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Comparing innovation systems: a framework and application to China's transitional context[☆]

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Abstract

This paper proposes a generic framework for analyzing innovation systems, anchored around five fundamental activities — R&D, implementation, end-use, education, linkage — and focused on the performance implications of a system's structure and dynamics. Rather than simply describing the role and performance of particular actors, institutions and policies, this approach focuses on system-level characteristics, including the distribution of these activities within the system, the organizational boundaries around them, coordination mechanisms, evolutionary processes, and the effectiveness of the system in introducing, diffusing and exploiting technological innovations. The framework is applied to a comparison of China's national innovation system under central planning and since reforms, revealing the evolving structure and dynamics of this system and current inconsistencies and perverse incentives that policymakers must address to realize their development goals. More generally, it provides a basis for addressing the implicit assumptions of organizational types, roles and convergence among innovation systems emerging in very different contexts, whether national, regional or industrial.

Keywords: Innovation system; Fundamental activities; System-level characteristics

1. Introduction

In this paper, we propose a framework to more explicitly address the "system" aspect of national innovation systems and thereby move this stream of research beyond descriptions of particular actors, institutions, policies and R&D achievements in particular countries. It is a logical and necessary extension of research explicitly focused on technological innovation systems started in earnest in the 1980s with Freeman's (1987) analysis of Japan's domestic context. Extensive research had linked innovative performance with competitive and economic outcomes at the national (Rosenberg, 1972; Porter, 1990; Mowery and Rosenberg, 1989) as well as regional and

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industrial levels (Saxenian, 1994; Piore and Sabel, 1984). Freeman and most researchers who followed (e.g. those included in Nelson's (1993) volume and Lundvall (1992)), as well as the policymakers who were their primary audience (e.g. OECD, 1997), were specifically interested in the structure and dynamics of *national* innovation systems. Fundamentally, these studies describe categories actors — government, universities, research institutes, firms — and their interactions with institutions and policies.

Cross-country comparisons based on descriptions of the performance and interrelationships of given categories of organizational actors and the policies and institutions that affect them are a natural approach from a policymaker's perspective. However, this level of analysis has faced considerable criticism. Many question the value of such an aggregate level of analysis. The regions and industries within a nation can be quite diverse and represent distinct "systems" of innovation (Nelson and Rosenberg, 1993; Carlsson and Stankiewicz, 1995). Others suggest that the concept of a "national" innovation system is becoming less meaningful as cross-border linkages and information flows increase along with the internationalization of corporate R&D (e.g. Patel and Pavitt, 1998). Still, national borders will continue to represent important policy, legal, regulatory and often cultural boundaries, and policymakers' are primarily concerned with and have influence over local actors, institutions and outcomes.

In this paper, we address the more fundamental weakness of current national innovation system research suggested by Lundvall (1992); namely, the lack of system-level explanatory factors. Although proposing to be analyzing "systems", most scholars have actually focused on the roles of specific actors and the impact of specific policies and institutions to explain system-level outcomes. They have proceeded from a generalized, organizationally-defined typology of actors and the generic, disembodied institutions that influence them. The ironic result is that we have no nomenclature to describe alternative system-level structures of which actors and institutions are only elements, and hence no way to make comparisons among alternative systems, a shortcoming also identified by Edquist (1997, p. 20).

One cause of this has been, until recently, the nearly exclusive focus of national innovation system research on basically similar countries. In reviewing the studies of 15 countries appearing in his edited volume, Nelson (1993) comments that the most striking feature of the comparisons is the similarity across the countries. This should not be surprising, however, if studies are limited to countries with similar economic principles and industrial organization. In such cases, cross-country comparisons will be limited to a discussion of differences in the roles of the same types of actors or elements of the systems, rather than a comparison of alternative system-level structures and their relative strengths and weaknesses. Nelson himself comments that had China or the Soviet Union been included, "the matter would have been different" (Nelson, 1993, p. 507).

Since then, however, researchers with backgrounds in political science, political economy, and economics have begun to analyze the innovation systems in China and former centrally planned economies. None of these studies, however, has explored the possibility that these nations, with very different starting conditions (i.e. central planning and functionally specialized organizations) and professed principles, could (or perhaps should) develop viable alternative system structures to accomplish technological innovation. One of the first foreign studies of China's national innovation system by the IDRC (1997) reflects the methodological and analytic assumptions of the researchers involved. They do an excellent job of identifying the key stakeholders, policies, and institutions of China's national innovation system. They also identify weaknesses in organizations and policies. However, they do not provide a system-level description of the system's structure, dynamics or performance. Hence, their discussion is necessarily limited to specific categories of actors, policies and institutions. Moreover, their report reflects implicit assumptions about the proper role of these actors and policies, understandably based on the researchers' experience in other countries with very different economic principles and industrial organization.

Most scholars would agree that the central issue in the large, formerly centrally planned economies is not the need to establish new organizational actors; ostensibly, the necessary actors already exist. Unlike most, however, we maintain that whether particular activities are undertaken by particular actors is not the most important issue. Instead, we argue that changes in organizational boundaries around activities comprising the innovation system, as well as the incentive structure and capabilities of actors to undertake these activities and perform well (their "economic competence" (Carlsson and Eliasson, 1994)), is the more important and fundamental issue. In other words, a thorough analysis should not presuppose a "natural" organization of these activities, and recommendations must take into account differences in initial starting conditions.

The organization and distribution of innovation-related activities differs fundamentally in these countries compared to the developed market economies. For example, Nelson defines innovation as the process by which firms master new technologies, with firms as the primary locus of industrial innovation (Nelson, 1993, p. 4). Other types of organizations and institutions may be important, but they are still treated as peripheral elements of the innovation system. Indeed, in the context of US manufacturing firms, internal RD&E departments were institutionalized early in the 20th century. Firms have been the center of not only implementation, but also the creation, of many technological innovations. Similarly, universities are assumed to be the locus of both education and research.

Most formerly centrally planned economies, however, illustrate the limitations of such preconceptions of relevant actors and their activities, and the limitations of an analytic approach that uses them as a fundamental unit of analysis. China followed the Soviet Union's model of establishing functionally specialized organizations whose activities and interactions would be managed by a central government body (McDonald, 1990; Maruyama, 1990; Lo, 1997). The scope of functional activities of "generic" types of organizations (such as "firm" or "university") were much more restricted than in other countries. [1] As a result, research (including all creative or innovative activity) was conducted by research institutes, manufacturing by factories, and distribution by distributors. Under central planning, the factories had neither mandate nor incentive to introduce innovation and change; similarly, research institutes also had neither mandate nor incentive to undertake manufacturing activities. Further, the central government directed both the internal activities of these functionally specialized organizations, as well as the transfer of resources among them and between them and the government (Naughton, 1990).

Such differences in initial conditions are obvious, and describe the fundamental characteristics of the starting point of these countries' transitions from central planning to greater market coordination and decentralized decision-making. Ironically, both foreigner and Chinese scholars seem to consider such differences and characteristics as barriers to change, rather than a basis on which to create a new system.

We argue that research in innovation systems, especially at the national level, is valuable and necessary for developing appropriate policies and understanding a particular actor's behavior. However, both understanding a system and comparing its strengths and weaknesses with other systems requires a generally applicable framework. As the discussion above shows, using such organizational categories such as "research institute", "firm" or "government" can generate more confusion than insights, since, in different national or industrial contexts, these may have very different meanings in terms of the range of activities they undertake. Similarly, in the socialist countries that implemented the Soviet-style of industrial organization, the distinction between "public" and "private" organizations and the relationship to the type of activities an organization undertakes may be very different.

Some scholars have begun to address truly system-level phenomena of innovation systems at the national and other aggregate levels of analysis (e.g. the chapters in Edquist's (1997) edited volume). To further empirical work, we present a concise and generalizable framework that enables us to describe a system's structure and dynamics based on the different organizational boundaries around a fundamental set of activities related to the creation, diffusion and exploitation of technological innovation within a system.

The following section introduces this framework and discusses the added value it can bring to innovation system research, including the benefit of providing a common set of terms that are conducive to cross-system comparisons. We then illustrate this

[1] As one reviewer pointed out, while their functional activities may be much more restricted, these organizations have had to undertake more welfare functions so that they were effectively self-contained communities, with their own schools, hospitals, stores, and other services. In this discussion, however, we are only focusing on their functional activities; i.e. those related to the organization's task, such as education for universities and manufacturing for factories.

