns of change: the links between microeconomic innovation and patterns of change at the industry level. Industrial structure is seen as evolving due primarily to innovation (technological competition) rather than purely as a result of market competition. The focus is on understanding the association between innovation and the evolution of market structure including industrial restructuring, bringing the analysis into a dynamic framework. Innovation is at the core of the analysis, viewed as a driving force rather than as a theoretical complication. Examples are explorations of the implications of different technological structures on entry/exit dynamics and on the evolution of market characteristics (market concentration, profitability variance, etc.) and learning, and of the links between the technological regime underlying an industry and the observed patterns of industry demographics. The emphasis is on understanding empirical regularities (patterns) over time - how industry structures change due to exploitation of scale economies, first-mover advantages, and organizational competence.

The analysis here (and in Industrial Dynamics as a whole) represents positive rather than normative economics; there is little discussion of public policy and few policy recommendations. Instead, public policies are viewed as part of the institutional infrastructure.

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[9] "Institutions are the rules of the game in a society or, more formally, are the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange, whether political, social, or economic. Institutional change shapes the way societies evolve through time and hence is the key to understanding historical change. " (North, 1990, p. 3)

In the 1990s there were numerous studies of infrastructure such as supply infrastructure, telecommunications infrastructure, intellectual property protection and standardization, as well as their interaction with industry evolution.

1B Entry, Exit, and Entrepreneurship

While innovation and institutional change are the main driving forces behind industrial evolution, the Schumpeterian process of 'creative destruction' is the main vehicle, and entry, exit, and entrepreneurship are the causal mechanisms. This is therefore a crucial area of Industrial Dynamics research. There are actually much fewer articles on entrepreneurship in the ID literature than I originally expected, especially during the 1990s. However, the number of articles in 1B doubled during the 2000s. This development is probably due to two factors: (1) the slow entry of entrepreneurship research into the economics literature (see Carlsson *et al.*, 2013), combined with (2) the emergence of new journals specializing in entrepreneurship research.

As Baumol (1968) pointed out, there is no place for the entrepreneur in equilibrium theory, and the introduction of entrepreneurship into Industrial Dynamics has been a slow process. Baumol showed that growth cannot be explained by the accumulation of various factors of production *per se*; human creativity and productive entrepreneurship are needed to combine the inputs in profitable ways. As a result, an institutional environment that encourages productive entrepreneurship and human experimentation becomes the ultimate determinant of economic growth. Baumol's theory (2004), in essence, is that vigorous competition, particularly in high-tech industries, forces incumbent firms to innovate in order to survive. This leads them to internalize innovative activities rather than leaving them to independent inventors. The bulk of private R&D spending comes from a tiny number of very large firms. Yet the revolutionary breakthroughs continue to come predominantly from small entrepreneurial enterprises, with large firms providing streams of incremental improvements that also add up to major contributions.

The essential contribution of entrepreneurial activity to our understanding of the process of industrial development and economic growth is the analysis of creative destruction – a process that requires both innovative (experimental and heterogeneous) entry and exit. In some industries the life cycle is characterized by rapid entry of new firms followed by a shakeout resulting from sharply falling entry while exit rates remain steady or rising over time. Observed empirical regularities suggest that shakeouts are not necessarily triggered by particular technological innovations nor by dominant designs, but by an evolutionary process in which technological innovation contributes to a mounting dominance by some early-entering firms. (Klepper & Simons, 1997)

The links between entrepreneurship and economic growth have remained elusive and have not been clearly established until the last decade. It turns out that knowledge spillovers are an important mechanism: knowledge created endogenously (within the economic system) results in knowledge spillovers which allow entrepreneurs to identify and exploit new opportunities (Acs *et al.*, 2009; Carlsson & Eliasson, 2003). The important action takes place at the individual level.

In addition to these more theoretically oriented contributions to the ID literature, Theme 1B (Entry, Exit, and Entrepreneurship) also contains numerous articles on the features of the organizational, cultural, geographic, institutional, sectoral, and policy context of entrepreneurial activity, on the characteristics of new entrants (firms as well as entrepreneurs), and on the determinants of post-entry performance.

The choice of journals included in this review reflects my expectation in the 1990s concerning where ID articles would appear. The management literature was outside my purview, and the entrepreneurship-oriented journals were just starting to emerge. *Small Business Economics* is the only economics-based journal focusing on entrepreneurship. Most of the entrepreneurship-focused research has been published in entrepreneurship journals in other disciplines or in books or edited volumes not included in this review.

1C Institutional and Regional Issues

There is a geographic or regional element to the transformative forces which Schumpeter identified as gales of creative destruction. Place and space matter in an evolving system. Economic agents located in different geographical spaces make different choices, thus creating variety. At any moment in time, interdependencies between agents are constrained by social and spatial structure. Without variety, the process of selection, by which certain products and processes of production are favored in the market, cannot operate. For example, empirical analysis has shown that U.S. production technology varies markedly over geographic space and that in U.S. manufacturing industries, regions tend to move along distinct trajectories of technological change. Also, the high mobility of capital, population and knowledge in the U.S. not only promotes the agglomeration of research activity in specific areas of the country but also enables diffusion and technological spillovers that are impeded in the European Union due to imperfect market integration and institutional and cultural barriers.

Recent literature has drawn attention to clustering of economic activity. In particular, knowledge-intensive industries tend to concentrate geographically because of the many spillovers that they generate. A major reason is the geographically bounded dimension of knowledge spillovers. Thus new biotechnology firms often set up in regions that have innovative firms, government laboratories and universities. Capabilities of organizations and regions vary, and scientific and technical competencies vary strongly among regions. Also, regions tend to concentrate competencies on a few domains of expertise. As a result, companies active in the same field of technology tend to cluster geographically, not only to take advantage of knowledge spillovers but also to share a common labor pool, and to obtain access to key markets and customers, such as large assemblers or government facilities. Co-located firms within related industries enhance the ability to create knowledge by variation and a deepened division of labor. Another reason why industries cluster is that entrepreneurs find it difficult to leverage the social ties necessary to mobilize essential resources when they reside far from those resources. Formal as well as informal institutions influence the evolution of the clusters or innovation systems.

Regional/spatial issues (1C) have been addressed primarily in journals specialized in economic geography. Given the geographic dimension of innovation systems and industry clusters, there is a good deal of overlap between 1E and 4E, especially in the *Journal of Economic Geography*. But most of the articles on innovation systems and industry clusters in this review have been published in *Research Policy* and *Industry & Innovation*.[10]

1D Modeling of Industrial Development and Economic Growth

Modeling of industrial development and economic growth is a complex matter which explains why there have been relatively few articles published in this domain. Yet, substantial progress has been made over the last couple of decades. What has emerged is a framework or complex system of which many important features and elements have been explored. In what follows I will try to synthesize the main features.

[10] It is interesting to note that of the 750 articles on innovation systems up to 2003, about 300 (40%) were published in journals and the other 60 % in books or edited volumes (Carlsson, 2007).

The system is dynamic (evolving) and complex[11] and never in equilibrium. The micro units (firms and technologies) are heterogeneous. Technologies have different impact in different contexts, and firms have different features such as strategies, organization, capabilities, and resources, and thus they behave differently. Through their behavior and interaction (including learning, experimenting, investing, and hiring) firms create new combinations (innovations), causing structural change (both within firms and in groupings of firms such as alliances, networks, industries, and development blocs) and aggregate growth. Thus, technological change is endogenous, but it can also be exogenous in the form of new discoveries, entrepreneurial activity, and institutional change. The system is path-dependent, partly through co-evolution of institutions, industries, markets, and technologies, and partly by being tied to historical time and place.

Many parts and dimensions of this system have been explored in the literature, but not all together in a single model. There are both formal and informal models. One of the earliest models is the Swedish micro-to-macro model developed by Eliasson (1977, 1978, 1985). In the 1990s, ‘appreciative theorizing’ led to more formal modeling in the form of evolutionary economic models referred to as 'history-friendly' (Malerba & Orsenigo, 2002; Malerba *et al.*, 2008). History-friendly models are formal models that aim to capture, in stylized form, qualitative and 'appreciative' theories about the mechanisms and factors affecting industry evolution, technological advance and institutional change. Such models can incorporate a variety of empirical insights and perspectives from scholars of industrial economics, technological change, business organization and strategy, business history, and other social sciences.

As could be expected, different models explore different aspects of evolutionary processes. Some models focus on technological regimes and firm entry, others on the relationship between variety and competition while distinguishing between inter- and intra-technology competition. Others focus on interactions among multiple boundedly rational agents who imperfectly learn how to innovate in environments characterized by notionally unlimited opportunities in which micro discoveries can generate persistent system-level effects. Some evolutionary models describe the relation between endogenous technological change and economic growth. In such models, firms are boundedly rational

[11] A complex system is defined as “consisting of many diverse and autonomous but interrelated and interdependent components or parts linked through many (dense) interconnections. Complex systems cannot be described by a single rule and their characteristics are not reducible to one level of description.
They exhibit properties that emerge from the interaction of their parts and which cannot be predicted from the properties of the parts. (www.BusinessDictionary.com)

in that they have only vague ideas about the relationship between their actions and outcomes.

Other models focus on the growing variety of the economic system resulting from the emergence of new products and services that provide growth opportunities for existing firms as well as new firms and that lead to new industrial sectors, while others describe diffusion processes, the processes of structural and institutional change, the causal links between entrepreneurial activity and economic growth, and the interdependence between economic, technological, and institutional processes. Other models describe how human capital accumulation through investment by heterogeneous firms in education and training can be a source of economic growth (Ballot & Taymaz, 1997). A few models focus on the demand side of economic growth and structural change – but very few in the literature reviewed here. Another aspect of Industrial Dynamics that is challenging to model – and largely missing in this literature - is the role of knowledge in general and of knowledge spillovers in particular.

THEME 2: ECONOMIC ACTIVITY IN THE FIRM

2A Strategy

While the literature on strategy appears mainly in management journals, given the heterogeneity of firms, business strategy is an important element of the dynamic processes that constitute industrial development and economic growth. Business strategies both shape and are shaped by the environment (industry, cluster, etc.) in which firms operate.

As could be expected, the part of ID literature that deals with strategy focuses primarily on knowledge creation and management, not on business strategy more generally. The general business strategy research continues to appear in the management literature.

It turns out that while there were only a handful of articles dealing with strategy in the 1990s in the ID literature reviewed here, there were many more in the 2000s. The articles in the 1990s were scattered among a variety of topics, but in the 2000s one main area of interest emerged: business strategies with respect to innovation, technology management and acquisition, and intellectual property management. Research focused on how to manage innovation, especially in knowledge-intensive industries such as biotechnology, information technology, and software – and how to balance internal resource development (learning) through in-house R&D and experimentation with external sourcing. It was recognized that knowledge could also be acquired from outside via networks, alliances, joint ventures, licensing, mergers & acquisitions of high-tech firms, and open sourcing. Integration and implementation of new knowledge in the firm's business activities and organization were also investigated. The management of intellectual property (IP) was examined with respect to acquisition, internal organization within the firm, and how best to derive benefit from acquired IP (patenting, licensing, and other forms of technology transfer). Several articles analyzed entrepreneurial strategy and issues having to do with specialization vs. diversification in the firm's technology strategy, and with strategies for internationalization.

2B Business Organization and Finance

The ID literature on business organization and finance is quite diverse, but as the field grew over the course of the 1990s, three main areas of research focus emerged: the evolution of organizational structure, the organization of innovative activities in the firm, and issues relating to finance of innovation, particularly in new and small firms.

A significant portion of research on the evolution of organizational structure takes an historical approach and builds on the work of Alfred Chandler's works, especially *Scale and Scope* (Chandler, 1990). Some studies extend Chandler's analysis of large European firms in the post-war period, emphasizing the increasing prevalence of divisional structure similar to that in the United States a few decades earlier. Other studies examine the increasing degree of 'organizational integration' in the USA and elsewhere, providing abilities and incentives as well as financial control to develop and utilize productive resources. Typical findings (in the 1990s) were that Japanese firms had become more organizationally integrated and more competitive than their American rivals and were organized in 'business groups' with operating units in technologically unrelated industries. This Japanese model had then been pursued by other late industrializing countries. Some papers offer theoretical and behavioral foundations for this development involving bounded rationality, cognition, and social learning, while others focus on problem complexity, decentralization, and modularity. One question to which these findings give rise is whether or not business organization in industrialized countries tends to converge over time. This seems doubtful; several authors discuss the role of path dependence, reflecting 'preindustrial factors' such as handicraft and guild traditions, family networks, educational systems, and other features that are nation-specific and that prevent such convergence. While the analysis in most of these studies is at the level of the manufacturing sector, there are also a few studies at the industry and firm level.

There are many ways in which technology influences the organization of activity in the firm and vice versa. For example, information and communication technologies (ICTs) and computer-aided production management affect the organizational configuration and operational practices within firms and can also influence the organizational dynamics in an industry. Innovation in a product's design can have significant implications for the organization of competencies across a production network. At the same time, organizational factors influence innovation. The organization of R&D, such as how R&D strategies, outsourcing and vertical integration are linked together, affects product performance in the market. The integration of knowledge acquired from outside (for example, via licensing) with technology developed in-house is important; knowledge coordination requires that systems integrators be able to span capabilities over a range of technological fields that is wider than the range of activities that they actually perform in-house.

The ID literature on the organization of R&D spans a large number of topics. Examples are the relationship between the organization and location of corporate R&D; the restructuring of R&D away from the previous dominance of a central R&D lab; the internationalization of R&D; the organizational configuration of R&D in multinational firms; the specific organizational requirements of basic research inside the firm; the choice between external and internal sourcing of new technology; the advantages and drawbacks of internal knowledge integration versus collaborative outsourcing as two polar modes of governance; the management of innovation within firms producing complex products and systems, and management of R&D in project-based organization.

