

The transition from imitation to innovation: An enquiry into China's evolving institutions and firm capabilities^{*}

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Abstract

How is the Chinese economy making the transition from imitation to innovation as the source of sustained long term growth? We address this question using the evolutionary approach to growth in which institutions support technical advance and enterprises develop capabilities to learn and innovate. Growth is seen as a series of disequilibria in which obstacles to innovation such as outdated institutions and weak incentive systems can cause growth to slow. We review existing literatures on institutions and firm behavior in China and compare these findings with those of our survey of Chinese firms in 2006. Industry and firm studies in the literature show how productivity is rising because of firm entry and exit rather than the adoption of new technologies. A striking feature both of the studies in the literature and our survey is the increasing competitive pressures on firms that encourage learning. Our survey of privately owned small and medium enterprises in five high tech industries in Zhejiang province found a market-based innovation system and evidence of much process and some product innovations. These enterprises respond to growing product competition and demanding customers with intensive internal learning, investment in R&D and a variety of international and research linkages.

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Introduction

China's rapid growth and integration into the world economy is spectacular because of its speed and the potential size of its economy. But growth based on a strategy of imitation is unsustainable. The price of success as a major exporter of labor intensive manufactured goods is beginning to rise in terms of potential protectionist actions abroad and rising pollution from industrial production at home. The Chinese authorities recognize this. One of the main goals of the 11th Five-Year Program (2006-10) adopted in 2006 is "scientific development" and a determined emphasis to encourage "an innovation-oriented nation":

In the 11th Five-Year Program period, we will implement the strategy of rejuvenating our nation through science and education and take science and technology advancement and innovation as a major driving force of economic and social development. We will give more strategic importance to developing education and fostering high-quality talented people who are endowed with capability and integrity, deepen system reforms, increase input, accelerate the development of science, technology and education, and make great efforts to build an innovation-oriented nation and strong nation with abundant human resources (Government of Peoples Republic of China, 2006a).

In this paper we examine China's transition from an economy in which growth is based on labor intensive production and imported ideas and technology to one in which growth is driven by domestic innovation. The developmental challenge is to move to the technological frontier from a position that is well behind it. For a time, a developing economy can grow rapidly by reallocating rural labor into low-cost manufacturing and exploiting economies of scale. Eventually, however, this source is exhausted and growth slows down unless, as much historical experience demonstrates, it is sustained by technological advance and innovation.

If China is making this transition, we should expect to see institutions that promote technological advance and firms that develop new capabilities, technologies and products. This view is based on Nelson and Winter's (1982) evolutionary approach to growth. Unlike Solow's (1957) growth model and Romer's (1990) endogenous growth model which are based on macroeconomic theory, Nelson and Winters and others focus on decision-making in the firm. Like Schumpeter (1943) they see capitalism by its very nature as evolutionary and constantly changing. Growth therefore may be a series of disequilibria along a path strewn with obstacles such as outdated institutions, inappropriate incentives or obsolete technologies. Because these obstacles build over time, they may also be difficult to modify, causing growth to slow. The evolutionists call this the "disequilibrium trap". South Korea's experience is instructive here. Important drivers of South Korea's takeoff to sustained growth included high literacy rates and universal education, high rates of savings and capital accumulation, export oriented policies and rapid technological learning. It had a strong central government that intervened extensively in the economy and a strong entrepreneurial spirit, both in the large *chaebols* and in smaller businesses. Eventually some of these characteristics

became obstacles to sustained growth and reforms were necessary to free up market forces (Kim 1997).

Nelson (1993) advances a general view of how technological advance occurs in the modern world. First, most technologies are science-based, although technologies can also give rise to new science. Second, most innovations involve trial and error; there is no silver bullet to devising a product or process with desirable attributes and many approaches involve problem solving or design changes. Third, he stresses the significance of institutions involved in industrial innovation. These are not only enterprises but supporting institutions (more recently referred to as the “national innovation system”) such as universities, government agencies and public policies; the nation’s schools and skills training and retraining programs; labor market institutions; financial institutions and governance at all levels. They include a society’s culture, its economic constitution and organizations, and public services – what Abramovitz and David (1996) refer to as “social capabilities” that influence the responses of people to economic opportunities.