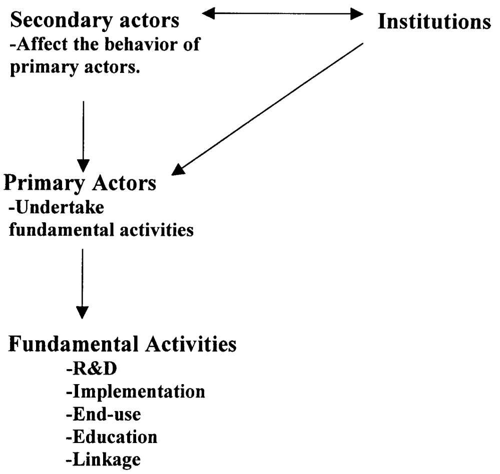

Fig. 1. Elements of generic framework for analyzing innovation systems.

framework through a comparison of the innovation system in one country, China, during two distinct periods; namely, under central planning (1949–1978) and after 20 years of reform (1978–2000). This approach highlights the major changes in the structure, dynamics and performance in China's innovation system, and also the systemic weaknesses that inhibit better performance. More generally, the analysis shows the usefulness of this generic framework for research in innovation systems, especially as it leads to differently framed questions and insights (Figs. 1 and 2).

2. Framework

The basic premise underlying our framework follows that suggested by Anderson and Lundvall (1997); namely, that the mode of innovation has national specificities. Practically, this implies that a system-level analysis should begin with an understanding of how fundamental activities of the innovation process are organized, distributed and coordinated. Accordingly, our framework begins with five fundamental activities suggested by prior research on innovation systems and, more generally, the technological innovation process (particularly Rosenberg, 1972; Mansfield, 1968, 1991; Teece, 1986; Freeman, 1991; Lundvall, 1992). These are: (1) research (basic, developmental, engineering), (2) implementation (manufacturing), (3) end-use (customers of the product or process outputs), (4) linkage (bringing together complementary knowledge) and (5) education. These activities extend beyond the R&D system, including important inputs to research activity as well as the use of research outputs.

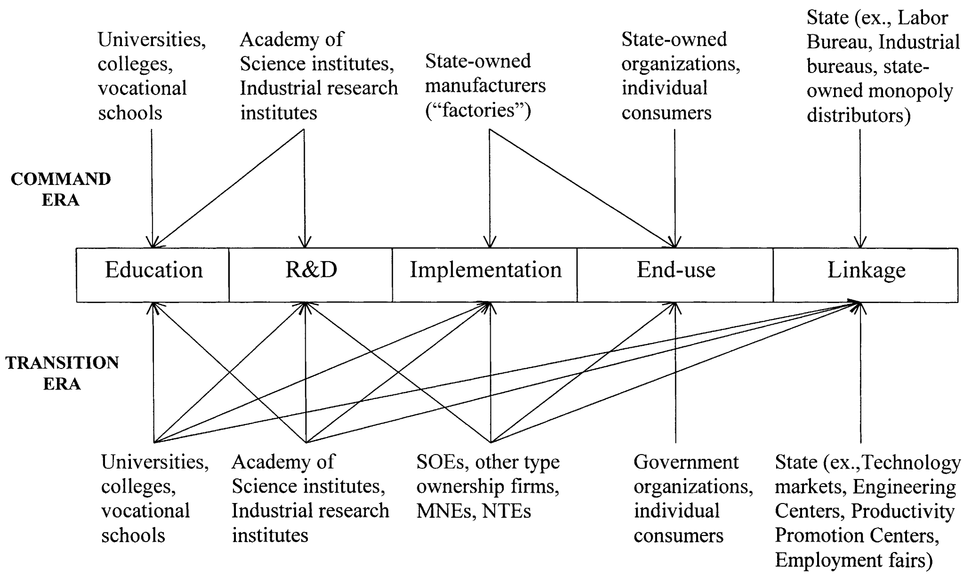

Fig. 2. Distribution of activities and primary actors in China's innovation system under central planning and since reforms.

Next, rather than starting with categories of actors such as "research institutes" or "universities" and then discussing the relative importance of each of these actors in an industry or nation's innovative performance, we feel it is necessary to use a more generic set of terms. We use *primary actors*, *secondary actors* and *institutions* to distinguish among elements of an innovation system based on their relationship with the five fundamental activities and system structure and dynamics. These terms avoid the system-specific issues of public versus private ownership and assumptions about specific activities undertaken by a given organization, which are sources of confusion and barriers to cross-system comparisons.

Primary actors are those organizations that perform one of the five fundamental activities identified above. They are the organizations in the system that undertake research, implement new technology, use the outputs of that technology, train those involved in any of these activities, or link actors undertaking complementary activities. A single primary actor may undertake more than one fundamental activity.

Secondary actors, in contrast, are organizations that affect the behavior of or interaction between primary actors. They may act directly, mandating particular behavior by primary actors as they undertake fundamental activities by dictating operational plans, setting organizational targets, or deciding other operational or strategic means or objectives related to any of the fundamental activities. Alternatively, they may affect the behavior of primary actors indirectly through the institutions that they create or shape. Indirect means using policy to create a particular incentive structure remove secondary actors such as government agencies away from making managerial decisions for primary actors (a direct approach). For example, secondary actors may institute changes in the tax system that reward or discourage certain types of investment behavior by primary actors.

Institutions are the set of practices, rules and other disembodied organizations that guide or constrain an actor's behavior.[2] Of course, such institutions may also be the object of an actor's behavior, as suggested by related research on structuration and the coevolution of organizations and institutions (e.g. North, 1990; Leyesdorff and van den Besselaar, 1994). Indeed, a fundamental role of government is to establish, maintain and adjust institutions such as the legal system, patent system and tax system. At the same time, government behavior usually must take into account extant institutionalized norms and beliefs, as well as established practice.

These elements make it possible to explore system-level phenomena in the context of an innovation system. With previous approaches, researchers asked actor-centric questions, such as: what is the role of universities (or private firms, or publicly supported research institutes, or government, etc.) in Country X's innovation system? How are these organizations related? The framework we propose leads to different questions and insights by explicitly focusing on system-level characteristics. This is similar to the dichotomy found in network analysis, with one approach focusing on characteristics of particular actors in a network and another on the structure of the network itself (Burt, 1992; Wasserman and Faust, 1995). Basic questions for a system-level analysis address system structure, dynamics and performance; for example

Structure	To what degree do organizational boundaries correspond to clusters of fundamental activities? Is there a distinct division of labor among organizations, or are the same activities undertaken by different types of organizations? What groups of activities are found within the same organizational boundaries, and which are not? Is coordination of the system highly centralized, multicentric or highly decentralized?
Dynamics	What brings the activities and actors together to bring an innovation from conception to use? How does the structure evolve; for example, how are organizational borders around activities altered? How do new institutions and new organizations arise?
Performance	How do structure and dynamics affect the effectiveness and efficiency of the system in introducing, diffusing and exploiting new innovations? What are

[2] This definition of "institutions" follows that by North (1990) rather than Nelson (1993), who used the term to indicate actors (such as universities) or a cluster of actors (educational system).

Performance	the relative advantages and disadvantages of different system structures?

Answering these questions leads to a better understanding of the system-level context that is necessary for a meaningful discussion of particular actors, policies and institutions. This is adequate for an analysis of one system or a cross-sectional comparison of two or more systems at a particular point in time.

These elements are also the basis of a longitudinal or evolutionary analysis of an innovation system. They suggest variables that, in turn, can be used to describe different system states emerging over time. However, an evolutionary analysis necessarily includes an explicit description or model of the interaction of these elements over time. The interaction process and the resulting system states are difficult to analyze and even harder to predict because an innovation system is inherently endogenous and encompasses a large number of actors, institutions and "events" (i.e. a system with many degrees of freedom). Indeed, many researchers may conclude that any attempt to "plan" an innovation system is futile as the outcome is the cumulative and unpredictable effect of each actor pursuing its interests, responding to institutions and creating institutions, along with exogenous events not usually considered part of an innovation system (for example, the change in the international trade regime and nature of competition when a country joins the WTO).

A less fatalistic and more normative view, and one that provides a role for policymakers, would suggest that the evolutionary process and therefore outcomes (system states) can be managed or at least constructively influenced. Consciously designed government policies, for example, may create opportunities for new actors to emerge, or dramatically change actors' incentive structures. Resulting changes in structure, behavior and performance of individual actors and in aggregate would, in turn, lead to further changes in system structure and dynamics, with (hopefully intended) changes in system performance. Of course, changes in government policies themselves are usually the outcome of policymaker's response to system performance (e.g. Sastry, 1997), reflecting the continual interaction of system elements over time that is the basis of an evolutionary analysis.

The following section illustrates this system-level approach through a comparison of the structure, dynamics and performance of China's national innovation system under central planning and the current transition era. Although within one national boundary, these two periods represent to very different modes of organizing innovation activities, as China has shifted from central planning to the current, still evolving system in which government regulation and market forces are both at work. Our analysis is basically cross-sectional, comparing the two system states characterizing these two periods of time, but we necessarily address the evolutionary process that links these two systems over time. The comparison enables us to understand the system that recent economic and organizational reforms are aimed at changing, as well as the remaining and newly emerging sources of sub-optimal innovation system performance. More generally, it shows how a system-level approach complements research that describes actors, policies and institutions in a particular context. As such, it is appropriate for discussions of innovation systems in other countries or in particular industries, not just in China or other transition economies.