The ID finance literature deals mostly with financial issues in small firms: for several reasons (especially lack of information available to financial intermediaries, a high ratio of intangible assets, and a high risk profile) they face tighter liquidity and borrowing constraints than larger and more established firms; few of them have access to external equity capital. As a result, they have to rely on internally generated capital (cash flow as well as personal savings). This is true especially for finance of R&D.

A significant portion of the finance literature in ID deals with venture capital (VC) and to some extent with initial public offerings (IPOs). It is noted that the success of a venture investment is strictly linked to the knowledge flow inspired and reinforced by the complementarities between the knowledge bases of entrepreneur and venture capitalist, rather than to a particular financing scheme as claimed in most of the literature. Several studies examine the relationship between the VC firms and the entrepreneurs. Among the findings are that prior founding experience (especially financially successful experience) increases both the likelihood of VC funding via a direct tie and venture valuation. Also, founders' ability to recruit executives via their own social network (as opposed to the VC's network) is positively associated with venture valuation. Across the range of different financial intermediation structures, including banks, life insurance companies, securities firms, corporations, and government bodies, there are further differences in the provision of governance and value-added advice provided to SMEs.

Several papers study venture finance in various countries, often contrasting the U.S. against European countries. Typical findings are that innovative small and medium enterprises in the EU find it more difficult to get started and grow than in the U.S. Some studies indicate institutional and organizational differences as explanatory factors.

2C Firm Capabilities and Resources

One of the fundamental differences between Industrial Dynamics and Industrial Organization is that ID encompasses analysis at the micro, and meso (industry) as well as macro levels, while IO focuses on the industry level. Hence in contrast to IO, ID is concerned with activities and capabilities inside the firm and how firms interact with the competitive environment.

In the area of firm capabilities and resources, research in the 1990s focused mainly on dynamic capabilities and a subset of these, technological capabilities. In the 2000s, management of innovation was added to the research agenda.

Dynamic analysis requires theory and concepts that are capable of dealing with change. Economic competence is such a concept. It can be defined as the ability to identify, expand and exploit business opportunities. Economic competence constitutes the means through which technological possibilities are converted into economic activity. It consists of four types of capabilities: (i) selective or strategic; (ii) organizational or coordinating; (iii) technical; and (iv) learning ability (Carlsson & Eliasson, 1994).

In the early 1990s a number of researchers realized the need to move beyond the static resource-based view (RBV) of how firms gain and maintain competitive advantage. It was noted that winners in the global marketplace demonstrate timely responsiveness and rapid and flexible product innovation, along with the management capability to coordinate and redeploy internal and external competences. This source of firm-specific competitive advantage was named 'dynamic capabilities' and refers to the key role of strategic management in appropriately adapting, integrating, and re-configuring internal and external organizational skills, resources, and functional competences in dealing with a changing environment (Teece & Pisano, 1994).

Firm-specific technological competencies help explain why firms are different, how they change over time, and whether or not they are capable of remaining competitive. The implementation of new techniques and the development of related know-how are cumulative and path-dependent. The knowledge incorporated into technologies becomes an integral part of a firm's repertoire of capabilities.

As technology evolves, so do industry characteristics, products and critical success factors. Firms without the right capabilities are forced to exit.

Several studies focused on the need for technological diversification, driven in large measure by increased product complexity as a result of increased use of computers, information and communication technology (ICT), and new discoveries in microbiology. Many firms have been forced to become multi-technological using a variety of approaches, often in combination: internal R&D, external sourcing of technology via licensing, alliances, joint ventures, networking, as well as via mergers and acquisitions.

Technological diversity influences the innovative activity at the firm level. Both R&D intensity and patents increase with the degree of technological diversification of the firm. Firms that diversify their technology can receive and absorb more spillovers from other (related) technological fields, and diversification can reduce the risk from technological investments.

Innovation is the main driving force in Industrial Dynamics, and firms are the main actors. It is therefore not surprising that a significant share of ID research is focused on innovative capability, its determinants, and its management. There are sources both internal to the firm - such as education of the labor force, prior work experience and R&D effort - as well as external ones through either bilateral or multilateral interactions (via networks) with other firms, including suppliers. The regional science base plays a role in nurturing high-tech spin-offs. There are important elements of path dependence: innovative success depends on leveraging existing knowledge through current R&D.

It is striking that the literature reviewed here addresses the problem of how knowledge creation, technology and organization are interrelated, not how internal R&D should be organized and managed. It is mostly about how firms integrate knowledge and capabilities across organizational boundaries. Knowledge and the capability to create and utilize knowledge are seen as the most important source of a firm's sustainable competitive advantage.

In-house R&D units are seen as the location for organized learning, the problem-solver of last resort in production, the in-house knowledge store and gatekeeper, and the focus for independent design and product development capacity. At the same time, innovations are being increasingly created through international corporate networks for technological development. Innovation is encouraged by newer, more flexible organizational forms, and further encouraged by knowledge flows – unintended spillovers as well as intentional technology transfers - between firms. Behind these developments are increasing product complexity, involving integration of multiple technologies, and the resulting need to both deepen the technology base and broaden it.

The variety of scientific disciplines that it is necessary to command in order to generate new technological knowledge is increasing. This poses difficult problems for knowledge governance and management of technology. Cognition at the most senior level can play a critical role in shaping the firm's response to discontinuities through both acquisition and reallocation of resources. At the same time, the R&D unit has not only a gatekeeping function – gathering and transmitting information – but also a knowledge transforming function – absorbing information and creating new knowledge. Managing the balance between searching for and absorbing external knowledge and creating new knowledge internally, perhaps through experimentation, is difficult in the presence of boundedly rational, heterogeneous and choice-restricted actors.

In the past, a high R&D intensity tended to be seen as an impediment to outsourcing, but in the last few decades firms in R&D intensive industries have increasingly started to rely on partnership relations with outside suppliers. For example, given that biomedical innovation involves intense collaboration across disciplines, occupations and organizations, integrative capabilities (the ability to move between basic science and clinical development) and relational capabilities (the ability to collaborate with diverse organizations) have been identified as crucial.

2D Firm Performance

The ID literature on firm performance is focused on innovation, with R&D activity often used as a proxy. Numerous articles relate innovative activities to performance at the firm level in several dimensions: survival, growth, productivity, profitability, exports, and market power. A positive and significant role is found for the firm's in-house R&D expenditure in influencing productivity growth. Expected returns and cash flows are important explanatory variables of firm research intensities. There are also many studies on the various factors within the firm that contribute to innovation – such as the coherence and scope of the knowledge base, the share of highly educated employees, and the application of human resource management practices within the firm.

Distinction is often made between radical and incremental innovation. It is noted that radical innovations often require interaction with other firms in conjunction with formal internal research. Development and management of close relationships with vertically related actors as well as knowledge institutions are not only positively correlated with the ability to innovate but also negatively correlated with the degree of innovative imitation. By contrast, incremental innovations rely mostly on the adoption of equipment goods accompanied by informal research. Radical innovations contribute significantly to productivity growth, whereas incremental or imitative innovations do not. Innovation height matters (Duguet, 2006).

Innovative performance is highly skewed; radical innovations tend to be concentrated to relatively few firms. The sales growth rate and rate of return to R&D are much higher for innovative than non-innovative firms. Low-technology firms follow different innovation paths compared with medium- and high-technology firms, but they seem to perform equally well and in some respects even better at process innovation.

The firm's location in the value chain (lead vs. non-lead firms) also affects innovative performance. Lead firms can capture higher value (gross profit) from R&D than contract manufacturers and component suppliers.

Mergers & acquisitions (M&As) can contribute to innovation depending on the relatedness between the acquired and acquiring firms' knowledge bases. R&D efficiency increases more when merged entities are technologically complementary than when they are substitutive. In contrast, when merged entities are technologically substitutive, they significantly decrease their R&D level after the M&A (Cassiman *et al.*, 2005).

THEME 3: FIRM BOUNDARIES AND INTERDEPENDENCE

3A Firm Boundaries

Most of the ID literature on firm boundaries deals with cooperation, alliances, and networking among firms and is summarized in Section 3C below. The articles reflected in the current section deal primarily with outsourcing, vertical integration, and diversification.

In many industries, the techno-socio-economic environment is becoming increasingly complex and uncertain. As a result, the boundaries of firms are in greater flux since firms are unable to develop individually all the competencies required to keep pace with the continual redefinition of business lines being driven by competition.

Outsourcing, particularly of services, became an important phenomenon reshaping firms' boundaries in the late 1990s and appeared in the ID literature in the 2000s. The rapidly increasing use of information technology (IT) altered the organizational dynamics in many industries. With product complexity and the need to acquire knowledge increasing at the same time, firms had to choose between producing an essential input in-house (full integration), buying it from an outside supplier (non-integration) and doing a combination of both (tapered integration). Outsourcing strategies were shown to be positively related to firms' innovation. In particular, the outsourcing of service activities was found to be mostly related to product innovation. Positive relationships were found between firm size, in-house R&D intensity, diversification, and vertical integration on the one hand with external sourcing of R&D on the other. It was also shown that in-house capability is needed to absorb and integrate procured R&D. The choice between procurement and in-house R&D was found to be affected by the strength of intellectual property rights (IPRs) and by the existence (and nature) of information spillovers. Stronger property rights favor independent suppliers over vertical integration. Both geographical and organizational proximity matter. Indeed, the positive association of services with innovation is strongly related to geographic proximity, which points to the importance of local user-producer relationships.

3B Spillovers

There has been a great deal of discussion about technological spillovers in the last 20 years, even though there is no commonly accepted definition of what constitutes spillover. As a result, the literature is unclear about whether both market-transacted (targeted and paid-for) technology transfers and non-market (untargeted and uncompensated) “true spillovers” are involved.[12] In most cases, “spillovers” refers to both. The basic idea, of course, is that firms benefit from discoveries made by others. However, findings indicate that the net impact of R&D spillovers on productivity can be either positive or negative depending on technological opportunities, firm size and competitive pressure. Although spillover effects are positively associated with the technological opportunities that a firm faces, this relationship is reversed when firm size is considered. While external R&D affects large self-reliant firms negatively, its impact on the productivity of smaller firms (who usually introduce incremental innovations that are characterized by a strong reliance on external technologies) is positive, and even higher than that of their own R&D (Kafouros & Buckley, 2008).

Some studies have looked at both formal (contractual) and informal cooperation among firms, finding that informal cooperation is both more prevalent and more important than formal cooperation. There is only weak empirical evidence for the relevance of incoming knowledge spillovers for formal as well as for informal cooperation. But a firm's ability to protect its proprietary innovations, i.e., to limit outgoing knowledge spillovers, has a positive effect on its propensity to engage in formal and informal cooperation

[12] For a discussion, see Carlsson (2013).

at the same time (Bonte & Keilbach, 2005). Large firms that operate an R&D department and that are involved in costly R&D projects tend to cooperate formally. Empirical evidence strongly suggests that in-house R&D increases a firm's ability to absorb spillovers from other firms, as well as contributing directly to profitability.

Firms collaborate with universities primarily to gain access to upstream modes of knowledge rather than specific products and processes (Feller *et al.*, 2002). A substantial proportion of the wider economic benefits to society from publicly-funded basic research is associated with scientists' migration into the commercial sector of the innovation system. Besides bringing scientific knowledge, academic scientists provide social capital that can be transformed into scientific networks that embed the firm in the scientific community.

Pure knowledge spillovers (as distinct from formal collaboration) provide the most benefit to firms that imitate existing technologies or that are involved in incremental innovation. By contrast, highly innovative firms appear to derive most benefit from formal collaborative research with universities. They benefit only marginally from aggregate (or industry-wide) spillovers (Monjon, 2003).

Academic spillovers are more localized than industrial spillovers (Adams, 2006). Geographic localization coincides with the public goods nature of academic research. This contrasts with relations to other firms, where contractual arrangements are needed to access proprietary information, often at a considerable distance.

Ever since Alfred Marshall introduced the idea of ‘industrial districts’ in the 1890s, agglomerations, whether industrial or geographic, have been part of the economic literature. In the 1990s terms such as industry clusters, innovation systems, competence blocs, and business groups began to be used to analyze the settings in which technological spillovers are likely to occur.

The essential function of technological innovation systems is to capture, diffuse, and magnify spillovers of technical and organizational knowledge. The nature of knowledge (i.e., the characteristics of knowledge and how it can be transmitted) in each system determines what types of spillovers are likely to occur, as well as the mechanisms through which they occur. Institutions (including both organizations and rules of the game) play an important role.

Significant technological spillovers occur within and around groups of advanced (R&D- intensive) firms, referred to as ‘competence blocs’ (Eliasson, 1996). Such firms function unintentionally as technical universities and research institutes, providing uncompensated and untargeted educational and research services. They also function as hubs in extensive networks of major suppliers (often in distant locations) in which new knowledge is generated and transferred. The local knowledge spillovers in such clusters may be quite limited, even though they may have significant effects on the local labor pool. The organization of the aircraft industry is an example. Japanese keiretsu groups exhibit similar features. Technology transfers from a core firm to its subcontracting firms are often substantial. There are also R&D spillovers stemming from the R&D activities of other keiretsu groups. Particularly remarkable are the spillovers between core firms of competing keiretsu groups (Suzuki, 1993).

Many spillovers occur within input-output (user-producer) relationships. They often originate in downstream sectors favoring the growth of upstream industries. Inter-firm informal contacts are more numerous than university informal contacts. Also, knowledge is more frequently acquired from engineers in other firms than through university-industry contacts.