We use this approach in this paper. In the next section we develop three variables and describe the data we use in the study. The first two variables are inputs that influence technological advance and innovation and the third measures the outputs of innovation. The first input variable is a country’s institutions and their features that support or obstruct innovation, R&D and design and marketing. The second input is firms’ performance and activities: how they capture knowledge, how they produce innovations and how they use their knowledge to capture profits and market share. The outputs of innovation are such variables as patents and copyrights. In the third section, we examine China’s institutions, particularly the national innovation system (NIS) and the policies and incentives that support or inhibit the development and diffusion of innovation. In the fourth section we study firm capabilities and the factors that encourage or inhibit learning, innovating and capturing the fruits of innovation. If China is making the transition, we should expect to find the NIS supporting technological development and diffusion and firms acquiring new equipment, re-organizing productions and marketing, raising productivity and creating new products and processes in order to grow. The fifth section contains our conclusions.

Variables and data used in the study

Institutions as input variables

Institutions as inputs include Nelson’s and others specific to China including science and technology (S&T) targets within a S&T development plan, enterprise ownership, and policies encouraging openness and infrastructure such as the Internet. A common aggregate measure is R&D spending as a ratio of GDP (R&D intensity), which varies by industry and is, of course, only one driver of innovation. China’s R&D intensity reached 1.6 percent in 2006 compared to 2.5 and 3.2 percent in the United States and Japan, respectively (OECD 2006).¹ R&D spending was mainly allocated to industry in 2004 (67 percent), with 10 percent going to higher education institutions. While these allocations are broadly in line with OECD averages the share allocated to government

research institutes was twice the OECD average. United Nations (2006) reports China's heavy investments in human resources in science and technology. By 2003 China had 926 thousand researchers, second only to the United States in number. It has also pushed ahead rapidly in cellular telephone use with 215 per thousand people compared to 664 per thousand as the OECD average.

Ownership is a significant institutional variable in China because of radical enterprise restructuring since the mid-1990s. Ownership forms have evolved from mostly state owned enterprises (SOEs) to a mix of SOEs, collectively-owned and non-state enterprises that often include government and private investors, as well as private and foreign-owned enterprises.

China's policies towards trade and foreign direct investment are also institutional variables. Export promotion encourages firms to learn to penetrate new markets and to achieve scale economies. Imports often embody knowledge which is added to the capital stock directly or encourages firms to learn by imitation. FDI and co-operative forms of production such as alliances and joint ventures involve learning through technological diffusion. Significantly, in each of these transactions there can be spillovers of knowledge to other firms and consumers as employees move, suppliers are trained, competition with other firms encourages imitation, and prices fall.

The Internet also influences innovation by facilitating rapid knowledge diffusion and the ability of multinationals to decentralize R&D functions. Foreign firms' use of information technology (IT) to manage increasingly complex and fragmented supply chains is shortening the product life cycle, even turning it on its head, as China becomes the location of both low value-added and some higher value-added products (Liu 2005). IT facilitates modular production² in which firms specialize in one aspect of a cross-border production process led by a foreign firm outsourcing design and production. Outsourcing design functions has become more common as multinational firms change their attitudes towards home-based R&D laboratories and decentralize them to cooperate with local laboratories.

Firm performance as input variables

How and how quickly do firms learn? One channel is through knowledge spillovers from foreign-owned firms to domestic firms and agents of production.³ Many Chinese firms imitate imports from foreign competitors and make small product and process improvements. They also purchase or license technologies from foreign firms and from research centers.

Another channel of firm learning is internally generated. In theory, firms achieve higher productivity through technological/ organizational advances in finance, management, outsourcing, and production as well as marketing. Productivity improvements are also achieved by improving product quality. And learning can be acquired through the diffusion of innovative products or processes through markets. This channel requires investments of financial and physical capital in some cases, or intangible/ human capital in other cases, or both.

Enterprise learning and innovation is also influenced by curious and demanding consumers. In serving the huge domestic market Chinese enterprises differentiate products to serve diverse customer needs; they also capture rural markets first before taking on foreign competition from multinational firms in city markets. These activities are apparent in data that show that Chinese firms obtain larger shares of design patents than invention patents (Liu 2005).⁴

Consistent with evolutionary growth theory, a number of obstacles can hinder enterprise learning and innovation. One obstacle is enterprises' own weaknesses such as lack of indigenous skills to capture spillovers from imports or the presence of foreign firms. These skills may be weak in part because the more complex technologies involving tacit knowledge are often embedded in individual or group know-how and organizational structures, and therefore are costly to transfer. Even the transfer of tested machines replete with blueprints and instructions can be difficult as Von Hippel and Tyre (1993) found, noting 27 problems that affected two new process machines in factory production.⁵

Enterprises may remain focused too long on imitating foreign competitors, making small product adaptations and design improvements, and be unable to develop the capabilities to introduce new products or processes. Such a pattern will be difficult to change unless and until outdated institutions and incentives are appropriately modified. These obstacles are magnified by lock-in and path-dependence, where the choice of one technology and the related improvements from usage and learning by doing make it difficult to switch to other more profitable technologies in the longer run.⁶

Another obstacle can be the reluctance of firms originating technologies to allow access to core technologies because they are unable to appropriate the returns to the innovation, or because they fear the prospect of the recipient becoming a new competitor.