3. China's national innovation system in transition

Economic and enterprise reforms over the last 20 years, including a large number of science and technology policy initiatives, have had a clear impact on the structure, dynamics and performance of China's innovation system. The changes have affected the distribution of activities among organizations, the locus of strategic decision-making and operational control over primary actors and activities, the nature of existing actors and the emergence of new actors, and the mechanism coordinating activities and actors in the innovation process. This section compares the structure and dynamics of the two systems — under central planning and after reforms — and identifies the current strengths and weaknesses of China's current system.

3.1. System structure under central planning

After founding the People's Republic of China in 1949, the Chinese leadership's primary objective was to revive and modernize China's industrial capacity that had been disrupted in the preceding two decades during the Japanese invasion and later civil war. To achieve this quickly, the government initiated a technology import and dissemination strategy, relying heavily on subsidized imports from the Soviet Union. During the first 5-year plan in the early 1950s, China imported 156 large turnkey facilities, mostly in heavy industry, power generation, mining, refining, chemicals and machine tools. China also established more than 400 research units, primarily focused on reverse engineering both the Soviet technology and that acquired elsewhere. These units evolved into three basic groups: those under the Chinese Academies of Science, with more emphasis on basic research; those within universities and charged with both training and research activities; and industry-specific research institutes for applied problem-solving and technology introduction into manufacturers.

To organize these activities, the Chinese attempted to replicate the industrial organization structure of the Soviet Union, characterized by high centralization and complete state-ownership. It created a range of governmental secondary actors to affect the state-owned primary actors both directly and indirectly. The State Planning Commission (SPC) was most influential, with ultimate control over economic plans, resource allocation and oversight. It issued annual and 5-year plans that dictated both the operational and "strategic" objectives and activities of primary actors. This included new R&D and production project selection, capital and labor allocation, production levels, price-setting, distribution and others.

Below the SPC was another level of secondary actors with more specific mandates and who influenced the activities in China's innovation system. In many cases they shared oversight of different activities within the same type of organization. For example, the main administrative body for science and technology activities was the State Science and Technology Commission (SSTC). Its mandate was to regulate and coordinate S&T activities in R&D institutes, production enterprises (manufacturers), and research centers in universities. However, the Ministry of Education also oversaw the education and training activities in these same universities, as well as vocational and technical schools. The industrial bureaus — such as the Ministry of Communications and Posts, Ministry of Machinery, and Ministry of Chemical Industry — also oversaw research institutes as well as the production and distribution enterprises within their respective industries. These industrial bureaus were also the primary actors responsible for linkage activities, directing technology developed at a research institute to one or several manufacturers under their jurisdiction.

Two characteristics of the Chinese government's technology strategy emerged during this period of central planning: policymakers' desire for national self-sufficiency, and their mission orientation. The drive for self-sufficiency was certainly related to China's not being diplomatically recognized by most advanced Western countries, as well as its strained relationship and ultimate break with the Soviet Union in the 1960s. In 1956 the government launched its 1956–1967 National Science and Technology Long-Term Plan, which focused on developing Chinese research and production capabilities in atomic energy, electronics, semiconductors, automation, computer technology and rocket technology (McDonald, 1990). This objective of this plan was for China to catch up with developed countries both in defense and advanced civil technologies. At the same time, several specific mission projects were initiated and ultimately successful; namely, developing atomic and hydrogen bombs (by 1964 and 1967, respectively) and launching satellites (by 1970).

3.2. *Structure, dynamics and performance under central planning*

The structure of China's national innovation system during this period had three defining characteristics. First, primary activities were distributed among thousands of functionally specialized organizations, and organizational boundaries were essentially defined by type of activity. For example, R&D was undertaken by research institutes (with a further distinction between basic and applied research institutes), implementation (e.g. manufacturing) by factories, and linkage by industrial bureaus. Second, decision-making (both operational and policy-related) was multi-centric, or what Lieberthal (1995) and others have described as "fragmented authoritarianism." Power was distributed vertically and horizontally (*tiao/kuai*) among a large number of governmental secondary actors with mandates defined by type of activity (such as education), industry (such as pharmaceuticals, machinery, and electronics) and institution (such as pricing).

Ostensibly, the State Planning Commission had overall authority over coordination of economic activities, including those related to the development, diffusion and exploitation of technological innovations. Third, the dominant performance criterion for primary actors was output scale, without any explicit attention to efficiency nor, in practice, quality of the output.

This structure — multi-centric and government directed, with functionally specialized primary actors and output-based performance measures — had two implications for the incentive structure of primary actors that, in turn, had important system-level performance implications. First, there were no incentives for primary actors to introduce, adopt or diffuse innovations proactively. There was neither market competition, profit, nor other operational efficiency-based criterion for performance. Nor were there any other institutional mechanisms absent government direction that encouraged primary actors (or the individuals within them) to improve upon the activities in their mandate, such as investing in technology development or adoption, or upgrade existing technology. The central government secondary actors claimed both authority and responsibility for such initiatives. Each primary actor's participation was limited to bargaining with the secondary actors within the central government over resources and output goals for their organization, whether R&D output, manufacturing output, students, or whatever was within the organization's functional domain.

This lack of incentives for primary actors to initiate change proactively has obvious consequences for the effectiveness of an innovation system to introduce new or improved technology. It also goes far in explaining China's relative technological backwardness compared to South Korea, which started from a similar state of industrial and economic development in the 1950s following a devastating civil war. Like China, Korea also aggressively imported technology, although primarily and with extensive support from the United States. Unlike China, however, the Korean manufacturing firms invested in developing their own R&D capabilities first to imitate and then to improve on world-class technology (Amsden, 1989; Kim, 1997). In contrast, China offers more examples of imported technology not being improved upon. For example, the Liberation Truck, whose design and production lines China imported from the Soviet Union in the early 1950s, was unchanged during the 40 years that China has mass-produced it.

The second implication of China's innovation system structure under central planning is that primary actors specialized in other activities had no incentives to initiate linkages with other primary actors — research institutes, manufacturers, distributors or users. Innovation research has consistently shown such linkages to be vital for successful technological innovation, diffusion and exploitation (Mansfield, 1991; Pavitt, 1991; Freeman, 1991; Rogers, 1983; Roberts, 1988; Tversky and Kahneman, 1974; Kogut et al., 1995; Pennings and Harianto, 1992). Instead, these actors depended on top–down allocations for necessary inputs, whether personnel, technology, capital, intermediary inputs, or other resources. As a result, they had to excel in linking activities with central government bodies, the secondary actors in our generic typology. On the other hand, they could largely ignore developing direct linkages with other functional organizations that actually created these resources (Saich, 1989). If anything, they were discouraged from developing independent horizontal linkages with other primary actors, as this would erode part of the power that the central government bodies had over them. Similarly, they had no incentive to "push" or market their output resources to other organizations; this was also the domain of the secondary actors. In other words, the activities which together comprise the objectives of strategic management in market-coordinated economies were irrelevant or qualitatively very different in this centrally planned system.

3.3. China's transition-era NIS: evolving institutions and actors

By the late 1970s, Deng Xiaoping and other pragmatic top leaders had recognized the inefficiencies and lower effectiveness of a centrally planned economy in practice.[3] They also recognized that achieving their national economic and developmental goals depended on increasing performance at the organizational level, and that technology played a critical role.

The economic and organizational reforms that they subsequently introduced over 20 years have had

[3] See Kornai (1980) for a general treatment of the systemic shortcomings of centrally planned socialist economies.

far-reaching consequences. Organizational boundaries around activities have changed dramatically, and primary actors are more autonomous and functionally diversified. Governmental secondary actors are shifting to indirect means (through institutions and policies affecting actors' incentive structures) to guide primary actor behavior, and more information is flowing horizontally among primary actors. While the performance of the current system in introducing, diffusing and exploiting technological innovation is promising, important issues remain unresolved and new challenges have emerged.

Because these changes have been spearheaded by the central government, the analysis of the China's transition-era innovation system begins with the institutions that have been the target of policy reforms and development.[4] We then examine changes in system structure and dynamics, in particular the location of decision-making and the distribution of particular functional activities in the system, as well as the performance implications of these changes.

3.3.1. Creating and recreating institutions

Two institutional changes epitomize China's reform period and have directly affected the structure, dynamics and performance of its innovation system. The first is the change in the legitimate criterion for evaluating performance, whether at the individual or organizational level (Groves et al., 1994; White and Liu, 1998). Although "political correctness" may still be necessary, it has been supplanted by economic measures as the dominant criterion. The command-era legacy of focusing on output scale still lingers, but measures that reflect economic activity — whether contract and licensing fees, sales or other sources of revenue — are now dominant. As discussed later, however, efficiency-based measures of performance such as profitability and return on assets are only slowly becoming incorporated into evaluations and decision-making (Broadman, 1995; Steinfeld, 1998; White and Liu, 1998).