3C Cooperation/Alliances/Networking

The literature on cooperation/alliances/networking emerged in the 1990s and multiplied in the 2000s. It represents a shift of focus from market structure and performance at the industry level in IO to processes of interaction among firms that create new knowledge and blur firm boundaries. The articles in this domain span a broad set of topics.

The literature on R&D and technological innovation has come to stress the role that networks of innovators play in the R&D, product development and marketing phases of technological innovation. This model stands in sharp contrast to the previously dominant model of innovation which envisaged the process as a linear sequence, with R&D conducted as a proprietary activity within a single firm.

Innovation networks differ from both ‘classical’ networking between firms in close proximity to each other, as in ‘industrial districts,' and from the joint venturing (Research Joint Ventures, RJVs) that occurs between firms that complement each other's activities but may be separated in space. Innovation networks are less formal in structure than strategic alliances (such as RJVs); the formation of a joint venture is necessary only in situations when contractual arrangements are necessary to monitor technological flows and to distribute cooperation rents. Innovation networks are characterized and motivated by complexity, rapid changes in technology, and turbulent environments – factors that make innovation costly and uncertain. Innovation networks may involve cooperation with customers, suppliers, competitors, and public research institutions. The firms that participate tend to be relatively large and

R&D-intensive, implying a high absorptive capacity (and a way to reduce transaction costs). Pure spillovers do not seem important as a motivating factor. Instead, R&D cooperation is more associated with paying license fees and acquiring patents, i.e., technology transfer. There is strong evidence of positive returns to collaborative research with other companies, but collaborative research with universities does not appear to enhance productivity directly. This implies that firms may conduct R&D with universities when appropriability conditions are weak and the outcomes of such research projects do not yield direct strategic benefits. On the whole, networks seem less effective in terms of technological development and innovation activities than they are in knowledge creation and transfer.

Strategic alliances became an important phenomenon in the 1980s. The choice of partners tends to reflect technological overlap (complementarity of resources). Rapid rates of technological change and a high degree of market uncertainty influence the formation of horizontal inter-firm strategic alliances in dynamic product markets. Joint R&D is used to complement internal resources in the innovation process. The intensity of in-house R&D also increases the probability of joint R&D activities with other firms and institutions.

Competitor and supplier cooperation tends to focus on incremental innovations, whereas customers and universities are important sources of knowledge for firms pursuing radical innovations. Larger RJVs are more likely to invite a university to join the venture as a research partner than smaller RJVs. Larger ventures are less likely to expect substantial additional appropriability problems to result because of the addition of a university partner and because the larger ventures have both a lower marginal cost and a higher marginal value from university R&D contributions to the ventures' innovative output (Link & Scott, 2005).

Firms with internal R&D strategies more heavily weighted toward exploratory activities allocate a greater share of their R&D resources to exploratory university research and develop deeper multifaceted relationships with their university research partners. In addition, firms with more centralized internal R&D organizations spend a greater share of their R&D dollars on exploratory research conducted at universities. In contrast to other external partners, universities are preferred when the firm perceives potential conflicts over intellectual property (Bercovitz & Feldman, 2007).

3D Dynamics Related to Firm Size

The domain of the dynamics of firm size has to do with the analysis of structural change and industrial demography. Many, if not most, of the articles in the 1990s and 2000s were concerned with a commonly observed pattern: a shift in the size distribution of firms across most industrial countries over the course of the 1970s and 1980s away from large firms and towards small business, breaking the trend of the previous century. The share of employment in small plants increased in many countries up to the 1990s but then stabilized. Small plants also increased their share of output up to the 1990s but then saw it decline. Over the entire time period, their share of output increased less than their share of employment, and therefore their relative labor productivity fell. The shrinkage in the average size of establishments in terms of employment (most of the data used were for establishments, not firms, and for manufacturing only) took place while overall manufacturing employment fell. Large establishments shrank more than others, but the smaller firms did not grow enough to make up the difference.[13]

The similarity of these trends across many countries suggests that the causes should be sought in similarities such as the technological environment rather than in country-specific factors. Indeed, a number of studies showed that new and more flexible technology, especially in manufacturing, made small-scale operations more competitive. The applicability of Gibrat's law - the idea that firm growth is unrelated to firm size – was studied by many authors but was almost universally rejected for many countries, and for both manufacturing and other sectors. The growth of employment in the smallest firms appears to be linked to a relatively high entry rate. However, many new entrants fail within a few years, and only a few grow rapidly. Meanwhile, the exit rate appears to be fairly constant over time.

Several studies showed that small firms are often more innovative than large firms: even though large firms produce a larger number of patents per firm, the patenting rate for small firms is typically higher than that for large firms when measured on a per-employee basis. Yet large firms can spread the cost of R&D over a larger output and thus benefit disproportionately (Cohen & Klepper, 1992).

The failure of most new and small businesses to grow is linked to various constraints. Firms must access, mobilize and deploy resources before they can generate resources for growth. Most new firms face financial constraints – limited access to external finance, liquidity constraints – and often an institutional environment unfavorable for small firms and entrepreneurial activity. Financial constraints to the development of innovation are often considered one of the main impediments to high-technology firms seeking to expand and grow. In particular this is the case for small and medium size high-tech firms. Traditional financial sources are often inadequate to finance innovative projects. As a result, many new firms must rely mainly on personal finance, and secondly on short term bank debt. An additional problem is that the owners of small firms are reluctant to give up control in conjunction with obtaining external finance.

[13] The size distribution of firms is an important outcome in IO but is viewed as part of industrial transformation in

A further problem for many small firms in the 1990s and 2000s was the restructuring of supplier networks. Many large manufacturers operating on global markets were moving towards multi-tiered global supply systems consisting of fewer major suppliers, each with its own supplier network. This often led to the exclusion of small independent firms, or to their being relegated into lower levels of the supply chain.

THEME 4: TECHNOLOGICAL CHANGE AND ITS INSTITUTIONS

4A General

The whole field of Industrial Dynamics grew, in part, out of the concern that there was no place in conventional static equilibrium theory for the analysis of technological change, its supporting institutions, and its fundamental role in generating economic growth and industrial development. Technological Change and Its Institutions is a very broad field, as will be demonstrated below. But even when it is subdivided into many sub-fields, there are articles that are difficult to classify under any specific heading. Among these are a few that are broader in range and that need to be classified in a General category. Indeed, some of the seminal research in this area does not appear at all in the journals reviewed here but is published in books instead. Nelson & Winter's "*An Evolutionary Theory of Economic Change*" (1982) and Dosi *et al.*, (1988) *Technical change and economic theory* are two primary examples.[14]

The topics in this General area include analysis of the determinants and characteristics of endogenous economic growth and industrial development, including social dynamics, and historical reviews of evolutionary processes in various industries, for example antibiotics, medicine and venture capital industry. A major topic is the analysis of innovation: the complex, iterative, uncertain, experimental, path-dependent and cumulative nature of the innovation process; and the cooperative and competitive behaviors of firms during the process of creative destruction.

There are conceptual papers on the nature and evolution of human know-how, on the appropriability (both for society and for the innovator) and the distribution of the benefits of innovation, and on the measurement of technological change in multi-technology product sectors, to name a few. What is the role of intersectoral flows? What are the links between innovation and productivity within and between sectors and for economies as a whole? How does technological change influence market structure? What

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ID.

are the rates of return on investments in new technologies, and how are they distributed among users and producers? Several papers deal with intellectual property rights and codification and transferability of knowledge.

4B Patterns/Regimes

Research in this area concerns the links between the microeconomics of innovation, the patterns of industrial change, and regularities in the evolution of industrial structures over time. This literature largely follows the terminology suggested by Dosi (1982) and Pavitt (1984): “technological paradigm” refers to patterns of solutions to selected technological problems, “technological trajectory” to the pattern of ‘normal’ problem-solving activity within a technological paradigm, and “technological regime” to the pattern of innovation within an industry.

Technological Regime

Several different types of technological regime have been identified. For example, distinction is made between creative destruction (the entrepreneurial regime, favorable to entry by new firms and less favorable for the survival and growth of established firms) and creative accumulation (the routinized regime that favors established firms within an industry) (Audretsch, 1992). The shift of dominance from small, specialized firms to large diversified firms in some industries has been observed. Technological regimes have been linked to different types of innovation, such as focus on cost reduction, technical performance, or capital productivity. The increasingly interrelated and complex nature of technological evolution has been examined, and also how path-dependent technological change is characterized by "creative incremental development."

Several papers have examined the relationship between the technological regime and the technological catch-up in countries such as South Korea and Taiwan (Lee & Lim, 2001; Park & Lee, 2006). Different patterns of catching-up were found in different industries. Different patterns were also found between Korean industries dominated by large diversified conglomerates (so-called Chaebols) pursing independent R&D and learning strategies, and Taiwanese industries characterized by more flexible, network-based, specialized firms and pursuing more cooperative R&D and learning strategies.

Technological Trajectories

[14] Other examples are Carlsson (1979) and Dahmén & Eliasson (1980).

Technological trajectories were examined in a variety of contexts. A number of studies looked at how new technological paradigms arise from advances in science and developments in technological knowledge, and the mechanisms through which knowledge emerges, grows, and transforms itself. It was shown that patent disclosure induces R&D competition and shapes firms' technological trajectories. This can generate knowledge spillovers, promoting multiple parallel research efforts on plausible targets and stimulating investment and competition. Other researchers explored the process by which radically novel technologies--such as radar and the turbojet--came into being.

Path Dependence

The role of path dependence has been pursued in many studies and at many levels. At the country level, evidence has been presented for the advanced OECD countries of uneven and divergent patterns of technological accumulation. In addition to diversity in cumulative technological trajectories, the divergent patterns reflect international differences in the capacities of management and of financial and training institutions properly to evaluate and exploit the learning benefits of technological investments. Persistent international differences in productivity levels were shown to be related to the choice between standardized mass production and craft/flexible production technologies (Broadberry, 1995). At the regional level, it has been argued that the differences in performance of California’s Silicon Valley and Boston’s Route 128 over the 1980s and 90s were attributable to differing cultures, inter-firm relations and internal organizational. It should also be noted that these differences were due in large measure to the fact that Route 128 was formed in a different period (prior to the transistor) and was oriented to large-scale defense-related products, whereas Silicon Valley was formed after the transistor and was oriented more towards civilian products whose development was not constrained by military contracts and could benefit from networking.

Studies of technological path dependence at the industry level have found that industry-specific competencies have endured over the twentieth century--industrial sectors patent most in their respective technological fields, and differences in overall technological profiles remain quite marked. However, in an increasingly complex technological environment, paradigms developed within one industry may spill over into others as firms seek to absorb them. Eventually, after long periods of time the spillovers may become large.

As a result of the cumulative nature of learning, the profile of corporate technological competence tends to persist over quite long periods, provided there is institutional continuity. Within the same firm, competence may evolve into related areas, but the firm's technological origins will remain identifiable in its subsequent trajectories. The science and the knowledge base, and the composition of products and markets may shift quite radically, but the firm's productive and technological system itself is potentially more stable. Firms tend to extend the range of their innovative activities in a non-random way, diversifying their innovative activities across related technological fields, i.e. fields that share a common knowledge base and rely upon common heuristics and scientific principles. Knowledge-relatedness is a major feature of firms' innovative activities.

Technological discontinuities

Path dependence is a double-edged sword. The cumulative nature of the innovation process that creates stability and predictability also impedes the emergence of new technologies that disrupt the status quo. The shift from a chemical to a biochemical knowledge base in the pharmaceutical industry, from mainframes to personal computers, and from cell phones to smart phones are good examples. Disruptive innovations create new markets and disrupt existing markets and value networks over a few years or decades, displacing earlier technologies. The process by which a technology achieves dominance when ‘battling’ against other technological designs is referred to as a technological discontinuity. Innovations based on radically new technologies often create advantages for entrants over incumbents in the relevant markets. Historical evidence suggests that entrants find greatest advantage when innovations disrupt established trajectories of technological progress, a circumstance associated with moves to new value networks - the contexts within which firms compete and solve customers' problems. It has been shown that the value network is an important factor affecting whether incumbent or entrant firms will most successfully innovate. The incumbent's disadvantage tends to be associated with an inability to change strategies, not just technologies (Rosenbloom & Christensen, 1994). A study of technology development in the disk drive industry found that incumbents led the industry in developing and adopting new technologies as long as the technology addressed customers' needs within the value network in which the incumbents competed. But new entrants led in developing and adopting technologies that addressed user needs in different, emerging value networks. It is in innovations disrupting established trajectories of technological progress in established markets that attackers proved to have an advantage (Christensen & Rosenbloom, 1995).

4C Sources of Innovation

Two things stand out in the review of ID literature on sources of innovation: the great diversity of sources of innovation and the importance of absorptive capacity (Cohen & Levinthal, 1990).

The most common source of innovation mentioned in the literature is R&D, but not only R&D within the firm. Typically, R&D cooperation and to a lesser extent R&D contracted out are found to have a significantly positive effect on internal R&D, but only if the companies have sufficient absorptive capacity, usually in the form of a full-time staffed R&D department. At the same time, firms are found to be more frequently engaged in R&D cooperation, the more they spend on internal R&D. Radical innovations are mainly generated in-house, whereas contracted R&D seems more oriented towards incremental innovations. Concerning the sources of *process* innovation, there seem to be complementarities between incremental and radical innovation. Firm size, the presence of formal internal R&D, and the use of suppliers as a source of knowledge all increase the chances that a firm will be a process innovator. The complementarity between internal R&D and external sourcing of technology is shown not only at the firm level but also at the industry level. In industries based on scientific breakthroughs such as biotechnology and nanotechnology, radical innovations tend to come from new entrants (often linked to academic research). The ability of incumbent firms to exploit new methods of inventing depends initially on access to tacit knowledge, but over time - as firms learn and/or the knowledge becomes codified in routine procedures or commercially available equipment - inventive output is more highly dependent on traditional internal R&D.