Output variables

The third set of variables, the outputs of innovation, is most commonly measured as patents and copyrights. In 2003, China lagged the OECD average of 248 patents per million population, producing only 5 per million (United Nations 2006). Another measure focuses on the development of tacit knowledge in the form of products or processes so that it can capture and hold a significant market share, both domestically and internationally. Often such investments are reflected in product diversification or in knowledge of production processes which are not easy to imitate, especially where intellectual capital is well protected. Countries such as South Korea and Japan, which borrowed technology while at relatively low R&D intensities, eventually found they had to invest heavily in R&D to develop new products and processes. Taiwan, which did not invest in high levels of R&D activity and related branding, developed an unusual capability for process innovation in which firms organized and reorganized quickly to share production for short periods.

Outputs are also measured by such variables as the share of high tech exports in total manufactured exports. China's performance is exceptional; in 2003, 27 percent of its manufactured exports were high tech compared to an OECD average of 18 percent, but performance in a broad range of medium technology exports was weaker (OECD 2006).⁷ As we will see in the third section, high tech export data can be misleading as an indicator of technological capabilities because production occurs in international networks within which high valued added components are largely imported. Indeed, UN data on technological performance for the late 1990s ranked China 45th among 72 countries (that is, among the top third of those labeled dynamic adopters) but well below those labeled leaders and potential leaders (U.N. 2001). Sachwald (2006) summarized four indices of technological capabilities in 47 developed and developing countries in the late 1990s and early 2000s. China ranked 33rd in one classification and between 39th and 41st in the other three – considerably below the developed and a dozen developing and transition economies.

Data sources

We use two main data sources. The first is three literatures that include statistical studies based on national surveys of large and medium-sized enterprises (LMEs) by China's National Bureau of Statistics (NBS); studies of the sectoral composition of China's exports; and industry and firm studies.

The second data source is from our own survey of small and medium-sized enterprises (SMEs) in Zhejiang province undertaken in June 2006. This survey provides insights into local institutions in Zhejiang, the most advanced province in freeing up market forces and supporting market-based innovation. The enterprises are all in high-tech manufacturing and include general machinery (2), electronics (2), electrical equipment (2), telecommunications equipment (2) and pharmaceuticals (2). They share similar ownership, industry and business characteristics which make them of particular interest. Four enterprises have more than 1500 employees while the others have between 300-700 employees (Table 1). Two enterprises had assets worth more than 1 billion yuan in 2005 while assets of the others ranged from a high of half that size to as small as 30 million yuan. Only one firm had annual sales of more than 1 billion yuan. All are private and located in industrial parks or industry clusters with good public infrastructure and government support. All have grown rapidly in the past decade of national industrial restructuring and face intense competition.

China's Institutions: the national innovation system

How supportive are the institutions of China's national innovation system (NIS)? In this section we first review evidence in the literature and consider our own survey findings in that context. A country's national innovation system is distinctive because it develops from existing private and public institutions. China's recently-announced "Mid to Long Term Science and Technology Development Plan, 2006-2020" has two bold aims: (1) to raise R&D intensity to the current OECD average by 2020 (increasing spending as a share of GDP from 1.3 to 2.5 percent); and (2) targets for particular sectors "to reduce sharply reliance on imported technology, obtain advanced core technologies in the equipment manufacturing and the information industry, increase agriculture

productivity and ensure national food safety, make a breakthrough in energy development, energy saving technology and clean energy technology and build several world-class science and research institutions and university and form a system for innovation that is characteristic of China” (Government of the People’s Republic of China 2006b).