The second institutional element that has undergone dramatic change has been the decentralization of decision-making over both resource allocation within the economy and operational decisions within primary actors. The Chinese government has gone far in decentralizing responsibility for achieving the new economic performance objectives (Jefferson et al., 1999; Groves et al., 1994; Naughton, 1994; McDonald, 1990; Child, 1994; Lieberthal, 1995; IDRC, 1997). The changes were first initiated in agriculture, as policymakers introduced the responsibility system that gave farmers more control over what crops to produce (Kelliher, 1992). This was later extended to industrial enterprises ("factories"), and most recently to research organizations. In each sector, the necessary authority to make decisions commensurate with the new levels of responsibility has moved down less smoothly, but the long-term trend has definitely towards greater responsibility and authority at the organizational actor level.

This has been accompanied by the central government's allowing and even fostering competition among organizations. In some cases, it has removed formal organizational ties among organizations that previously formed huge state monopolies, or curtailed the control of industrial bureaus over functional activities in particular industries. These organizations are now individually accountable for functional and economic performance (Baark, in press). The government has also allowed new entrants — including private enterprises or collectives, such as the township and village enterprises (TVEs) — to compete directly with former or still state-owned enterprises in most industries (Nee, 1992).

Changes in the labor market, especially since the mid-1990s, illustrate the extreme changes in the role of the government in allocating resources and the resulting effect on competition among organizations. Under the command economy and through the early 1990s, all university graduates waited for work assignments in state-funded organizations. The graduates had no choice, nor could they freely change jobs after they started. Reforms, however, have reduced the state labor bureau's role in allocating human capital to sponsoring a voluntary clearinghouse of information on open positions and available workers. Although some bureaucratic control remains, such as residency restrictions, an

[4] The Chinese government has initiated numerous policies and programs specifically targeting science and technology activities. For a description of these programs, see Gu (1999), Jiang (1997), McDonald (1990), IDRC (1997), Yuan and Gao (1992) and Ma and Gao (1997).

individual may quit and change jobs relatively freely.

The implications for state-funded enterprises that never had to compete for qualified scientific and technical personnel are obvious. They are losing a high percentage of their most qualified personnel to both foreign and domestic organizations that can offer them better conditions. As long as such personnel are in short supply, and they will be for the foreseeable future, financially-strapped and lethargic state-funded organizations will continue to see a net outflow of qualified personnel. Nor is this outflow inconsequential at the system-level. It represents an "internal brain drain" as scarce technical personnel are attracted to jobs, such as in investment banking and finance, which are not directly related to the innovation process. This has negative implications for the performance of China's innovation system if such scarce human capital is not contributing to the system's R&D outputs, implementation of innovations, linkage among actors, or other fundamental activities of the innovation system.

3.3.2. Redistributing activities among actors

The Chinese government has introduced these institutional changes in an attempt to increase performance at two levels: at the organizational level to reduce the drain on the central government budget and enhance the quality of organizational outputs, and at the system level (industry and national) to increase the competitiveness of domestic industries and better diffuse and exploit technological innovations to improve China's standard of living. There have been two basic changes in the organization of activities in the innovation process. First, the division of labor is less stark; activities no longer define organizational boundaries, as more organizations diversify into other functional activities. This is one result of the devolution of operational decision-making, as primary actors choose to undertake additional activities in the innovation process. Second, new primary actors are emerging, including new entities created or allowed to develop by the government, as well as multinationals.The following section describes the major changes in each type of activity — R&D, implementation, end-use, education, and linkage — and the system-level consequences of these changes.

3.3.2.1. R&D. The transition period has seen major changes in both the nature and distribution of R&D activities, with important implications for the performance of China's innovation system. First, reforms have created strong incentives for applied research institutes to be more responsive to downstream problems of manufacturers and end-users. The government has done this by reducing its financial support to force the institutes to find outside sources of revenue. After 2000, over 5000 research institutes will no longer receive support from the government for their operating budgets, although ministries will award more competitive research project grants. At the same time, the institutes have considerable discretion in deciding how to respond to this fiscal stimulus. They are now allowed to sell or license the technology they develop, conduct contract research or provide consulting services for other organizations. Some have opted to keep their technology in-house by establishing manufacturing operations on-site or creating technology-based spin-offs (Gu, 1995, 1999).

On the other hand, the government has increased its direct funding of basic research. For example, the government launched its 973 Program in 1998, devoting RMB 4.5 billion to support basic research. This is in addition to RMB 5.4 billion allocated to the Chinese Academy of Sciences to develop world-class scientific bases and technical infrastructure (Fang, 2000), particularly in "strategic" high-tech industries such as information technology and biotechnology.

The second fundamental change has been in the organizational locus of R&D activities. A major thrust of S&T reforms throughout the transition period and across different government bodies has been the attempt to co-locate R&D activities with implementation; i.e. for manufacturing organizations to undertake R&D. Academic researchers have supported the government's drive to promote R&D activities in existing manufacturing firms (Shi, 1996; Jiang, 1996; Tong, 1996; Xu and Wei, 1995; Jiang, 1994). To this end, the central government has created incentives for firms to establish in-house R&D departments, and these units have increased dramatically, from 7000 in 1987 to over 24,000 by 1998 (China Science and Technology Statistics, 1992, 1998).

Considerable evidence, however, suggests that research units within firms have increased their share of R&D inputs, but have not increased their relative

Table 1
Share of national R&D expenditure by sector[a]

	Research institutes (%)	Universities (%)	Enterprises (%)
1987	54	16	30
1990	50	12	27
1993	50	18	23
1994	43	15	32
1995	44	14	32
1996	41	13	37
1996	43	12	43
1998	43	10	45

[a] Source: China Science and Technology Statistics Data Book, various years. Ministry of Science and Technology, Beijing.

contributions to China's R&D outputs compared to other types of organizations. Indeed, the number of research units in firms has increased dramatically, and their share of R&D expenditures has increased from 30 to 45% over the same period (Table 1). In contrast, the number of research units in institutes and universities has stayed constant over the same period, and their relative shares of R&D expenditures have decreased. However, firms have not shown a comparable increase in R&D outputs. For example, firms have increased their share and account for a larger number and percentage of total patents than universities or research institutes (Table 2), but that is concentrated in design patents (Table 3). The increase in R&D units and spending by firms has not been reflected in a proportional increase in more technologically intensive invention or utility patents. Although firms account for nearly all design patents and these modifications may have meaning in the marketplace, they do not represent significant innovations.

Instead, manufacturing firms have dramatically increased their funding of R&D by outside research institutes, overtaking the government as the main source by 1994 and nearly doubling government support in 1995 (Table 4). This reflects the perception among firm managers that buying or contracting for research from outside research institutes is more cost-effective than

Table 2
Total and joint patenting activity[a]

	1992	1993	1994	1995	1996	1997
Total patents	7836	12902	7576	7762	10898	17256
Joint patents (% total)	6.7	4.6	6.1	5.7	3.3	2.2
Universities						
Total university patents	1214	1774	1078	891	854	774
University patents as % total	16	14	14	12	8	5
Joint patents with						
Universities (%)	0.06	0.02	0.03	0.04	0.03	0.04
R&D institutes (%)	0.39	0.24	0.25	0.16	0.11	0.13
Firms (%)	1.15	0.89	0.92	0.94	0.61	0.36
R&D institutes						
Total R&D institute patents	1705	2558	1514	1485	1387	1472
R&D institute patents as % total	22	20	20	19	13	9
Joint patents with						
Universities (%)	0.39	0.24	0.25	0.16	0.11	0.13
R&D institutes (%)	0.40	0.19	0.25	0.17	0.19	0.06
Firms (%)	2.20	1.38	1.94	1.62	0.80	0.44
Firms						
Total firm patents	4917	8570	4984	5386	8657	15010
Firm patents as % total	63	66	66	69	79	87
Joint patents with						
Universities (%)	1.15	0.89	0.92	0.94	0.61	0.36
R&D institutes (%)	2.20	1.38	1.94	1.62	0.80	0.44
Firms (%)	2.53	2.02	2.95	2.89	1.74	1.37

[a] Calculations based on data from the Annual Review of Patents, 1992–1997. National Bureau of Intellectual Property Rights, Beijing.