Diversity

The diversity of sources of innovation is striking, especially in the services industry which is itself quite diverse, not least in its innovative behavior. Diversity may itself stimulate technological progress. Empirical results on the relationship between the diversity of R&D activities within industries and their rate of technical advance indicate that there is a selection effect, a scope effect and a complementarity effect, each associated with a more rapid pace of technological change (Cohen & Malerba, 2001). The multimodal character of innovation in services firms involves interaction with both clients and providers, often facilitated by the use of information and communications technologies (ICT). Knowledge intensive services (KIS) have a key role in the creation and commercialization of new products, processes and services. These services include technological advice, applied research, strategic consultancy, and engineering. KIS are fundamental as carriers and creators of both technological and organizational innovation by firms in other sectors (Garcia-Quevedo & Mas-Verdu, 2008).

While intra-company knowledge sources, own-generation, and bought-in R&D influence innovative performance, the benefits of joint innovation efforts in the form of cooperation are less clear. Large firms depend for their innovative output on direct and indirect R&D inputs, whereas small firms depend more on spillovers from research activities carried out by universities and by other firms. Research on Chinese large- and medium-size manufacturing enterprises indicates that inter-industry R&D spillovers and foreign technology transfers are significant sources of innovation and that in-house R&D and inter-industry R&D spillover are complements in shaping innovation performance (Bin, 2008).

Users

The sources of innovation differ between industries for mass production of commodities and those for complex products and systems. Highly customized, engineering-intensive goods often require several producers to work together simultaneously. Therefore, user involvement in innovation tends to be high and suppliers, regulators and professional bodies tend to work together with users to negotiate new product designs, methods of production and post-delivery innovations (von Hippel, 1986). In the instrument industry, innovations with high scientific content tend to be developed by instrument users, while innovations having high commercial importance tend to be developed by instrument manufacturers (Riggs & von Hippel, 1994; Eliasson, 1996).

The role that user firms have played in shaping the innovation dynamics of machine tools has been investigated for many decades. The empirical findings show that capital investments of user sectors have had a significant long-term impact on the innovation performance of the machine tool industry. There have been continuous user entries into machine tools from the beginnings of industrial development, prominently by car producers from the middle of the 1950s, and by electronics firms in the 1970s. User firms have participated vigorously in the innovation of machine tools (Lee, 1996).

Networks

There is strong evidence in the literature of the importance of networks in the innovative activities in many industries, particularly in small manufacturing firms. In low- and medium-technology sectors, much knowledge can be acquired by informal means. For example, it has been shown that in the construction industry, working with customers and suppliers and having a broad market orientation are sources of both product and process innovation (Salter & Gann, 2003; Reichstein *et al.*, 2008). The evolution of UK retail banking displays the characteristics of a distributed process of innovation in which developers of technologies, service suppliers and customers contribute to the process of structural change in the industry (Consoli, 2005).

Public science

Public science is among the most important sources of technical knowledge for innovative activities. The overall U.S. industrial base relied heavily on public science in the creation of new chemical, electrical and machinery industries in the early 20th century and continues to do so today (Carlsson *et al.*, 2009) . The biotechnology industry depends on public science much more heavily than other industries, especially for basic scientific research (McMillan *et al.*, 2000). More than 90 % of product and process innovations in German industrial firms in the mid-1990s relied on publicly funded research at universities, polytechnics and federal research laboratories (Beise & Stahl, 1999).

Universities

After the passage of the Bayh-Dole Act in the United States in 1980, a lot of research has examined the effects of technology transfer from universities in the form of business start-ups and technology licensing in addition to spillovers via university graduates and published research. The degree of success of technology transfer programs depends not only on the nature of the interface between the university and the business community but also on the receptivity in the surrounding community as well as the culture, organization, and incentives within the universities themselves. Firms who adopt 'open' search strategies and invest in R&D are more likely than other firms to draw from universities. The resources and capabilities of the firms partnering with universities, as well as institutional, financial, commercial and human capital are important for the outcomes of university spinoffs. Basic research flows are large within a few industries such as petrochemicals and drugs, and within software and communications; otherwise universities dominate in basic research.

4D Adoption/Diffusion

This is a relatively new area of research– Google Scholar lists only a handful of articles on this topic published before 1990 – and it encompasses many disciplines. Only a small fraction of the research in this domain is published in the journals reviewed here. The number of articles identified in this domain in the present review increased dramatically from the 1990s to the 2000s: from 37 to 133. More than 60 percent of the articles are case studies of diffusion of technology. Given the time period, it is not surprising that many articles focus on information and communication technology (ICT), representing both product innovations (e.g., integrated circuits, mobile telephony, and network technologies, as well as process innovations in manufacturing (such as advanced manufacturing technology, flexible automation, and numerically controlled machine tools, and process technology in the semiconductor and ferrous casting industries), and in retail trade (Electronic Data Interchange, E-commerce, and supermarkets in developing countries). Other studies have examined containerization in the shipping industry, the use of knowledge-intensive business services (KIBS) in various industries, oil and gas processing technologies, environmental practices, and organizational innovations. Several articles have examined product innovation related to the environment (energy-efficient lamps, renewable energy technology, and other green products).

An important segment of this literature deals with more general aspects of diffusion of innovation, highlighting the role of absorptive capacity, skilled worker mobility, user-supplier linkages, the role of local context such as supply chains, industry clusters, intra- versus inter-firm diffusion, and high-tech versus low-tech sectors. An almost universal observation is that small firms are slower to adopt new technology than large firms. Some studies have emphasized the connection between changes in the production process and simultaneous adoption of organizational changes. A few articles examine knowledge diffusion processes (the role of social proximity and informal contacts as well as formal technology transfer in the form of licensing or technology sharing contracts).

The dominant stylized fact of technology diffusion is that the usage of new technologies over time typically follows an S-curve. There are many ways to generate an S-curve; the most commonly used model is the so-called epidemic model. An alternative model is the probit model. There are about a dozen articles in the ID literature reviewed here dealing with modeling of diffusion, often building on Rogers' seminal work *Diffusion of Innovations*, first published in 1962. Rogers proposes that five main elements influence the spread of a new idea: the innovation itself, the adopters, the communication channels, time, and the social system. These elements recur in most of the articles.

4E Innovation systems/industry clusters

It is noteworthy that Cooperation/Alliances/Networking (Theme 3C) and Innovation systems/Industry Clusters (Theme 4E) constitute the two largest segments of the ID literature, jointly representing more than 700 articles or about one-quarter of the ID literature.

Industrial Districts/Industry Clusters

The literature on clustering of economic activity goes back to Alfred Marshall's *Principles of Economics* (1920), first published in 1890. Marshall distinguished between local or regional "agglomerations" and "industrial districts" – the latter resulting from the use of specialized labor, machinery, and subsidiary trades in a local agglomeration. With the addition of entrepreneurship ("industrial leadership") and innovation ("introduction of novelties") (Marshall, 1923), industrial districts can be transformed into what is now usually referred to as industry clusters. The term business or industry cluster was popularized by Michael Porter (1990 and 1998) and Paul Krugman (1991). Porter defined an industry cluster as a geographically proximate group of firms and associated institutions in related industries, linked by economic and social interdependencies. The key difference between Marshall's and Porter's concepts of industry clusters is the inclusion of institutions and non-economic linkages in the latter.

The literature on industrial districts reviewed here seems to have been inspired by the successful performance of traditional Italian industrial districts (especially in combination with the use of flexible specialization) and by a new type of industrial organization in the form of regional patterns of cooperation and linkages among small and medium-sized firms, as against the traditional model of scale-intensive industry. Distinctions were made between 'classical' networking between firms in close proximity to each other, in industrial districts, and the joint venturing between firms that complement each other's activities but may be separated in space. Other types of industrial districts were identified: hub-and-spoke industrial districts, revolving around one or more dominant, externally oriented firms; satellite platforms in the form of an assemblage of unconnected branch plants embedded in external organization links; and state-anchored districts, focused on one or more public-sector institutions. The importance of being connected, not just co-located, either locally or non-locally, was observed. Having a high absorptive capacity seemed to raise the innovative performance of firms only indirectly, through non-local relationships. The role of entrepreneurship and of a high rate of new firm formation was also noted.

In the 1990s, the literature on industry clusters was mostly descriptive. The main findings may be summarized as follows. Given that a significant portion of the modern world economy consists of a patchwork of dense industrial agglomerations - clusters of innovative industries - much of the analysis of such clusters is driven by the need to understand global long-term techno-industrial change. Innovative activities are concentrated in a few industrial sectors and in a few technological fields, especially biotechnology and information and communications technology, sectors that invest intensively in R&D and that are based on technological breakthroughs in the 1950s (the structure of DNA and the transistor). In biotechnology, the generation of new economic knowledge tended to result in a greater propensity for innovative activity to cluster during the early stages of the industry life cycle and to be more highly dispersed during later stages of the life cycle. The main agent of attraction to new firms to enter the biotechnology industry is the presence of a strong science base at that location. There is also positive attraction and feedback between a group of sectors within the biotech industry – therapeutics, diagnostics, and the equipment/research tools sectors. But in other sectors of the industry – chemicals, food and to some extent agriculture – there is much less attraction and interaction between firms. This implies that clusters of firms tend to develop only in particular sectors of the industry, and positive feedback mechanisms do not extend to other parts of the industry.

In the 2000s, the literature on industry clusters became more analytical, focusing more on dynamics and on knowledge flows. Many articles showed that co-location is not enough. Spatial concentration does not necessarily imply a close network of input-output relations. Locally embedded networks of small firms no longer represent an organizational structure as robust and stable as in the past. Globalization challenges require adjustments that transform the nature of the district away from the traditional stereotype towards a configuration characterized by the presence of leading firms and moderate hierarchy. The exchange of tacit knowledge, however, is facilitated by spatial proximity, but knowledge and technology transfer often happens on an international scale. Knowledge is not diffused evenly "in the air", but flows within a core group of firms characterized by advanced absorptive capacities.

Whereas location in a cluster densely populated by other innovative firms positively affects the likelihood of innovating, strong disadvantages may also arise from the presence of non-innovative firms in a firm's own industrial sector. Being located in a cluster *per se* can actually have a negative effect on firm R&D intensity. Innovation in industry clusters is influenced more by agglomeration externalities than by higher individual R&D effort, emphasizing the importance of technological spillovers as channels of knowledge accumulation and diffusion in these areas.

Knowledge flows within regions are characterized by face-to-face contacts. Inter-firm informal contacts are more numerous than university informal contacts, and knowledge is more frequently acquired from engineers in other firms than through university-industry contacts. In some sectors, such as the aircraft industry, knowledge exchanged through non-regional knowledge flows via formal channels is more valuable than knowledge flows within the region.

To generate a successful high-tech regional cluster, the existence of world class scientific talent (skilled engineers) is a necessary but not a sufficient condition. Ancillary or complementary factors must also be available to translate this knowledge into a commercialized product. The complementary factors include the presence of venture capital and other forms of finance, the existence of an entrepreneurial culture, and transparent and minimal regulations fostering the start-up and growth processes. Also, the economic factors that give rise to the start of a cluster can be very different from those that keep it going (Bresnahan *et al.*, 2001). Agglomeration economies, external effects and ‘social increasing returns’ of any sort arise almost naturally after a cluster has taken off. The most difficult and risky part is to get the new cluster started.

Innovation Systems[15]

The first paper using the term "system of innovation" was written by Chris Freeman in 1985 but not published until 2004 (Freeman, 2004). The first time the term appeared in publication was in Freeman's 1987 book (Freeman, 1987) in which he used the term "national system of innovation" in analyzing Japan's technological infrastructure, how it differed from that in other countries, and how the differences were reflected in Japan's international competitiveness. Freeman was criticizing international trade theory, showing that changes in international competitiveness cannot be explained by wage rates/prices/currency rates but that technological leadership can give absolute rather than comparative advantage and that technological leadership may change over time; technological leadership reflects institutions (innovation systems) supporting coupling, creating, clustering, comprehending and coping in connection with technology.

The innovation systems concept caught on quickly and has been used widely since the early 1990s. It was initially used at the national level but was soon used also at sub-national levels. In the late 1980s a group of Swedish researchers adopted a similar systems concept, that of *technological innovation system* (Carlsson & Stankiewicz, 1991; Carlsson, 1995 & 1997)[16]. In the mid-1990s the concept of *regional innovation system* was pioneered by Phil Cooke (Cooke 1996; Cooke *et al.*, 1997), and in the early 2000s Franco Malerba introduced the concept of *sectoral innovation system* (Malerba, 2002; Malerba, 2005).

The various concepts of innovation system are not mutually exclusive; national systems may consist of several regional, sectoral, and technological systems, and national and regional institutions may support several sectors, industries, and technologies. Systems may change over time as technological paradigms and trajectories shift. The appropriate level of analysis depends on the problem at hand. In principle, all innovation systems involve the creation, diffusion, and use of knowledge, and all involve three basic dimensions: a cognitive, an institutional/ organizational, and an economic one, but the emphasis varies. Analyses of national innovation systems tend to focus on national institutions supporting innovation (see e.g. Nelson 1992; Mowery, 1992), whereas regional innovation systems analyses focus on the concept of regions as a nexus of competencies and on the regional innovation infrastructure, particularly in the institutional and organizational dimensions (Cooke *et al.*, 1997). National and regional innovation systems are defined geographically, whereas technological and sectoral systems are defined by the knowledge base supporting a sector or set of technologies.