Science and technology has been the cornerstone of China’s development strategy since the 1980s, with a heavy initial emphasis on public funding of projects and investment in infrastructure (Sachwald 2006). The architecture of China’s NIS has evolved from a central-planning model in which industrial R&D centers are located in ministries and organized by product. This structure effectively separated and prevented communications among producers and users. Since the mid-1980s government has encouraged closer integration among R&D institutes and science parks through investment in R&D clusters, and mergers of R&D institutes into enterprise groups (some such as Huawei, Datang and Lenovo subsequently evolved into major IT enterprises). As a result of such policies and China’s openness to FDI, technology market transactions increased, as did in-house R&D. Outsourcing of science and technology from universities and research institutes to various types of domestic firms and to international firms expanded, although the share of the latter is still relatively low (Motohashi 2006). Multinational firms are now locating basic research facilities in China to take advantage of the abundant supplies of low-cost skilled researchers in Beijing and Shanghai (OECD 2006).⁸

The strong government role in investing and restructuring the NIS suggests the government has not settled a key question: whether to concentrate on scientific mega-projects or incremental innovation. Careful international research into characteristics of successful innovation policies has concluded that such policies are more likely to succeed if they promote incremental change rather than “big bangs” or leaps and structural changes, and if the private sector is given leeway in dealing with the inevitable uncertainties involved (Lipsey and Carlaw 1996).⁹ Initial conditions are important. Removing obstacles takes time and change is likely to be incremental as institutional and regulatory barriers are removed and sunk costs and learning costs are absorbed. It is not until many of these obstacles are removed that the incentives are in place for more rapid changes or large leaps. Recent South Korean experience illustrates how, in the absence of appropriate checks and balances, ambitious “techno-nationalist” goals and public funding for stem cell research set by the government figured in the rise – and fall – of the researchers and their institution. Reports in the prestigious journal *Science*, that Korean researchers had created the world’s first stem cells from cloned human embryos, were subsequently exposed as fabrications.¹⁰

The literature notes a number of inappropriate policies and institutional inadequacies that influence the incentives for China’s enterprises and economic agents. Kroeber (2006) argues the Plan fails to recognize the importance of non high-technology, incremental innovation, driven by competitive forces that is widespread. Hout (2006) also argues that the incentive structure for technology-based innovation is shaped by firms in the private sector responding to market forces, not government policies and funding. He

notes how China's weak protection of intellectual property rights reduces the incentives to innovate. Gu and Lundvall (2006) argue that reforms have led to a "system" that is oriented more to international markets than to local and domestic ones. Foreign firms dominate the export sectors so it is inevitable that they would develop, and governments would encourage, linkages with and among the international firms (including their joint venture partners). But this emphasis proved costly for local firms in that similar linkages within the domestic sector were not developed. "In general potential local or domestic links along and between value chains have been slow to develop and hard to expand" (Gu and Lundvall 2006). As well the technology markets introduced as far back as 1985 have failed to develop on the scale expected; instead R&D and production became vertically integrated to internalize the risks and costs, a feature commonly found in centrally planned economies.

These weaknesses documented in the literature suggest lock-in effects in China's NIS. Continued vertical integration is a central planning legacy which is slow and difficult to change and undermines incentives for incremental innovations by non-state firms. Preferences for high tech projects and international markets may stimulate learning but can discourage export-oriented firms' learning to innovate on their own.

Our study of enterprises in Zhejiang province held many of these institutional factors constant in that the provincial government has long been in the vanguard of market-friendly administrations. Not surprisingly we did not find some of the weaknesses noted at the national level. Growth of private sector activity has been rapid for several reasons. The first is the relative absence of SOEs. China's central planners located SOEs in the hinterland, fearing Zhejiang's proximity to the coast as a source of vulnerability. People moved into this vacuum by relying heavily on their own ingenuity and networks. The local government tolerated markets; light industries requiring little capital or skills developed around clusters in which competition was intense and a high degree of division of labor developed among otherwise very small enterprises (Kanamori and Zhao 2004).

The enterprises we studied regarded the Zhejiang government as supportive and market-friendly, investing in transportation infrastructure and R&D and industrial parks, and providing common services, some project funding and loan guarantees. Three telecommunications and electrical equipment manufacturers emphasized competitive pressures, their own methods of knowledge collection and exchange, and reliance on demanding customers as more important than the NIS. But the majority indicated their reliance on institutions in the NIS through a variety of linkages. These include direct interactions with local or national technical institutes and the activities of owners, directors or consultants as university administrators or professors (3 cases). Technical professors at Zhejiang University often start their own companies or act as directors of companies in addition to their teaching and research activities. One enterprise was founded by a university department and then spun out. Another was involved in joint research projects with the local government research institute; another actually invested in a university laboratory. Other firm linkages included regular interactions with the university and the Chinese Academy of Science, collaboration with universities in

creating industry standards (2 cases) and a financial contribution to university scholarships (1 case).