Table 3
Patenting activity by organization type and patent type[a]

	Total	R&D institutes (%)	Universities (%)	Firms (%)
Invention patents				
1987	250	43	48	9
1988	484	43	43	14
1989	849	43	38	20
1990	863	38	38	24
1991	877	42	34	25
1992	876	39	35	26
1993	1514	38	33	29
1994	870	41	33	27
1995	767	40	34	27
1996	654	38	34	29
Utility patents				
1987	1677	30	19	50
1988	3076	28	19	53
1989	4000	28	18	54
1990	4227	30	17	53
1991	4601	27	14	59
1992	5742	23	16	62
1993	8480	22	15	63
1994	5084	22	15	62
1995	4275	24	15	61
1996	5075	20	12	68
Design patents				
1987	174	3	1	96
1988	239	5	1	93
1989	509	4	4	93
1990	640	5	1	93
1991	1185	4	1	95
1992	1218	4	1	95
1993	2908	4	1	95
1994	1622	2	0	97
1995	2720	6	0	94
1996	5161	2	0	98

[a] Source: China Science and Technology Yearbook, various years.

attempting to develop new product or process technology in-house (White, 2000). Enterprise R&D units are primarily involved in process scale-up, quality assurance, and other activities more closely associated with implementing rather than creating new technology.

Empirical studies have identified some of the barriers to firms becoming important centers of innovation. In addition to financial resource constraints, Gao and Fu (1996) found that managers cite lack of technical personnel and access to relevant market and technical information, and unclear property rights as the most important barriers to investing more in technological capabilities and undertaking more innovation activities. Personnel constraints were even more acute in a later survey of high-tech firms (Gao, 2000). Other researchers have also highlighted the reluctance of Chinese manufacturing firms to invest in process innovations (Yang and He, 1994; Wang and Xu, 1993). The large state-owned enterprises (SOEs) are particularly reluctant to invest in R&D activities or even take advantage of special funds to support such activities. For example, manufacturing firms only received 8% of the funds allocated by the National Key Science and Technology Tackle Program, which was specifically directed at applied research for large engineering projects.

Another change in the locus of R&D activities in China's innovation system is the entrance of multinationals and, more recently, their R&D centers as a small but growing category of primary actors. One objective of Deng's (1979) Open Door Policy that signaled the beginning of the reform period was to bring modern technology into China to support national development goals (the "four modernizations" of agriculture, science and technology, industry and the military). This, in turn, was the main objective

Table 4
Sources of R&D funding[a]

	1988	1990	1994	1995	Increase 1988–1995 (%) (RMB billion and (share of total))
Total	28.2	42.1	74.3	88.4	213
Government	11.8 (42%)	13.9 (33%)	20.9 (28%)	23.1 (26%)	96 (−38)
Enterprises	10.1 (36%)	17.4 (41%)	29.9 (40%)	41.2 (47%)	308 (30)
Banks	4.9 (17%)	5.2 (12%)	11.1 (15%)	11.4 (13%)	133 (−26)
Other	1.3 (5%)	5.6 (13%)	12.3 (17%)	12.7 (14%)	877 (212)

[a] Source: Science and Technology Indicators of China, various years.

in encouraging foreign direct investment in China, in addition to extensive technology imports.

Indeed, scholars have argued that the ability of a country to acquire new technology from whatever geographical source should be considered a part of its national innovation system (McFetridge, 1993; Tolentino, 1993). This is particularly relevant in developing country like China that is trying to catch-up technologically (Wu et al., 2000). Although most technology used by MNEs has been developed outside China, it has flowed into China through all of the possible technology transfer modes: hardware sales, licensing agreements, joint ventures and wholly-owned subsidiaries. Furthermore, this technology has been responsible for upgrading many of China's key industries (e.g. steel, computers, pharmaceuticals, automobiles).

Success in tapping foreign sources of R&D outputs, however, may not have benefited China as much as it could have. The Chinese have focused more on embodied and codified technology (instruments and equipment, drawings and software, production lines) rather than intangible assets. They have neglected other exchanges and interactions — such as collaborative development and problem-solving — which would provide greater opportunity for the transfer of tacit knowledge (Harbody, 1995).

The internationalization of the R&D activities represents another and potentially very significant change in the structure and performance of China's innovation system. First, over 50 MNEs, including Microsoft and Intel, have established R&D centers in China to tap the local pool of technical personnel. They represent a new type of primary actor undertaking R&D activities in China's innovation system. While in many cases these centers doing localization-oriented R&D, an increasing number are acting as nodes in these MNEs' global R&D activities (Xue and Wang, 1999). Second, more and more Chinese firms, such as Haier, Hi-Sense, Stone, Legend, Huawei, and Konka, are establishing R&D centers abroad, almost exclusively in developed countries and leading markets. These trends represent a geographic expansion of the distribution of R&D activities — indirectly through MNEs, directly by Chinese firms — and a contribution to China's innovation system.

It is too early to evaluate the system-level performance implications of either type of internationalization, but MNE entrance into China has particularly engendered ambivalent emotions. The Chinese are proud that technologically leading firms evaluate the environment in China as developed enough to contribute to their corporate R&D efforts. On the other hand, policymakers fear continued dependence or loss of indigenous technology as scarce human capital is diverted to such centers, benefiting MNEs at the expense of Chinese organizations.

3.3.2.2. Implementation. The transition period has seen a dramatic increase in the type of primary actors implementing new technology in manufacturing or other business processes, as well as an increase in the co-location of manufacturing and R&D activities within the same organizational boundary. New types of actors include township and village enterprises (TVEs), private firms, Sino-foreign joint ventures, and wholly-owned subsidiaries of MNEs, and these have emerged as important primary actors. They have been more proactive than state-owned manufacturers in undertaking other activities in the innovation process in addition to manufacturing.

Another significant change has been in the distribution of manufacturing activities. Other previously functionally specialized organizations — in particular, universities and research institutes — have diversified into manufacturing, often in the form of spin-off ventures, in response to greater freedom and incentive to pursue revenue-generating activities (Gu, 1999). While allowed but not wholeheartedly promoted by the central government, many of them have chosen to implement technology developed in-house themselves rather than sell or license it to existing manufacturers. They have done this in three fundamental ways, either spinning off part of their organization as a new and independent venture, transforming an internal institute or department as a licensed entity in a technology development zone (while it remains an integrated part of the organization), or by supporting individuals who formally leave the organization to start a new venture (Gu, 1999). As a result, the number of technology-based spin-offs from universities and research institutes has exploded, to over 1600 and 4300, respectively (Table 5). Together they recorded RMB 2.8 billion in profits in 1997. Several have developed into dominant domestic or internationally competitive firms, such as the Founder Group and

Table 5
Technology-based spin-offs from universities and research institutes[a]

	Universities		Research institutes	
	Number	Profits[b]	Number	Profits[b]
1994	1797	937240	4973	1168723
1995	1679	843010	4775	1176799
1996	1491	1019820	4702	1352863
1997	1611	1065400	4334	1702317

[a] Sources: S&T Statistics of Higher Education, 1994–1998. Ministry of Education. China Science and Technology Yearbook, 1995–1998. State Science and Technology Commission.
[b] RMB thousand.

Stone Group (both whose core technology originated from research within Beijing University) and Legend Group (from the Institute of Computing Technology under the Chinese Academy of Science) (Lu, 1997).

MNEs have also become an important actor in the implementation of new technology in manufacturing in joint ventures and, more recently, in wholly-owned subsidiaries. The government expects Sino-foreign joint ventures to contribute to the overall performance of China's innovation system by increasing the overall domestic system's stock of technology, as well as its capacity to adopt and exploit new technology. The MNE typically supplies the core technology used in a manufacturing process. To the extent that the foreign partner contributes managerial as well as technical skills, the joint ventures may indeed be more efficient at exploiting new technology than a completely domestic firm. In his survey of Sino-foreign joint ventures, Wang (1996) found that most had introduced new technology to the Chinese market. This is in addition to the first-hand experience in new product and process development that they are acquiring through joint efforts with their foreign partners.

3.3.2.3. End-use. Reforms have largely removed the central government from specifying product characteristics or allocating production to end-users, whether industrial or individual consumers. The result has been to give a new and important role to end-users in China's innovation system. This represents a major departure from the centralized, government-led, technology-push structure under central planning, and is recently receiving attention by Chinese researchers (e.g. Wu and Xie, 1996).

Of course, the government is a major customer in many industries, including defense and government monopolies like telecommunications. In other industries it may set or influence specifications for purchases or even dictate purchase lists, as in the case of reimbursement lists in the pharmaceutical industry. Generally, however, market-oriented reforms have resulted in end-users becoming an important influence on upstream R&D and implementation activities. Increasingly sophisticated and diversified demands from non-captive customers have combined with the manufacturers' increasing need to generate profits (Fischer, 1989; McMillan and Naughton, 1992; Rawski, 1994). This has increased the motivation for firms in most industries to introduce innovations, whether originating in-house or from research institutes.