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[15] The literature on innovation systems has been reviewed previously – see Carlsson (2006) and Carlsson (2007).

What distinguishes technological innovation systems from geographically defined innovation systems is the emphasis on dynamics, on the importance of the knowledge base and knowledge flows, and on the role of individual actors, especially entrepreneurs. Dynamic systems consist of subsystems and components, relationships among these, and their characteristics or attributes.

> The central features of technological [innovation] systems are economic competence (the ability to develop and exploit new business opportunities), clustering of resources, and institutional infrastructure. A technological [innovation] system is a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology. Technological [innovation] systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. In the presence of an entrepreneur and sufficient critical mass, such networks can be transformed into development blocs, i.e. synergistic clusters of firms and technologies which give rise to new business opportunities (Carlsson & Stankiewicz, 1991).

In order to generate industrial dynamics (and economic growth), the innovation system (the supply side) needs to be linked to a market (demand side). This requires interaction at the micro level between a variety of actors who create and use technology on the one hand and demanding customers on the other. The innovation system captures the conditions that are conducive to creation of a variety of new technologies, whereas the conditions that are necessary and sufficient for the efficient selection and capturing of new technologies and products may be referred to as a competence bloc (Eliasson, 2000). The confrontation between actors and between actors and ideas in the markets for innovation gives rise to industrial dynamics (Carlsson & Eliasson, 2003).

Sectoral systems of innovation are similar to technological innovation systems but are broader in scope. They provide a multidimensional, integrated and dynamic view of sectors.

> A sectoral system is a set of products and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A sectoral system has a specific knowledge base, technologies, inputs and demand. Agents are individuals and organizations at various levels of aggregation. They interact through processes of communication, exchange, co-operation, competition and command, and these interactions are shaped by institutions. A sectoral system undergoes change and transformation through the co-evolution of its various elements. Sectoral systems are based on three building blocks: knowledge and technologies, actors and networks, and institutions (Malerba, 2002 & 2005).

Applications of innovation systems analysis

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[16] The technological system concept was originally applied at both the technology and the sector level (Carlsson, 1995).

Much of the work on innovation systems in the 1990s and 2000s was largely descriptive, but there are a few examples of the use of the concept as an analytical tool. One example is the analysis of economic growth. Freeman (2002) discusses the relevance of innovation systems (continental, national as well as sub-national) to explaining economic growth in Britain in the 18th century, the United States in the second half of the 19th century and the innovation systems of catching-up countries in the 20th century. Radosevic (1999) explores the patterns of transformation of socialist science and technology systems in central and Eastern Europe into post-socialist systems of innovation.

In spite of rapid globalization in recent decades and the sometimes disruptive changes that globalization imposes on the geography of innovation systems, there were not many studies of the degree of internationalization of innovation systems during the period reviewed here (see Carlsson, 2006). (However, this topic has drawn significant attention after 2010.) The few studies that exist show that national innovation systems are becoming internationalized, even if the institutions that support them remain country-specific. To the extent that the far more numerous studies of internationalization of corporate R&D discuss innovation systems at all, they point to the continued importance of national institutions to support innovative activity, even though that activity is itself becoming increasingly internationalized.

One of the main areas of application of innovation systems analysis is the renewable energy sector (Jacobsson & Bergek, 2004). There are also several papers dealing with the need in developing countries to blend various international and domestic sources of knowledge to compensate for initially weak national production and innovation systems. One vehicle is the spread of global production networks combining location of production by multinational companies in developing countries with systemic integration, creating new opportunities for international knowledge diffusion. Institutional reforms are often necessary to improve the effectiveness of third world innovation systems - strengthening the knowledge base, stimulating capacity building, opening space for local firms and creating incentives for innovation. Some articles focus on the need for institutional changes involving academic values and attitudes, governmental policies, university-industry relations and endogenous knowledge generation.

After the initial burst of studies on institutional infrastructure supporting innovation at the national level in various countries, more recently the analysis has shifted to the industry level. The concept of innovation systems has been applied to the analysis of the commercialization of science and technology in "new economy" sectors such as telecommunications, information technology and biotechnology. A study of the evolution of the Israeli software industry is a good example (Breznitz, 2007). Another example is an analysis of the global dynamics in biotechnology (Cooke, 2006). Focusing on Europe's leading bioeconomy, the UK, global network analysis is performed based on research into collaborations between 'star' scientists and their institutes in bioregions at a global scale. The hierarchical structure and main network axes in the global bioscientific research system are revealed, showing links to the strongest bioregions in North America, particularly around Boston, San Diego and San Francisco. Other examples are studies of the success of Taiwan and Singapore in the global electronics industry despite their pursuit of two distinct industry creation strategies, resulting in two quite different patterns of specialization (Weiss & Mathews, 1994; Poh, 1995).

Innovation systems analysis has also been applied at the firm level. Some studies have found firm-specific determinants of innovation to be more important than either region-specific or external factors, while other studies show the opposite: building external interactions is of greater importance than developing internal innovative competences. Also, unintended knowledge flows (spillovers) have less influence on regional innovative performance than deliberate ones (technology transfers). In some sectors, universities are particularly important external sources of knowledge.

Modeling

Given the complexities of innovation systems, it is not surprising that there are only a handful of examples of formal modeling in the literature reviewed here.[17] These include an enterprise-centered model of knowledge sources and knowledge flows in an innovation system using data from the European Community's Innovation Survey (Padmore *et al.*, 1998), a model of regional industrial clusters combining the dimensions of Porter's 'diamond' with infrastructure and market data for regions (Padmore & Gibson, 1998), a simulation model of the relationship between regional attributes and the generation and exploitation of technology (Janszen & Degenaars, 1998), a model of how incremental technological change led to discontinuities in system design in the semiconductor industry (Funk, 2008), a Schumpeterian model of innovation in health services involving interactions among service providers, patients, and policy makers (Windrum & Garcia-Goni, 2008), a model of the interdependence and interaction among flows of capital, human resources, knowledge, technology, products in the integrated circuits industry in Taiwan (Lee & von Tunzelmann, 2005), a stochastic frontier model of the increasing disparity in innovation performance between Chinese regions (Li, 2009), and a model of intersectoral and international technology inflows in the agricultural research system in Italy (Esposti, 2002). The variety of modeling approaches and topics illustrates the difficulty of the task (Eliasson *et al.*, 2004).

[17] Some important contributions, such as Eliasson (1985, 1987, and 1991), have not been published in the journals reviewed here.

4F Institutions

The term “The New Institutional Economics” was coined by Oliver Williamson (1975). The analysis in this new field is rooted in Coase (1937, 1960), with major contributions by North (1990). A major review article appeared in 2000 (Williamson, 2000). While much of the research lies within conventional economics, in Industrial Dynamics the dominant themes in this domain concern the institutions supporting innovation and entrepreneurship. Almost one-third of the articles deal with intellectual property rights (IPR) and another third with other infrastructure for entrepreneurship and innovation, including the policy and regulatory environment and university-industry interaction. 85 % of the ID articles on institutional economics appeared in the 2000s; almost all the articles concerning IPR were published in the 2000s.

IPR

The ID literature on IPR reflects the shift in the developed countries towards increasingly complex, innovative and interdependent economic activities, increasing the need for intellectual property protection; this is an example of the co-evolution of technology and institutions. Among the major institutional changes are the introduction of the Bayh-Dole Act in the United States in 1980 – designed to stimulate commercialization of the results of federally funded research - and the subsequent dramatic increase in patenting and licensing activity, the extension of patent protection to software and business models, and the strengthening of patent laws as a result of the Trade Related Intellectual Property Rights (TRIPS) agreement in 1994. The TRIPS agreement presented a significant institutional change for industry in developing countries and influenced the choices of ownership structure of transnational firms for their affiliates. The strengthening of IPRs affected the alliance networks and market structures in industries such as the global system for mobile communications and favored independent suppliers over vertical integration generally. In certain discrete technologies, patent "fences" were shown to exclude competitors whereas in complex technologies, "thickets" of patents represent exchange forums for complementary technology (Reitzig, 2004). Indeed, it was shown that the establishment of tougher criteria for patentability favors industries using a portfolio approach in their R&D, putting other industries and smaller firms at a disadvantage. It was also demonstrated that in complex technologies patents are often used as bargaining chips to prevent ‘lock-out’ from use of state-of-the-art components developed by competitors rather than as a stimulus to R&D. The increased effectiveness of intellectual property protection (with patents as the most frequently used mechanism) influenced the formation of research partnerships.

The usefulness and efficacy of the patent system has also been debated. While economic theory typically views patents as policy instruments aimed at fostering innovation and diffusion, patents may not be the most effective means of protection for inventors to recover R&D investments when imitation is costly and first mover advantages are important. The probability that a firm rates secrecy as more valuable than patents declines with increasing firm size for product innovations, while there is no such relationship for process innovations (Arundel, 2001). Some papers (e.g., Dosi *et al.*, 2006) have presented evidence that, broadly speaking, IPRs have at best no impact, or possibly even a negative impact, on the rates of innovation. Walsh *et al.* (2007) examined the impact of patents on access to the knowledge and material inputs that are used in subsequent biomedical research. They found that in biomedicine, access to knowledge inputs is largely unaffected by patents. On the other hand, accessing other researchers' materials and/or data such as cell lines, reagents, or unpublished information was found to be more problematic.

University Patenting

The last two decades of the 20th century witnessed a dramatic increase in patenting and licensing activity of universities, particularly in the United States but also elsewhere. This led many scholars to investigate the extent to which this increase should be attributed to the Bayh-Dole Act. Mowery *et al.* (2001) concluded that Bayh-Dole was only one of several important factors behind the rise of university patenting and licensing activity. Similar increases in academic patenting and licensing activity were reported for other countries also. During the 1980s, universities in several West European countries were charged with a “Third Task” of incorporating economic and social development as part of their mission, in addition to their original tasks of teaching and research. Emerging “entrepreneurial universities” began to integrate economic development as an additional function.

Technology transfer

Consistent with the rights and incentives provided by the Bayh-Dole Act, U.S. universities have increased their involvement in patenting and licensing activities by establishing their own technology transfer offices (TTOs). TTOs may be seen as institutional entrepreneurs involved in building legitimacy for novel technologies. Technology dissemination can be both informal - via publication of research results, sometimes in joint publications between academics and industry scientists and via industrial consulting – and formal via licensing and technology-based spin-out companies.

Success in technology transfer is only partially reflected in licensing income generated for the university or the number of business start-ups. There are both private and social returns, and the latter are hard to measure. Only a few U.S. universities are obtaining large private returns, while many others are continuing with technology transfer activities despite negligible or negative returns. The degree of success in research commercialization depends not only on the nature of the interface between the university and the business community but also on the receptivity in the surrounding community as well as the culture, organization, and incentives within the universities themselves. The number of spin-out companies created (with or without equity investment by the university) is positively associated with expenditure on intellectual property protection, the business development capabilities of technology transfer offices and the royalty regime of the university. The most critical organizational factors are faculty reward systems and TTO staffing/compensation practices. The more successful universities have clearer strategies towards the spinning out of companies and possess a greater expertise and better networks to foster spin-out companies (Lockett *et al.*, 2003; Lockett & Wright, 2005). A U.S. study (Siegel *et al.* 2003) suggests that TTO activity is characterized by constant returns to scale and that environmental and institutional factors explain some of the variation in performance.

While the number of university technology transfer offices has grown dramatically over the last few decades, there have also been many critical voices. The U.S. university invention ownership model, in which universities maintain de jure ownership of inventions, has been criticized as sub-optimal in terms of both economic efficiency and as a vehicle for advancing the social interest of rapidly commercializing technology and encouraging entrepreneurship. The U.S. model has also been compared and contrasted with those of other countries where the inventor rather than the employer (the university) owns the intellectual property rights. Technology transfer offices have been set up in many universities in Europe as well. One study (Siegel *et al.*, 2008) found that U.S. universities are more efficient than UK universities and that the production process is characterized by either decreasing or constant returns to scale. A study on patenting activity in Italian universities found that the main obstacles to university patenting activity are lack of support mechanisms (including insufficient reward for researchers, lack of a TTO, lack of funds to cover patenting costs), commercialization problems, too heavy teaching and administrative duties, and personal/cultural problems (related to the scarce knowledge of institutional-level patent regulations and to the "open science" mentality of the university).

Division of labor between academic and industrial research

The increase in university patenting and licensing led to a lot of research on the role of universities and academic research in the overall economic system. Rosenberg & Nelson (1994) found that

> most university research is basic research in the sense that it aims to understand phenomena at a relatively fundamental level. However, this does not mean that such research is uninfluenced by the pull of important technological problems and objectives. The majority of university research is in the engineering disciplines and applied sciences which, by their nature, are oriented toward problem-solving. Industry does very little of such basic research because the payoffs are of a long-run nature, and difficult to appropriate. The vast bulk of industry R&D is focused directly on shorter term problem-solving, design and development. Universities are not particularly good at this sort of work. Industry is more effective in dealing with problems that are located close to the market place.

Another study (Perkmann & Walsh, 2009) of university–industry collaboration in engineering found that basic projects are more likely to yield academically valuable knowledge than applied projects. However, applied projects show higher degrees of partner interdependence and therefore enable exploratory learning by academics, leading to new ideas and projects.

Comparisons have also been made between the research systems in various countries. For example, it has been shown that consortia in Japan and the U.S. have made very different choices about how they conduct research. Almost 9 out of 10 Japanese consortia conduct research in member firms, compared with a little over 4 out of 10 U.S. consortia. Japanese consortia focus on a narrower range of R&D activities than do U.S. consortia, with Japanese consortia completely avoiding university-based R&D. Japanese consortia depend heavily on government funds for their support, whereas U.S. consortia depend mostly on member dues (Aldrich & Sasaki, 1995).

A German study analyzed the co-operative relationships that public research institutions in Germany have developed with manufacturing firms and with each other. It was found that collaboration with firms is highly concentrated on regional partners. Research institutions contribute significantly to innovation processes in the respective regions by absorbing knowledge from beyond the region and making it available to local companies (Fritsch & Schwirten 1999). Another study found that American structures support long-term and open-ended co-operation, whereas in Germany, the dominant form of contract research primarily supports short-term problem solving with pre-defined results (Schmoch 1999).

The increase in commercialization of academic research gave rise to questions about the impact on academic research, particularly the impact of Bayh-Dole on the quality of university patents. An early study (Henderson *et al.*, 1998) found that the quality of academic patents declined dramatically after Bayh-Dole, but Sampat *et al.* (2003) found the result of the earlier study to be attributable to changes in the inter-temporal distribution of citations to university patents, rather than a significant change in the total number of citations these patents eventually receive.

The volume of patenting by universities as well as faculty members has been found to vary widely. Stephan *et al.* (2007) found work context and field to be important predictors of the number of patent applications. They also found patents to be positively and significantly related to the number of publications. Several other studies also reported that publishing and patenting are positively related whereas academic status and patenting are not.

The growing share of university research funded by industry has sparked concerns that academics will sacrifice traditional scholarly activities to pursue commercial goals. One study found that researchers who maintain a relationship with the sponsor experience a decrease in publications implying that academics' careers may be a function of the type of funding received, not only talent; that academic merit does not necessarily serve as a funding criterion for sponsors; and that citation and publication measures of academic output are often not useful proxies for short-term commercial or social value (Goldfarb, 2008).

Furman & MacGarvie (2009) found a pattern in which firms in the pharmaceutical industry with lesser R&D capabilities were generally constrained to work with local partners, while firms with greater internal R&D capabilities primarily engaged local partners for smaller-scale projects requiring generalist skills and distant partners for larger-scale efforts and extraordinary projects. The findings suggest that pharmaceutical firms that collaborated with universities achieved higher rates of patenting and laboratory growth.

A UK study (D'Este & Patel, 2007) examined the different channels through which academic researchers interact with industry and the factors that influence the researchers' engagement in a variety of interactions. The results show that university researchers interact with industry using a wide variety of channels, and engage more frequently in consultancy and contract research, joint research, or training than in patenting or spin-out activities.

Entrepreneurial environment

An important part of the institutional arrangements supporting industrial dynamics is the entrepreneurial environment which has been described and analyzed in numerous studies. The entrepreneurial environment is made up of many elements that constitute an important sub-system within the economic system. Five major components have been identified in the literature:

1) The science base and mechanisms of technology generation and dissemination (via technology transfer as well as spillovers). The volume, nature, organization, and funding of research are important elements.

2) The bridging mechanisms between the science base and business creation in new and existing firms. These may be either formal institutions (often public-private partnerships) such as business incubators or other business support services that facilitate startups and business network formation, or informal in the form of the density of networks of companies in related industries. The structure of buyer-supplier ties may play a role.

3) The entrepreneurial culture. Supportive social capital and entrepreneurial support services, as well as actively engaged research universities, are conditions that reflect the successful establishment of an entrepreneurial culture. A culture that includes strong links between academics and business, for example by facilitating academics to found start-ups while retaining their academic posts and status as well as being involved in a commercial enterprise, may promote entrepreneurship.

4) Infrastructure. Important elements are the availability of finance, access to venture capital, and a well-functioning labor market, especially for technical skills and entrepreneurial management skills.

5) The legal and policy environment and other infrastructure. Especially important is whether or not the system promotes commercialization of technology via incentives or fiat. Top-down policies aimed at commercializing innovations while at the same time discouraging academics from actively participating in the commercialization of their ideas are counterproductive. Institutionalized incentives for ingenuity are important. Examples are taxation of entrepreneurial income, incentives for wealth accumulation, wage-setting institutions, and labor market regulations. The legal and policy environment may not allow for entrepreneurial activity in certain sectors such as the health care and welfare sectors and household-related services.

Perhaps most important of all is the consistency and complementarity between all these components to work as a system.

Infrastructure for innovation

Most of the ID articles dealing with the institutional infrastructure for innovation are classified under "innovation systems." A few articles have analyzed the historical evolution of the institutional structure of R&D in the United States. Carlsson *et al.* (2009) explore the relationship between knowledge creation, entrepreneurship, and economic growth in the United States over the last 150 years. The changes over time in the locus and content of new knowledge creation are examined: the role of universities, particularly engineering schools and land-grant universities, industrial laboratories, and corporate research and development (R&D) laboratories prior to World War II. The practical orientation of U.S.

academic R&D and the close research interaction between academia and industry are noted. The unprecedented increase in R&D spending in the United States during and after World War II and how it was converted into economic activity via incumbent firms in the early postwar period and increasingly via new ventures in the last few decades is discussed. Mowery (2009) looks at the changes that have taken place during the postwar period, emphasizing the continuity between the industrial research "system" in the late 19th and early 20th centuries, containing many of the elements of the "open innovation" approach to R&D management 100 years later.

Similar studies have been made of the evolution of the Japanese infrastructure for innovation. Fukasaku (1992) notes that since World War II, technological capabilities were accumulated through in-house research and development, which in turn played a significant role in facilitating assimilation of imported technology and catching up with Western technology. An examination of prewar government policy toward research and in-house research shows that there existed a well-defined policy of placing priority on industry-related research since the beginning of the 20th century. As in the postwar period, research activities were geared toward adapting and improving imported technology. The institutional arrangements of Japan's system of catching-up included industrial policy, the keiretsu industrial groups, a centralized bank-centered financial system, lack of enforcement of the antimonopoly law, a weak intellectual property regime, and education and employment systems that emphasize conformity, loyalty, and stability. While these features may have been a key to success in catching up, they are also found to be the source of Japan’s current weakness in new industries such as software (Anchordoguy, 2000).

Cohen *et al.* (2002), comparing the R&D labs in the manufacturing sectors in the U.S. and Japan, have shown that intra-industry R&D knowledge flows and spillovers are greater in Japan than in the U.S. but that the appropriability of rents due to innovation is less. Patents in particular are observed to play a more central role in diffusing information across rivals in Japan, and appear to be a key reason for greater intra-industry R&D spillovers there.

A comparison between the infrastructure for innovation in the United States and the European Union shows that the higher mobility of capital, population and knowledge in the U.S. not only promotes the agglomeration of research activity in specific areas of the country but also enables a variety of territorial mechanisms to fully exploit local innovative activities and (informational) synergies. In the European Union, in contrast, imperfect market integration and institutional and cultural barriers across the continent prevent innovative agents from maximizing the benefits from external economies and localized interactions (Crescenzi *et al.*, 2007).

Public technology infrastructure refers to public resources that bring new R&D into existence. Examples are public research that yields knowledge spillovers and government contracts that broker new research. Cassi *et al.* (2008) study the role of research network infrastructure in fostering the dissemination of innovation-related knowledge. They examine the structure of collaborative networks and of knowledge transfer between research, innovation and deployment activities in the field of information and communication technology. Research collaboration is a key mechanism for linking distributed knowledge and competencies into novel ideas and research venues. The need for effective inter-institutional knowledge flows is particularly important in emerging domains of research.

Financial infrastructure

While financial institutions play an important role in many studies in the ID literature, there are relatively few articles that deal explicitly with financial infrastructure. In large measure this reflects the (unfortunate) separation between financial economics and other sub-disciplines within economics. As a result, the most significant research on financial institutions does not appear in the literature reviewed here. The articles classified under 4F (Institutions) dealing with financial infrastructure (all of which appeared in the 2000s) focus primarily on developmental financial institutions in emerging markets and on the changing structure of the financial services industry in conjunction with the global financial crisis in 2007-2008.

4G Indicators

In the 1990s, most of the articles under the 4G heading dealt with the problem of measuring the results of the innovation process and finding appropriate indicators. The traditional measures of R&D intensity and patent counts were widely recognized as inadequate, reflecting only the input side of the innovation process. Several approaches were proposed: counting innovations that are mentioned in the 'product news' columns of trade journals (Kleinknecht & Reijnen, 1993; and Santarelli & Piergiovanni, 1996); calculating the number of years a patent is renewed and the number of countries in which protection for the same invention is sought (Lanjouw *et al.*, 1998); detailed analysis of knowledge formation and technical development (Laestadius, 1998); composite measures using R&D, patent and educational data (Jacobsson *et al.*, 1996) or factor analysis depicting the technical (input side) and the market dimension (output side) for both product and process innovations (Hollenstein, 1996); and using multiple indices to represent both technological dynamics and structural change, including intrinsic and environmental qualities of a process; rate of renewal, relevance of R & D; product quality and degree of diversification; and several others (Barbiroli, 1995).

While in the 1990s the focus was on innovation at the firm or industry level, in the 2000s attention shifted to the innovation systems, regional, and national levels. Several new measures of national technological capabilities were developed by international organizations such as The World Economic Forum (WEF), the UN Development Program (UNDP), the UN Industrial Development Organization (UNIDO), and the RAND Corporation. Other attempts involved combining performance indicators such as national wealth (GDP per capita), R&D intensity (GERD/GDP) and scientific impact (citations/paper) to compare innovation systems (Katz, 2006). Also, attempts were made to measure the knowledge base of economies, combining the perspective of regional economics on the interrelationships among technology, organization, and territory with the triple-helix model (Leydesdorff *et al.*, 2006).

Still, the main interest of researchers remained on patents. Roughly half of the articles dealing with indicators of innovation (nearly all in the 2000s) focused on patents, albeit not in the form of simple patent counts. The relative ease of access to patent data is probably the main explanation. The primary focus was on analyzing patterns in the data. Among the topics covered were the changing composition of innovative activity in the U.S. (Hicks *et al.*, 2001), the surge in the 1990s in U.S. patenting activity (due to changes in R&D expenditures, patent yields, and the high tech sector) (Kim & Marschke, 2004), and in Europe (van Zeebroeck *et al.*, 2009); and the flows of knowledge across time and across institutions in the field of energy research using patent citations (Popp, 2006). Other studies focused on patents as indicators for the technology life cycle (Haumpt *et al.*, 2007); and using indicators of patent quality to analyze regional innovation (Ejermo, 2009). An issue with the use of patents as an indicator is that a large and perhaps growing share of new technology creation is not patented.

There was also significant interest in the role and nature of academic patenting. Mowery & Ziedonis (2002) analyzed the effects of the Bayh–Dole act on the content of academic research and patenting at Stanford and the University of California and found that they were modest. The most significant change in the content of research at these universities was the rise of biomedical research and inventive activity, but Bayh–Dole had little to do with this growth. However, the analysis of U.S. university patenting more generally suggested that the patents issued to institutions that entered into patenting and licensing after the Bayh–Dole act were indeed less important and less general than the patents issued before and after 1980 to U.S. universities with longer experience in patenting.

Several authors examined whether the observed increase in entrepreneurial activity within academia had reduced the number of publications added to the scientific commons or that academic research would be directed exclusively towards the application-oriented needs of industry. Van Looy *et al.* (2006) found that inventors publish significantly more than non-inventors, suggesting that patenting and publishing actually reinforce each other. Breschi *et al.* (2007), using European data, also found a strong and positive relationship between patenting and publishing, even in basic science. The results suggested, however, that it is not patenting *per se* that boosts scientific productivity, but the advantage derived from solid links with industry. Fabrizio & Di Minin (2008) also reported that publication and patenting are complementary, not substitute, activities for faculty members. They also found, however, that average citations to publications appear to decline for repeat patentees, suggesting either a decrease in quality or restrictions on use associated with patent protection.

5 ROLE OF PUBLIC POLICY

5A Role of Public Policy: General/Theoretical

Given that Industrial Dynamics is new and evolving as a theoretical framework, it is not surprising that analysis of the implications for public policy is only emerging. Of the 122 articles classified under 5A (General/Theoretical), 100 were published in the 2000s, and most of these focus on innovation or innovation systems.

There are essentially two different views concerning what is the appropriate domain for innovation policy resulting from different interpretations of what “innovation” means. The traditional view is that innovation is basically the result of investment in research and development (R&D), whereas the alternative (evolutionary) view places innovation in a broader socioeconomic, systemic context.

In conventional (orthodox) economic theory, innovation is viewed as a growth-enhancing factor in the aggregate production function. This is the view in endogenous growth theory as formulated by Romer (1986, 1990) and others. Innovation is driven by new knowledge that is created by investment in research and development (R&D). Given market failure resulting from insufficient incentives to engage in R&D (only a portion of the results can be appropriated, and some of the results “spill over” to other users), the primary role of public policy is to stimulate research and development activities via science and technology policy.

In the late 1980s a new view of innovation and innovation policy emerged, based on the concept of innovation systems. This is the prevailing view in Industrial Dynamics. The innovation process is seen as non-linear and having a systemic character. In this view, innovation policy is much broader than science and technology policy; innovation is deeply embedded in the competitive processes of the economy and interacts with many other areas of policy. It matters where and how new knowledge is created and how (by which mechanisms) new knowledge is converted into innovation and economic growth. Investment in R&D does not automatically result in economic growth. Innovation is the result of interactions among many actors and institutions, not simply of R&D activities, and the outcomes are highly uncertain. In addition to market failures (due to externalities, absence of markets, etc.), there are also nonmarket (system) failures, such as lack of absorptive capacity, institutional failures (e.g. due to poorly designed financial regulation and intellectual property laws), and network failures. Such failures justify policy intervention not only through the funding of basic science but more widely to ensure that the innovation system as a whole performs well.