As in the case of R&D and manufacturing, MNE's have also emerged as important new primary actors providing an impetus to upstream innovation activities within China. Whether joint ventures or wholly-owned subsidiaries, they often have specifications for inputs that are more demanding than local firms. To meet their demands, local suppliers may have to innovate or at least adopt innovations developed by other organizations. In many cases, MNEs work with local suppliers to help them introduce new technology — both product and process — to meet the MNE's specifications. At the system level, then, such MNE demands stimulate R&D and implementation activities by Chinese organizations and increase the overall performance of China's innovation system.

3.3.2.4. Education. Unlike the other activities within China's innovation system, significant new actors undertaking education activities have not emerged during the transition period, especially in science and engineering fields. Control over these activities also remains highly centralized in the Ministry of Education, although organizational boundaries have been expanding beyond education as universities and technical schools are allowed to pursue other revenue-generating activities, such as establishing new technology-based spin-offs. There are also increased expectations that universities will play a more important role in R&D activities. However, their role in either R&D or implementation of new innovations (through start-ups, as discussed above) is still secondary to dedicated research institutes.

Perhaps the most important change in this area has been the government's attempt to address important shortcomings, including the general problems of inadequate funding, backward pedagogical methods, and an irrational educational system structure (Fang, 2000). The most directly relevant development for China's innovation system has been the government's recognition of the need to increase the national capacity to produce graduates in the sciences, engineering and management. Starting in the early 1990s, the Ministry of Education has provided funds to promote graduate programs at the masters, doctoral and post-doctoral levels at a large number of universities. This has resulted in a steady increase in graduates in these fields in both absolute numbers and as a percentage of all graduates. For example, graduates in the sciences and engineering increased from 38% in 1991 to 49% of all graduates by 1995, with engineering graduates representing 75% of those (China Science and Technology Yearbook, 1998).

3.3.2.5. Linkage. Reforms drastically changed the nature of linkage activities in China's innovation system, affecting the distribution of this type of activity across organizations, the means that secondary actors use to influence it, and the emergence of new actors. Under the command era, specific government bodies governed the linkages between primary actors, dictating the transfer of output resources from one functionally specialized organization to another. For example, the Labor Bureau assigned university graduates to jobs in R&D institutes, manufacturers and other state-supported organizations. The industrial bureaus directed transfers of technology from research institutes to manufacturers, and of products from manufacturer to end-user.

Reforms have ended the government's direct control of resource transfers and other interorganizational coordination among primary actors in the innovation process. In some cases, the same administrative body has become a facilitator, and the primary actor is responsible for procuring the inputs they need, whether human capital, manufacturing technology, intermediate inputs, or final products. For example, the Labor Bureau now acts as one clearinghouse for those offering and those seeking jobs. New graduates may ask for a job assignment, but they also may find jobs through their own contacts. This has had serious ramifications for state-supported organizations, the end-user that previously could depend on highly educated graduates being directed their way. They are faced with a new and vital need to attract and retain S&T personnel, as well as other highly educated employees, who are in high demand in China's newly mobile labor market.

Well into the reform period, however, the government was frustrated by what it considered to be an inadequate transfer and exploitation of technology within the national innovation system (Saich, 1989; Lu, 1997; Baark, in press). For example, a survey by the State Science and Technology Commission revealed that only 15% of the output of 564 technology development projects funded between 1987 and 1991, which it would have expected to be applicable to industry, had been disseminated (SSTC, 1994). Part of the explanation had to do with incomplete changes by primary actors in response to reforms. There are still only limited incentives for individual scientists and engineers to tackle applied industrial problems within these organizations. More fundamentally, scientific personnel in these institutes and universities are still relatively unfamiliar with industrial conditions. Furthermore, there had been no government funding specifically designated for pilot plant and related feasibility studies. These factors left a gap that was not being bridged with the policy and incentive mechanisms the government had put in place.

Part of the government's effort to bridge this gap and better link activities and primary actors in the innovation process has been to establish a new set of actors; namely, quasi-governmental organizations with both policy and commercial objectives. Some of these focus on deficiencies in existing primary actors. For example, the government recognized that many manufacturers did not have the in-house ability to scale up and implement technology from research institutes. Therefore, since 1991 it has established engineering centers within well-run R&D institutes — concentrated in agriculture, energy, electronics, communications, materials, textiles, drugs and environmental engineering — to assist firms in implementing technology originating in these institutes. New productivity promotion centers help disseminate technology to firms without the financial capacity to adopt new technology. Over 28 thousand technology markets are operated by local governments and act as an agency overseeing transactions between suppliers and users of new technology. More recently, incubation centers in high-tech zones are charged with creating and nurturing new firms by linking R&D with implementation activities.

3.3.3. Performance implications and challenges for China's innovation system

Economic and enterprise reforms during the last 20 years have dramatically altered the structure and dynamics of China's innovation system. The system is no longer characterized by a strict division of labor among functionally specialized organizations, as primary actors are diversifying into other activities in the innovation process. At the same time, new primary actors have emerged or been created. Policies and institutional reforms have fundamentally changed the way decisions over activities — resource creation and allocation in the innovation process — are made. Operational and strategic decision-making has been decentralized from secondary governmental actors to primary actors, and more information flows directly among primary actors. This has been accompanied by forcing organizations to compete with each other based increasingly on their ability to perform functional activities more effectively and efficiently.

Of course, policymakers are concerned with the performance implications of the specific changes in the structure and dynamics of China's innovation system resulting from reforms. Although still in flux, there are overall positive developments in China's apparent capacity to introduce, diffuse and exploit technological innovations. First, aggregate indicators of inputs are showing a positive trend. Data from the Ministry of Science and Technology (China Science and Technology Statistics, 1998) show that over the 1990s, China's R&D expenditures have tripled to RMB 55 billion, although as a percentage of GDP it has been confined to 0.6–0.7%. Furthermore, the number of R&D units within organizations has increased dramatically, from 18,000 in 1987 to over 30,000 by 1998. Other indicators of technological outputs, such as scientific papers and patents, have also been increasing dramatically throughout the 1990s (Tables 2, 3 and 6).

Evidence of improved diffusion and implementation of technological innovations is in some cases indirect or ambiguous. The explosion in product choices that have become available to industrial and individual consumers suggest real improvements. On the other hand, researchers attempting to track changes in productivity that would reflect improved production methods, implicitly based on better production technology, have found mixed results. Some (Rawski, 1994; McMillan and Naughton, 1992) have claimed that SOE productivity has risen through out the 1980s and early 1990s, while others (Woo, 1997) argue that there has been little improvement after a one-time increase in the early 1980s.

Other researchers have argued that there have been dramatic improvements in the development, diffusion and implementation of technological innovations. Gu (1999), for example, has carefully documented the emergence of new technology enterprises (NTEs). She describes this as an "unlocking" of R&D assets from research institutes, since over 80% of these NTEs are spin-offs or primarily supported by research institutes and universities. This has been spurred by the cut in central government funding to these research organizations, coupled with changes in the legal and regulatory environment that allows them to establish such new ventures. These NTEs are leading the commercialization of advanced technology in the most science-intensive industries, such as computers and information technology, biotechnology, and new materials. Not only have the NTEs generated their own profits (Table 5), but they have also made new technology embodied in production equipment and inputs available to other manufacturers, thereby supporting quality and productivity improvements in these organizations.

Although the Chinese government has made dramatic progress towards a more effective and efficient national innovation system compared to its performance under central planning, a number of important issues remain. Most involve elements of the institutional environment and role of secondary actors, specifically (1) an incomplete shift from direct control by governmental secondary actors over primary actors, (2) perverse or inadequate incentives affecting primary actors' innovative behavior and related decisions, and (3) an inadequate legal environment that cannot yet provide a reliable environment for interorganizational relationships that are crucial in the innovation process. A fourth issue is the large and growing discrepancy among regions in terms of innovative activity, which the Chinese government has

Table 6
Total and joint Chinese science and technology papers[a]

	1992	1993	1994	1995	1996	1997
Total papers	98575	101983	107492	107991	116239	120851
Joint papers (% total)	13	13	15	18	17	18
Universities						
Total university papers	53405	57332	63361	66494	72447	76986
University papers as % total	54	56	59	62	62	64
Joint papers with						
Universities (%)	8.1	8.5	9.6	11.9	10.9	11.8
R&D institutes (%)	8.1	7.6	7.8	8.3	8.6	9.0
Firms (%)	3.2	3.5	3.7	3.9	4.2	4.4
R&D institutes						
Total R&D institute papers	25901	24621	24257	23623	24780	24821
R&D institute papers as % total	26	24	23	22	21	21
Joint papers with						
Universities (%)	17	18	20	23	25	28
R&D institutes (%)	6.1	5.7	8.3	7.6	6.9	6.9
Firms (%)	2.5	2.9	3.0	3.3	3.5	3.4
Firms						
Total firm papers	10489	10665	10134	8827	9022	8606
Firm papers as % total	11	11	9	8	8	7
Joint papers with						
Universities (%)	16.00	18.90	23.00	29.30	34.00	39.40
R&D institutes (%)	6.2	6.8	7.2	8.8	9.7	9.9
Firms (%)	1.8	2.1	1.9	3.5	3.5	3.7

[a] Calculations based on data from The statistical analysis of S&T papers of China, 1992–1997, China S&T Information Institute.

recognized but been largely ineffectual in addressing. A full treatment of these issues is beyond the scope of this paper, but it is necessary to outline the main implications they have for the overall performance of China's innovation system.

First, while the central government has relinquished most of its microeconomic planning role, it still relies heavily on an active industrial policy approach. The legacy of decades of top–down, central government control over all aspects of the economy contributes to this lingering tendency towards centralized guidance. It is reinforced by the government's perception of the modern industrial development process in Japan, South Korea, Taiwan and Singapore. Chinese policymakers have interpreted these late-industrializing countries' development success as being a result of an active role by the government in formulating industrial policy and providing strong direction to domestic organizations to implement it.

While there may be a case for an interventionist government role in promoting technological development, the Chinese government seems to have less understanding of the importance of managerial initiatives and objectives, especially towards building internal organizational capabilities and a culture of entrepreneurship, that made the development and economic success of its "model" countries possible. In this vein, Gao (2000) argues that simply increasing the number of R&D units and personnel within firms is not enough, and that China's current policies and programs do not fulfill the need for internal entrepreneurs who provide the "internal impetus" that is so crucial in the innovation process.

The Chinese government also has little experience in designing and predicting the outcome of policies that affect behavior without dictating it (Naughton, 1990). Its policies so far suggest that it is uncomfortable with the idea of simply establishing objectives without dictating means. This is particularly obvious in the government's approach to promoting linkage activities among primary actors. It has attempted to address the need for linkage activities in the innovation system by establishing new primary actors. These new actors essentially replace the central government bodies that, under the command system, undertook linkage activities. The government has been much less successful in motivating existing primary actors, especially state-owned manufacturing enterprises, to seek out linkages themselves. It has created new actors rather than focus on developing institutions that would motivate and support interorganizational linkages by primary actors involved in complementary activities. This is especially true for state-owned manufacturing enterprises that have been shielded from competition.

A second set of issues involves the perverse or unintended consequences of the government's making research institutes more dependent on non-government sources of funding. The current incentive structure does increase the motivation for research institutes to undertake revenue-generating activities. This does not, however, necessarily increase their motivation to conduct research, especially when other activities are more lucrative. Furthermore, they have little incentive to invest resources in mid- to long-term research projects or those whose outcomes are less certain.

The central government's reforms have also been inadequate to motivate most SOEs to innovate, part of the larger problem of inadequate performance by these firms. Essentially, the government has tried to rely on positive incentives to induce SOEs to undertake R&D. However, until SOEs are allowed to go bankrupt — the necessary discipline in an efficiency-based, competitive market system — the incentive for them to introduce process and product innovations will be inadequate. Furthermore, these firms still preferentially receive bank loans compared to firms of other ownership types, even though they are less likely to be able to repay them. While they swallow over 70% of China's industrial investment, their proportion of industrial output has decreased to less than 50% (Broadman, 1995; World Bank, 1997). The government's actions since the late 1990s suggest that it will continue to try to merge poorly performing SOEs into groups or with a successful SOE rather than allowing them to go bankrupt. This "safety through scale" policy, however, merely masks underperformance and does not promote greater innovation activities. Actually, by forcing successful firms to take on these ailing firms, it will probably reduce the ability of the successful firms to maintain, much less increase, their level of investment in innovation activities.

Performance of TVEs and other collectives that have emerged during the transition period provides a stark contrast with most SOEs. These firms now account for half of China's GDP and profits. These firms have no government safety net, and are quickly closed if they cannot maintain profitability. These firms are very proactive in implementing new technology and, given their resource constraints, undertake R&D that is vital for their survival. However, they primarily compete with small and medium SOEs in low-tech industries, such as cement products, textiles and foodstuffs, where innovation and technological upgrading has not required major investments (Report of S&T Development of China, 1999).

Third, policies and the legal infrastructure for assigning, exercising and protecting property rights are inappropriate for the stated objectives of its innovation system. China has proceeded so far in its economic transition by introducing competition first, leaving privatization until later (Stiglitz, 1998). The Chinese leadership has so far avoided privatizing state assets (as discussed above), in contrast to the policies of other formerly centrally planned economies that are also making the transition to market-based coordination. There is still neither legal framework nor recognized precedent for transferring the key elements of property rights, including the right to use, extract rents from, or transfer ownership of an asset. The resulting uncertainty surrounding property rights has hindered organizational restructuring that could make the overall innovation system more efficient and effective. There is still no general precedent for the government at any level to sell loss-making enterprises, even if they can find a buyer willing to take on the enterprise's debt. It also represents a barrier to the merger of organizations in different administrative jurisdictions, another reason that even the leading manufacturers in many industries have not been able to buy or merge with R&D or development institutes, or with manufacturers in other provinces.

Another result of China's inadequate system of property rights and legal enforcement is the disincentive it creates for investing in R&D and pursuing cooperative interorganizational, network-based strategies. As already discussed, unclear property rights and protection are one barrier to firms investing in R&D to pursue proprietary knowledge, especially in high-tech firms (Gao and Fu, 1996; Gao, 2000). Free-riding, possible under a weak intellectual property rights regime, clearly reduces the incentive for an organization to invest in R&D activities. China's patent law has undergone positive changes in both wording and implementation since enacted in 1985, motivated by the dual objectives of promoting technological activity within China and assuaging the fears of technology suppliers outside China (Liu and White, in press). The result has been a steadily increasing propensity to patent, matched by the growth in lawsuits claiming patent infringement (Patent Newsletter, 24 November 1998). Still, both domestic and foreign critics cite uneven implementation and inadequate enforcement (Dai and Xu, 2000). The patent system and intellectual property rights protection in general has an important effect on primary actors' motivation to innovate, and the government must continue to refine it, as well as coordinate it with changes in the legal system for its enforcement.

Similarly, organizations with different complementary assets are less likely to cooperate if the risk that they will not be compensated is high. This helps to explain the relative decline in the tendency of organizations to cooperate in later stages of the innovation process. The comparison of joint scientific and technical papers (Table 6) and patents (Table 2) provides a stark contrast in how patterns of interorganizational relationships are changing. The total numbers of both scientific papers and patents have increased dramatically over the period 1992–1997. The trend in the percentage of joint outputs, however, is very different for the two. For joint papers, the trend is clearly positive not only in the aggregate (joint papers as a percentage of all papers), but also each type of organization (university, R&D institute, manufacturing firm). In contrast, the trend for joint patents has been strongly negative for both aggregate as well as between each type of organization. Together, these trends suggest that all organizations are cooperating more in the upstream stages of the technological development process, but cooperating less in the downstream stages as the commercial potential becomes clearer.

One explanation of this trend lies in inadequacies in the current environment that undermine moves towards a more efficient system-level allocation and exploitation of resources through interorganizational cooperation. As governmental secondary actors withdraw from their central planning era roles as governors of interorganizational relationships, primary actors must rely more on formal contracts and trust (whatever the source of that trust; e.g. Zucker, 1986). If actors perceive that there is high risk in cooperation (such as the risk of opportunistic behavior by a partner, with no effective legal or other safeguards), they will try to avoid such relationships. For example, universities and research institutes currently have a strong incentive to choose to implement new technology themselves, even if the overall potential return is less, rather than sell or license the technology to a manufacturer and risk not being paid. Such inadequacies in interorganizational contract law is particularly detrimental in a system like China's in which the primary actors have traditionally been functionally specialized and so suffer from small-scale diseconomies as they undertake new functional activities. Although technology markets may make it easier to *transfer* knowledge assets, such as new technology, between organizations, they do not promote cooperative *creation* of such assets.