The analysis of the role of public policy in Industrial Dynamics reflects this transition from a neoclassical to an evolutionary view of innovation and increasing recognition of the complexity and systemic nature of innovation.

Unfortunately, due to the fact that much of the early analysis of innovation systems was largely descriptive (i.e., static) and focused on the national level, the policy discussion was focused on national institutions and not on the behavior and activities of multiple and heterogeneous individual actors (firms and organizations) whose interaction characterize the innovation process. As a result, rather than taking a systems view, the policy discussion focused on institutions and macroeconomic outcomes of linear processes much like science and technology policy targets R&D spending.

Lipsey (2002) captures the differences in understanding of innovation that gives rise to different approaches to innovation policy. He compares and contrasts the general types of policy advice that follow from three different approaches to understanding economic growth and technological change.

> Neoclassical theory gives policy advice that is assumed to be relevant for all countries at all times: remove sources of "market failures". Romer's branch of new macro growth theory stresses the nature of knowledge, non-rivalrous and partly appropriable. Structuralist-evolutionary theory is micro based and stresses the uncertainty that is associated with technological advance. Both of the latter approaches conclude that the neoclassical optimal allocation of resources is unachievable and hence the policy advice of removing impediments to achieving that optimum is not well grounded. As a result, policy advice for enhancing technological change must rely on a mixture of theory, empirical analysis and policy judgment.

Ekboir (2003) also moved toward a systems view of innovation, recognizing that the increasing complexity of technology development and adoption was changing the effectiveness of conventional scientific and technological policies and that complex technologies are developed and disseminated by networks of agents. The impact of such networks depends on the assets they command, their learning routines, the socio-economic environment in which they operate, and their history. Similarly, Rycroft & Kash (1994) emphasized the role of community in the continuous innovation of complex technologies.

Justman & Teubal (1995) propose a technological infrastructure policy (TIP) to create capabilities and build markets, and Teubal (1997) presents an evolutionary framework for horizontal[18] technology policies. Kim (1999) draws on South Korea's experience and presents an analytical framework for building technological capability for industrialization. Cantner & Pyka (2001) classify technology policy in an evolutionary framework using the taxonomy of mission- and diffusion-oriented policy design. Chang & Cheema (2002) and Ahrens (2002) examine the conditions for successful technology policy and governance and the implementation of technology policy in developing countries.

In the 2000s the policy discussion in the ID literature moved from technology to innovation. It was increasingly recognized that what is needed is an evolutionary *cum* systemic approach to innovation policy. The purpose of innovation policy is not to promote individual innovation events or outcomes but rather to set the framework conditions in which innovation systems (once they emerge) can better self-organize across the range of activities in an economy. The focus is on dynamics of change and their drivers. The "generic" issues for public policy in a systemic *cum* evolutionary approach are 1) increasing the absorptive capacity in the economy (or system) as a whole; 2) increasing connectivity within as well as among systems; and 3) creating variety (Carlsson & Jacobsson, 1997).

Mytelka & Smith (2002) argue that there needs to be a close connection between theory and policy, so that theory and policy learning can be seen as an integrated, co-evolving and interactive process. The learning process involves several dimensions: evolution of theory, improved understanding of policy implications, identification of policy targets, choice of policy instruments, and implementation, with feedbacks throughout the process. A new approach in German innovation policy that organizes contests of proposals for developing innovation networks is an example of the iterative nature of the learning process. Public procurement may be a useful tool in the learning process, illustrating the experimental nature of interaction between buyer and seller of new technology.

[18] I.e., not industry- or product-oriented.

Avnimelech & Teubal (2008a and 2008b) develop a generic three-phase innovation and technology policy ("Evolutionary Targeting") model that differs from traditional 'picking winners" policies. The model focuses on triggering (via direct government support of R&D), reinforcing (supporting emerging industries/structures), and sustaining (by providing access to venture capital) market-led evolutionary processes.

Based on in-depth studies of several innovation systems, Bergek *et al.* (2008) present a generic framework for public policy that addresses the main functions of innovation systems: knowledge development and diffusion, influencing the direction of search, legitimation, entrepreneurial experimentation, market formation, resource mobilization, and development of positive externalities. The authors also suggest how the functional approach can be operationalized.

Entrepreneurship and innovation, particularly in the area of high technology, are issues that are increasingly being related to clusters and networks. These are made up of many component organizations, private, public, non-profit, and others that are interrelated in complex ways. Understanding the role of public policy in this setting requires viewing the system as a whole rather than the component parts individually. One of the primary challenges for policymakers is to create a favorable climate for private entrepreneurship, often related to the formation of clusters/systems. However, cluster formation cannot be directed, only facilitated; markets are essential. Planning cannot replace the imaginative spark that creates innovation. Still, once clusters have been formed, a comprehensive set of facilitating policies, from information provision and networking to tax codes and labor laws, can be helpful. These policies must recognize both the requirements of cluster/system development and the life cycles of individual firms.

5B Case studies

As shown earlier, it is only in the last few years that the innovation systems literature has begun to move from description to analysis. As a result, many policy analyses are mostly ad hoc, not theory-driven. Most of the case studies reviewed here deal with science & technology or R&D support policies and their outcomes in various countries and sectors. However, about one-third of the 119 studies view innovation as a complex, uncertain, and non-linear process and focus on policies oriented to building innovation systems, frameworks, or components thereof: infrastructure (such as venture capital industry), the nature and composition of networks or other links between various actors, and acquisition of capabilities.

CONTRIBUTION OF INDUSTRIAL DYNAMICS: Accomplishments and Future Challenges

Having summarized the main findings in Industrial Dynamics in the previous sections, it is time to reflect on what has been accomplished and what lies ahead. The main challenge in Industrial Dynamics is to shift the analysis of industrial transformation and economic growth from a static to a dynamic frame of reference. The main contribution of Industrial Dynamics is the understanding of the economy as a complex and dynamic system consisting of many diverse and autonomous but interrelated and interdependent parts, capable of generating transformation and growth from within. The system is multidimensional and multilevel; it cannot be reduced to a few equations. There is a micro to macro perspective throughout; the industrial transformation process takes place in a larger context that influences, and is influenced by, the elements within the system. It is the evolutionary process and its driving forces that are in focus, not just the outcomes. The primary driving forces are technological and institutional change. Economic growth is the result of co-evolution of technology, industrial structure, and supporting institutions coordinated by markets.

Industrial Dynamics has similar roots to Industrial Organization, but its analysis is dynamic, not static, and it is broader in scope. There are important links to other fields in economics - especially entrepreneurship, economic history, economic geography, and institutional economics - as well as management fields such as organization theory, strategy, finance, and business history.

As this survey of the literature has shown, significant progress has been made since the term Industrial Dynamics was first used in 1985, but much remains to be done. Perhaps the greatest remaining challenge is to bring the whole field together in a coherent theoretical framework. This is an extremely difficult task, but I hope that the present survey provides a good starting point, some useful insights, and some suitable building blocks for further development.

1. Causes of Industrial Development and Economic Growth

The first part of the survey deals with the causes of industrial development and economic growth, subdivided into several sub-themes. *1A, Dynamics and evolution of industries*, involves in-depth analysis of industrial transformation and its driving forces at the micro, meso (industry) as well as macro levels linked to economic growth at the macro level. The long-term evolution of various industries is examined, including the role of technology, institutions, and infrastructure, as well as the emergence and diffusion of general-purpose technologies, such as digitization of information technology, that cut across and re-shape industry boundaries. The analysis is more about new activities and products than about higher productivity in any given industry, and more about linkages among technologies and firms than about market structure. Empirical regularities in the structures of industries and firms and in the patterns of change are identified and analyzed. The literature reviewed here is geared towards theory building, not testing, representing positive rather than normative economics. There is little discussion of public policy and few policy recommendations. Instead, public policies tend to be viewed as part of the institutional infrastructure.

The research on this theme is not only broader and deeper than in Industrial Organization; it addresses more dynamic questions and builds links to understanding economic growth at the aggregate level. But ID analysis has only begun to integrate micro and macro analysis.[19] Such integration is one of the greatest challenges for future research.

Theme *1B*, *Entry, exit and entrepreneurship*, introduces entrepreneurship into the analysis of industrial development and economic growth. The concept of entrepreneurship was late entering into economic analysis (it has no place in equilibrium theory) and was initially treated in the IO literature under the heading of “entry and exit.” In the late 1990s entrepreneurial activity was beginning to be viewed in the ID literature as a mechanism for industrial transformation and growth, not just as an interesting phenomenon per se. This is an important step forward, but the causal links between entrepreneurship and economic growth have only begun to be explored. Much remains to be done here; this is a major challenge for future research.

Economic activity takes place in an institutional and geographic context; place and space matter in industrial transformation and growth. That is the focus of research under theme *1C, Institutional and regional issues*. There is recognition of the importance of clustering of economic activity, particularly in knowledge-intensive sectors. Both formal and informal institutions and their role are examined. Much of the research in this area has been conducted by economic geographers. Further integration of institutional economics and economic geography into Industrial Dynamics looks promising.

Moving from static to dynamic analysis is an enormous challenge. Modeling the economic system as a dynamic (evolving) and complex system that is never in equilibrium is extremely difficult. That is the focus of research in theme *1D Modeling of industrial development and economic growth.* Heterogeneity of micro units (firms and technologies) and their interactions (including learning and experimenting) result in new combinations. Complex systems cannot be reduced to simple rules and a single level of analysis. The results of the interaction of many heterogeneous moving parts cannot be predicted.

[19] Even though work on the Swedish micro-to-macro model was begun in1974.

In spite of the difficulties, some progress has been made in the form of history-friendly modeling and some formal modeling of various aspects (such as technological regimes, firm entry, inter- and intra-technology competition). However, there are only a handful of comprehensive models, the main example being the Swedish micro-to-macro model.

2. Economic Activity in the Firm

For Industrial Dynamic analysis to be truly multi-level, economic activity in the firm needs to be considered. Bringing firm strategy into the analysis of industrial transformation and economic growth is an important contribution (theme *2A, Strategy)* in that it recognizes the importance of heterogeneity of firms. The ID literature in this domain deals primarily with strategy concerning knowledge creation and management. Given the importance of technological change in industrial transformation and growth, this is a significant contribution. There is also room for taking business strategy more generally into consideration.

Bringing a historical perspective on business organization and finance and integrating it into to the analysis of industrial transformation and economic growth is another important contribution of Industrial Dynamics. This literature is reviewed under the heading *2B, Business Organization and Finance*. The relationships among business organization (including outsourcing and networking), finance, and innovation are important building blocks. The meaning and role of path dependence are explored. Integrating financing of innovation, particularly that of innovative small firms, into the analysis is an important step forward.

The review of the literature under theme *2C, Firm capabilities and resources* shows a move from a static resource-based view of the firm to dynamic capabilities and economic competence. This represents a major step forward in tying firm capabilities into dynamic analysis, opening possibilities to examine how firms create competitive advantage and how this leads to innovation, industrial transformation, and economic growth. The role of technological diversification and of management of capabilities across organizational boundaries in an increasingly complex and uncertain world seems to be a particularly promising topic.

Firm performance in the ID literature (*2D Firm performance*) refers primarily to long-term innovative performance, not to profitability and survival as in the IO literature. The role of various combinations of in-house R&D, outsourcing, networking, and mergers & acquisitions is considered, along with the importance of absorptive capacity. The differences between radical and incremental innovation, and who the firms are that generate them, are also examined.

3. Firm Boundaries and Interdependence

In a rapidly changing, complex, and uncertain world, the changing configurations of firms and their interactions with one another are a fundamental part of the industrial development process. This is the central focus in theme *3A, Firm boundaries.* Outsourcing, vertical integration, diversification, and refocusing involve reconfigurations of firm boundaries and are important elements of industrial transformation. More systematic analysis in this area is likely to yield further insight.

The literature is often unclear about the distinction between market-transacted (targeted and paid-for) technology transfers and non-market (untargeted and uncompensated) “true spillovers.” As a result, the spillover literature (surveyed in theme *3B, Spillovers*) is less clear than it should be about the results of knowledge dissemination and the benefits of formal and informal cooperation. This is true especially with respect to interaction between academics and business firms and in agglomerations such as industry clusters and innovation systems. Given the role of knowledge creation and dissemination in industrial transformation, there is a great need to clarify and deepen the analysis of the mechanisms involved.

The literature on cooperation/alliances/networking that emerged in the 1990s and multiplied in the 2000s (theme *3C, Cooperation/alliances/networking*) represents a shift of focus from market structure and performance at the industry level in IO to processes of interaction among firms that create new knowledge and blur firm boundaries. This represents recognition of the need for new forms of interaction among firms in dealing with complexity and uncertainty inherent in a dynamic rather than static world. This model differs markedly from the previously dominant model of innovation which envisaged the innovation process as a linear sequence, with R&D conducted as a proprietary activity within a single firm. This is another promising area for future research.

In the 1990s it became evident that there are significant shifts over time in all the advanced countries in the relative competitiveness of firms of different sizes and that this has implications not only for the size distribution of firms but also, and more importantly, for the industrial transformation process. This is the area of research in theme *3D, Dynamics related to firm size*. Further analysis of the role of technology and institutional change in long-term shifts of this nature and their impact on industrial transformation and economic growth would be welcome.