All of these challenges are exacerbated by the primary actors' severe resource constraints (both managerial experience as well as financial resources) and the absence of specific guidance about how to respond to the new demands for innovation, efficiency and effectiveness. Decentralizing decision-making to primary actors only results in better decisions if the managers in those organizations have the information and ability to devise and implement appropriate strategies. This is a key determinant of a firm's "economic competence" that differentiates firms (Carlsson and Eliasson, 1994) and which is particularly weak in large Chinese SOEs. That most firms continue to make similar products using similar technology, even in the current buyers-market, is an indicator that market-oriented behavior lags market-oriented reforms. This is particularly evident in organizations that were established during the central planning era. While there have been successful organizational transitions to the new market-oriented environment (e.g. Changhong (Lu, 1999)), most senior managers in these organizations cite lack of experience and

Table 7
Regional variation in innovation inputs and outputs[a]

Location	Invention patents 1985–1995 (% China)		Regional GDP[b] 1995 (% China)		RRD&E Personnel[c] 1995 (% China)		R&D expenditure[d] (% China)	
Eastern Region	7825	68	3661	63	750	56	6261	67
Beijing	2538	21.9	140	2.4	145	10.9	1452	15.6
Fujian	175	1.5	216	3.7	17	1.2	90	1.0
Guangdong	383	3.3	573	9.9	49	3.7	473	5.1
Guangxi	132	1.1	161	2.8	13	0.9	144	1.5
Hebei	383	3.3	285	4.9	46	3.5	258	2.8
Henan	300	2.6	300	5.2	52	3.9	355	3.8
Jiangsu	576	5.0	516	8.9	98	7.3	790	8.5
Liaoning	899	7.8	279	4.8	93	7.0	509	5.5
Shandong	656	5.7	500	8.6	68	5.1	444	4.8
Shanghai	787	6.8	246	4.2	100	7.5	1204	12.9
Tianjin	506	4.4	92	1.6	39	2.9	256	2.7
Zhejiang	490	4.2	353	6.1	32	2.4	288	3.1
Central Region	2238	19	1290	22	312	23	1401	15
Anhui	144	1.2	200	3.5	32	2.4	152	1.6
Heilongjiang	359	3.1	201	3.5	52	3.9	197	2.1
Hubei	500	4.3	239	4.1	72	5.4	313	3.4
Hunan	411	3.5	220	3.8	44	3.3	245	2.6
Inner Mongolia	74	0.6	83	1.4	19	1.4	63	0.7
Jiangxi	151	1.3	125	2.1	24	1.8	118	1.3
Jilin	344	3.0	113	1.9	40	3.0	197	2.1
Shanxi	255	2.2	109	1.9	28	2.1	118	1.3
Western Region	1521	13	848	15	272	20	1658	18
Gansu	128	1.1	55	1.0	23	1.7	141	1.5
Guizhou	86	0.7	61	1.1	19	1.4	57	0.6
Hainan	17	0.1	36	0.6	10	0.8	15	0.2
Ningxia	25	0.2	17	0.3	5	0.4	27	0.3
Qinghai	32	0.3	17	0.3	5	0.4	23	0.2
Shaanxi	399	3.4	100	1.7	69	5.2	425	4.6
Sichuan	582	5.0	353	6.1	105	7.8	797	8.6
Tibet	0	0.0	6	0.1	0	0.0	2	0.0
Xinjiang	52	0.4	83	1.4	16	1.2	70	0.8
Yunnan	200	1.7	121	2.1	20	1.5	101	1.1
Total	11584	100	5799	100	1334	100	9320	100

[a] Sources: Annual Patent Statistical Report, 1987–1997; China S&T Indicators, 1992, 1994, 1996; Statistics on Science and Technology in China, 1949–1989.
[b] RMB billions.
[c] Thousands.
[d] RMB millions.

managerial expertise as major barriers to making necessary adaptations (Gao and Fu, 1996).

Finally, innovative activity, closely linked with economic development, has been very uneven across regions in China (MOST, 2000; Liu and White, in press). In general, the Eastern Region,[5] including the coastal provinces, has benefited most from reforms. The Central and Western regions have lagged far

[5] The Eastern Region includes Beijing, Tianjin, Hebei, Fujian, Guangdong, Guangxi, Shanghai, Jiangsu, Zhejiang, Shandong, Henan and Liaoning; the Central Region includes Shanxi, Inner Mongolia, Anhui, Hubei, Hunan, Jilin and Heilongjiang; and the Western Region includes Guizhou, Ninxia, Tibet, Qinghai, Gansu, Xinjiang, Yunnan, Sichuan, Shaanxi and Chongqing.

behind in both absolute terms and growth in basic indices of innovative inputs (technical personnel, R&D spending) and outputs (scientific papers, patents and technology-intensive manufacturing and services), although there is also considerable variation within these three broad regions (Table 7). The Chinese leadership has recognized the potential social and political danger of allowing the already wide discrepancies among regions to continue to increase. In response, the central government has recently embarked on a broad "Develop the West" initiative, with ministries supporting specific programs under their domains. Targeted areas include education, science and technology development, physical infrastructure, and tax incentives for innovative activities and commercial ventures. Critics, however, doubt whether these programs and the relatively small funding they receive (especially for education) will have any appreciable impact on the relative paucity of technical personnel or the attractiveness of these regions as locations for scientific research and technology-intensive industry. Moreover, any meaningful change in the underlying social infrastructure to support more innovation activity in these regions will take decades to realize. This presents a dilemma for the central government. While it certainly needs to provide resources to support innovative activity and development in the Central and Western Regions, it is foregoing more immediate and probably higher returns in the Eastern Region.

4. Conclusions

The comparison of China's national innovation system under central planning and since economic reforms has illustrated the usefulness of a system-level framework to compare the structure, dynamics and performance of these two very different innovation systems. Anchored around the set of fundamental activities in the innovation process, it focuses attention on differences in the organization of these activities, as well as the dynamics and outcomes of change in the organization of these activities and the actors undertaking them. Furthermore, the approach and the questions that are the basis of this framework are not limited to China, transition economies, or even the national level of analysis. It also provides a basis for comparing the innovation systems of particular industries or regions within a country.

This approach, therefore, bridges the gap in the levels of analysis between the outcomes of interest — in this case, a nation's aggregate ability to introduce, diffuse and exploit technological innovations — and the individual elements of the system — actors and institutions. To explain system-level outcomes, prior studies of national innovation systems have actually described only elements of a system — categories of actors, institutions and policies — rather than system-level characteristics. The framework introduced in this paper, in contrast, has focused on system-level characteristics, such as the organization and distribution of activities in the innovation process, control and coordination mechanisms, and information flows, that affect the outcomes of interest.

Although critics of national innovation system research argue that this level of analysis is too aggregate and general to be useful, the issues it addresses are of concern and subject to influence by central government policymakers. National borders also represent important boundaries around alternative forms of organizing economic activity, including institutions, policies and differential outcomes in terms of technological development, sectoral specialization and performance. Research that identifies systemic weaknesses is a valuable and necessary input for discussions about how to improve policies and outcomes.

Although we believe that such an analysis can inform policymaking, we are aware of the limitations to predicting behavior and outcomes in such a complex system as a national innovation system. The system includes a huge number of actors (both primary and secondary) pursuing their sometimes complementary, sometimes competing interests. Policies and institutions shape and are themselves shaped by these actors' behaviors. A detailed analysis of how these elements interacted so that the system under central planning evolved into the current system is beyond the scope of a journal article. Similarly although we have discussed particular characteristics of the system that have a clearly negative impact on the system's performance, we have not made specific policy recommendations. The focus of this article was the comparison of the innovation systems of two different periods, and an adequate analysis and comprehensive recommendations for improving the performance of the current system is beyond the scope of this paper.

While the current paper could not address these issues, the system-level framework we introduce does provide the basis for comparing alternative system structures, dynamics and their relative performance. For example, our analysis does suggest that the current system is much more effective than that under central planning at introducing, diffusing and exploiting technological innovations. At the same time, there are important weaknesses and inherent contradictions that policymakers must address to increase the system's performance.

On the other hand, the implications for both policy objectives and specific measures are more ambiguous. It is far from clear that evolving into an innovation system similar to that found in developed market economies is a possible or even advisable objective for China or other countries emerging from central planning regimes and Soviet-style industrial organization.

This ambiguity relates to a broader issue that we have not been able to address in this paper, namely, the fundamental debate concerning the convergence or divergence in innovation systems across nations. Studies of less developed and transitional economies' innovation systems reflect an implicit assumption of convergence. For example, although the IDRC's (1997) report on China's innovation system studiously avoids specific recommendations, the issues it highlights as deserving attention reflect an implicit assumption that Chinese policymakers must think of ways to make their actors and institutions more like those of other "market" economies. Ironically, evidence from academic papers and conference discussions within China by Chinese academics and policymakers similarly reflect this bias towards essentially recreating the elements and structure of innovation systems in "successful" market economies.

As a result, shortcomings in actor's performance or resistance to policy objectives is seen as something to overcome, rather than an indication that there might be an alternative system that is equally effective and efficient in introducing and diffusing technological and related organizational innovations but more appropriate for a particular context. This response is appropriate and constructive only if we accept that national innovation systems will converge on a single "best" organizational and policy structure. Otherwise, it is necessary to accept the possibility that fundamentally different but equally viable national innovation systems could emerge in China, other formerly centrally planned economies, or other nations with similarly very different legacies of industrial organization and social systems. Studies of such countries could provide the data necessary to make comparisons of alternative system-level structures and their relative strengths and weaknesses. Policymakers would then be able to better evaluate which system structure is most appropriate, given the particular characteristics of their national context and the costs and likelihood of successfully introducing changes to move towards an alternative system structure.

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