4. Technological Change and Its Institutions

One of the most important contributions of ID is to bring technological change and its component mechanisms and supporting institutions to the analysis of industrial transformation and economic growth as a fundamental driving force, not as a theoretical complication. Almost half of the ID literature focuses on technological change, and indeed most published analyses of technological change are contained within this literature. A major topic is the analysis of innovation: the complex, iterative, uncertain, experimental, path-dependent and cumulative nature of the innovation process; the cooperative and competitive behaviors of firms during the process of creative destruction; and the essential role of entrepreneurial activity.

In theme *4B, Patterns/regimes*, research concerns the links between the microeconomics of innovation and the aggregate outcomes in the form of patterns of industrial change, and regularities in the evolution of industrial structures over time. Technological regimes, technological trajectories, path dependence, and technological discontinuities are key concepts whose essential elements have been analyzed and used to improve our understanding of industrial transformation and economic growth.

Two things stand out in the ID literature on sources of innovation (Theme *4C, Sources of innovation)*: the great diversity of sources of innovation and the importance of absorptive capacity. Innovation is viewed as a process with uncertain and unpredictable outcomes with multiple inputs from a variety of sources, not as a predictable result of a single input (R&D). Besides R&D (both within firms and in cooperation with others), users, networks, public science, and universities are important sources.

Research on adoption and diffusion of technology (theme *4D, Adoption/diffusion*) is of fairly recent origin, with only a handful of articles published before 1990. Most of the articles are case studies, often focused on information and communication technology. An important general finding is that absorptive capacity plays an essential role, and that skilled worker mobility, user-supplier linkages, and industry clusters are important vehicles.

The analysis of *innovation systems/industry clusters (4E)* and of *cooperation/alliances/ networking (3C)* constitute the two largest segments of the ID literature, jointly representing more than 700 articles or about one-quarter of the ID literature. While the literature on clustering of economic activity goes back to Marshall (1890), the field grew rapidly in the 1990s and 2000s following Porter (1990 and 1998) – "Industry clusters" – and Freeman (1987) – "innovation systems," respectively. In the 1990s, the literature on industry clusters was mostly descriptive but became more analytical in the 2000s, focusing more on dynamics and on knowledge flows. The innovation systems concept was first applied at the national level but soon was used at regional, sectoral, and technology levels.

National innovation systems tend to focus on national institutions supporting innovation while regional innovation systems focus on regions as a nexus of competencies and on the institutional and organizational dimensions at the regional level. What distinguishes sectoral and technological innovation systems from geographically defined ones is the emphasis on dynamics, on the importance of the knowledge base and knowledge flows, and on the role of individual actors, especially entrepreneurs. These elements are essential for innovation systems to be useful as tools for dynamic analysis. Dynamic systems consist of subsystems and components, relationships among these, and their characteristics or attributes. In order to generate industrial dynamics (and economic growth), the innovation system (the supply side) needs to be linked to a market (demand side). This requires interaction at the micro level between a variety of actors who create and use technology on the one hand and demanding customers on the other.

Much of the work on innovation systems in the 1990s and 2000s was largely descriptive, but there are a few examples of the use of the concept as an analytical tool. After the initial burst of studies on institutional infrastructure supporting innovation at the national level, more recently the analysis has shifted to the industry level, esp. "new economy" sectors such as telecommunications, information technology and biotechnology.

However, if the concept of innovation systems is to live up to its potential as a useful tool for the analysis of industrial development and economic growth, much more needs to be done. There needs to be much deeper analysis of the dynamic properties of complex systems, particularly knowledge creation and knowledge flows and the interaction among actors and other components. An issue that arises when the system is not defined geographically is how to determine the relevant population, i.e., delineate the system and identify the actors and/or components. What are the key relationships that need to be captured so that the important interaction takes place within the system rather than outside? Another (but seldom discussed) issue is how to measure the performance of the system. What is to be measured, and how can performance be measured at the system level rather than at component level? There is plenty of room for further research in this domain.

In *4F, Institutions*, the dominant themes concern the institutions supporting innovation and entrepreneurship (not institutions in a general sense). Almost one-third of the articles in this domain deal with intellectual property rights (IPR) and another third with other infrastructure for entrepreneurship and innovation.

The ID literature on IPR reflects the shift towards increasingly complex, innovative and interdependent economic activities, increasing the need for intellectual property protection. The Bayh-Dole Act, instituted in the United States in 1980 and designed to stimulate commercialization of the results of federally funded research, has attracted a lot of research attention as an important institutional change.

The dramatic increase in university patenting and licensing after 1980, both in the U.S. and elsewhere, has been analyzed, particularly the role of university technology transfer offices in technology dissemination. The division of labor between academic and industrial research, both over time and between countries, has been examined. The entrepreneurial environment has been identified as a particularly important institutional feature in the infrastructure for innovation.

The main contribution here is the incorporation of institutional features in the analysis of innovation. Much still remains to be done to integrate institutions into the analysis of industrial change and economic growth.

In the 1990s, most of the articles on indicators (theme *4G*) of innovation dealt with the problem of measuring the results of the innovation process and finding appropriate indicators at the firm and industry levels. The traditional measures of R&D intensity and patent counts were widely recognized as inadequate, reflecting only the input side of the innovation process. Several new approaches were proposed, such as counting innovations instead of patents; using composite measures of R&D, patent and educational data; and using multiple indices to represent both technological dynamics and structural change.

In the 2000s attention shifted from individual technologies to the innovation systems and to the regional and national levels. Several new measures of national technological capabilities were developed by international organizations. Attempts were also made to measure the knowledge base of economies.

Still, the main interest of researchers remained on patents. Roughly half of the articles dealing with indicators of innovation (nearly all in the 2000s) focused on patents, albeit not in the form of simple patent counts. The primary focus was on analyzing patterns in the data: the changing composition of innovative activity, particularly in the U.S.; the surge in the 1990s in U.S. patenting activity; the flows of knowledge across time and across institutions using patent citations; patents as indicators for the technology life cycle; and using indicators of patent quality to analyze regional innovation.

5. Role of Public Policy

Given that Industrial Dynamics is new and evolving as a theoretical framework, it is not surprising that analysis of implications for public policy is only emerging. Of the 122 articles classified under 5A (General/Theoretical), 100 were published in the 2000s, and most of these focus on innovation or innovation systems.

There are two different views concerning what is the appropriate domain for innovation policy. In *conventional (new growth) theory*, innovation is viewed as a growth-enhancing factor in the aggregate production function. Innovation is driven by new knowledge that is created by investment in research and development (R&D). Given market failure resulting from insufficient incentives to engage in R&D (only a portion of the results can be appropriated, and some of the results "spill over" to other users), the primary role of public policy is to stimulate research and development activities via science and technology policy.

In the late 1980s an *evolutionary view* of innovation and innovation policy emerged, recognizing the complexity and systemic nature of innovation based on the concept of *innovation systems*. This is the prevailing view in Industrial Dynamics.

Innovation policy is much broader than science and technology policy. Innovation is viewed as deeply embedded in the competitive processes of the economy and as interacting with many other areas of policy. It matters where and how new knowledge is created and how (by what mechanisms) new knowledge is converted into innovation and economic growth. Investment in R&D does not automatically result in economic growth. Innovation is the result of interactions among many actors and institutions, not simply of R&D activities, and the outcomes are highly uncertain.

In addition to market failures (due to externalities, absence of markets, etc.), there are nonmarket (system) failures, such as lack of absorptive capacity, institutional failures (e.g. due to poorly designed financial regulation and intellectual property laws), and network failures. Such failures justify policy intervention not only through the funding of basic science but also more widely to ensure that the innovation system as a whole performs well.

In the 2000s the policy discussion in the ID literature moved from technology to innovation.
What is needed is an evolutionary *cum* systemic approach to innovation policy. The purpose of innovation policy is not to promote individual innovation events or outcomes but rather to set the framework conditions in which innovation systems can better self-organize across the range of activities in an economy.

The "generic" issues for public policy in a systemic *cum* evolutionary approach are 1) increasing the absorptive capacity in the economy (or system) as a whole; 2) foster interactions among agents (both public and private) and among systems; and 3) creating variety.

The innovation systems approach requires broad policy categories rather than particular types of policy intervention

- technological infrastructure policy to create capabilities and build markets
- horizontal (rather than industry- or product-specific) technology policies.
- building technological capability for industrialization
- both mission- and diffusion-oriented policies.

There is increasing understanding of the need for more robust connections between theory, policy, and practice. Theory building, policy formulation, and practical learning (implementation) should be seen as integrated, co-evolving, iterative, and interactive processes. Too often there are gaps between theory and policy and between policy and implementation. The learning process involves several dimensions: evolution of theory, improved understanding of policy implications, identification of policy targets, choice of policy instruments, and policy implementation, with feedbacks throughout the process. Public procurement may be a useful tool in the learning process, illustrating the experimental nature of interaction between buyers and sellers of new technology.

A general framework for public policy that addresses the main functions of innovation systems has been proposed. These functions are knowledge development and diffusion, influencing the direction of search, legitimation, entrepreneurial experimentation, market formation, resource mobilization, and development of positive externalities.

Entrepreneurship and innovation are increasingly being related to clusters and networks. One of the primary challenges for policymakers is to create a favorable climate for entrepreneurial activity, often related to the formation of clusters/systems. However, cluster formation cannot be directed, only facilitated; markets are necessary.

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Table 1 CLASSIFICATION OF INDUSTRIAL DYNAMICS ARTICLES

1	**CAUSES OF INDUSTRIAL DEVELOPMENT AND ECONOMIC GROWTH**
1A	Dynamics and Evolution of Industries
1B	Entry, Exit, and Entrepreneurship
1C	Institutional and Regional Issues
1D	Modeling of Industrial Development and Economic Growth
2	**ECONOMIC ACTIVITY IN THE FIRM**
2A	Strategy
2B	Business Organization and Finance
2C	Firm Capabilities and Resources
2D	Firm Performance
3	**FIRM BOUNDARIES AND INTERDEPENDENCE**
3A	Firm Boundaries
3B	Spillovers
3C	Cooperation/Alliances/Networking
3D	Dynamics Related to Firm Size
4	**TECHNOLOGICAL CHANGE AND ITS INSTITUTIONS**
4A	General
4B	Patterns/Regimes
4C	Sources of Innovation
4D	Adoption/Diffusion
4E	Innovation Systems/Industry Clusters
4F	Institutions
4G	Indicators
4H	Case Studies
5	**ROLE OF PUBLIC POLICY**
5A	General/Theoretical
5B	Case Studies

Table 2. Journals and Time Periods Covered

	Years covered	Number of articles
Economic Geography	1990-2009	572
Economics of Innovation and New Technology	1990-2009	471
Industrial and Corporate Change	1992-2009	627
International Journal of Industrial Organization	1990-2009	1,068
Journal of Economic Geography	2001-2009	253
Journal of Evolutionary Economics	1990-2009	450
Journal of Industrial Economics	1990-2009	542
Journal of Industry Studies/Industry & Innovation	1993-2009	283
Research Policy	1990-2009	1,441
Review of Industrial Organization	1990-2009	842
Small Business Economics	1992-2009	843
Structural Change and Economic Dynamics	1990-2009	479
Total		7,871

Table 3. Classification of Industrial Dynamics Articles by Journal and Theme, 1990-2009

Journal	JIS/I&I	ResPol	ICC	EINT	EcGeog	SBE	JEcGeo	JEE	SCED	IJIO	RIO	JIE	Total
Yrs.	93-09	90-09	92-09	90-09	90-09	92-09	01-09	91-09	90-09	90-09	90-09	90-09	
# articles	283	1,441	627	471	572	843	253	450	479	1,068	842	542	7,871
1A	18	22	57	9	23	23	3	19	25	13	11	2	225
1B	4	16	32	0	5	99	1	18	2	16	15	4	212
1C	4	10	17	2	56	22	55	6	5	2	2	0	181
1D	5	5	9	6	2	6	2	26	19	1	0	0	81
2A	15	25	18	7	6	12	3	1	1	2	1	0	91
2B	10	37	86	13	20	36	6	4	2	1	1	0	216
2C	12	78	75	23	4	13	3	7	0	3	3	1	222
2D	5	14	7	14	5	16	1	4	0	3	1	1	71
3A	3	2	10	4	4	0	0	0	3	2	0	0	28
3B	10	23	9	21	1	4	7	6	2	4	3	3	93
3C	76	183	33	39	21	26	18	12	3	7	6	2	426
3D	1	4	9	3	0	62	1	2	0	3	0	0	85
4A	4	39	11	22	2	1	0	11	7	3	1	0	101
4B	10	65	21	18	4	4	2	21	7	5	2	1	160
4C	5	63	11	10	1	6	6	4	1	2	3	0	112
4D	5	67	16	25	5	13	4	11	6	11	5	2	170
4E	58	118	14	14	49	20	4	11	5	4	2	0	299
4F	22	124	55	27	8	31	7	10	2	9	3	0	298
4G	2	71	1	17	0	1	0	0	2	5	0	1	100
4H	2	14	8	1	0	1	4	2	1	0	0	0	33
5A	10	67	8	8	3	12	0	9	4	1	0	0	122
5B	17	59	4	6	4	19	0	1	2	3	2	2	119
Total ID art.	298	1,106	511	289	223	427	127	185	99	100	61	19	3,445
Not ID	33	370	216	204	256	495	151	270	392	947	747	513	4,594
Not classified	19	45	32	8	10	15	13	22	7	25	38	9	243
% ID	81.6	71.2	60.4	55.0	53.5	39.5	35.2	35.1	16.7	9.0	6.8	3.7	38.5