We also note that the telecommunications and general equipment manufacturers (firms 3, 5, 6 and 9) encountered problems with incentive structures created by governments. The growth of one of the smaller telecommunications equipment enterprises was suffering from uncertainty and delay in standard setting that strongly affected its product segment; the other faced financial difficulties attributed to its SOE customers who were very slow to pay. One electrical equipment firm faced stiff competition from a SOE with military connections producing military products and another faced problems of technology imitation by domestic competitors and lack of IPR protection despite its patenting activities.

Firms and firm capabilities

In this section we examine how firms learn, develop new products and processes and human resources. Firm level surveys in the literature show two things. First, Chinese firms depend on the diffusion of knowledge from imports and foreign producers. Enterprise and industry studies, however, show that market forces are encouraging firms to raise productivity and develop industrial capabilities through the creative destruction of firm entry and exit. Second, while national institutions have changed the incentives to learn and innovate, inappropriate structures still exist.

Dependence on foreign producers is evident in studies of the sectoral composition of China's exports using Customs General Administration data. These studies show that China's major manufactured exports are based on adaptation or industrial upgrading, not by domestic firms, but by foreign firms and joint ventures. Feenstra and Hanson (2005) found that foreign invested enterprises' (FIEs) exports accounted for 48.4 percent of total exports in 2002 and 55 percent in 2004 (Whalley and Xin [2006]). Gilboy (2004) using the same data source shows that in 2003 foreign firms and joint ventures produced 77 percent of China's exports of industrial machinery. Foreign firms were just as dominant in the products commonly cited as evidence of China as a high-tech exporter, producing 90 percent of China's exports of computers, components, and peripherals and 71 percent of exports of electronics and telecommunications equipment. In consumer electronics and IT hardware the *domestic* value added in China's exports is still only 15 percent (Branstetter and Lardy 2006); and while China assembles and ships the major part of the global value of laptops each year, only 10 percent of the typical branded laptop's value added originates in China, mostly from Taiwanese subsidiaries (Hout 2006).

Fuller (2006) argues that basic innovation is weak among domestic firms. Three-quarters of R&D is in development, rather than in research, and patent applications are dominated by foreign firms. Gilboy (2004) argues that Chinese-owned firms lag behind foreign-invested enterprises because they have failed to invest in long term technological capabilities. Horizontal networks – with research institutions, financiers, partners, suppliers and customers -- are valuable in transforming knowledge, capital, products and talent. But China's political system favors vertical political and bureaucratic

relationships particularly at the regional and local levels, in which firms must rely on relationships with bureaucrats and politicians for subsidies and other favors. The result is to limit intra- and inter-industry contacts. Industry associations are controlled by the Communist Party, leaving few channels for firms to work together on common interests. Party officials tend to promote local growth and investment which leads to corruption; limited cooperation across regional or bureaucratic boundaries leads to fragmented industries and overlapping investments. The negative impact on industrial efficiency helps to explain why higher-technology industries and exports are heavily weighted to foreign firms.

A study of the firms located at Zhongguancun (ZGC) Science Park in Beijing, China's pre-eminent research park, describes a similar lack of trust in potential partners by such firms:

...which stems from ZGC's incapacity to ensure accountability, protection of intellectual rights (sic), or legal conduct of enterprises. Not only is there no information source to check the references of potential partners, there is also little recourse for illegal or unethical conduct. If contracts are violated or firms are cheated, the victim has to assume full costs to right the wrongs. The high risk of external transactions discourages flexible network arrangements (Zhou 2005).

Many authors note the impact of China's institutions on firms' incentives. Alwyn Young (1995, 2000 and 2003) found evidence of extensive distortions created by government intervention in trade and industrial production. Dougherty and Herd (2007) analyze the NBS industrial firm database for 1998-2003 and conclude that such barriers have fallen. Private firms have broken away from government intervention, transforming the productive landscape by creating and expanding new businesses. Brandt et al (2007) note lags in development of firm capabilities in interior regions, continuing barriers to links across regions, the negative effects of high state ownership and government regulation in some sectors, and limited contract enforcement and weak property rights. Motohashi (2006) used the NBS database to examine the growing links between public research institutes and industry and concluded that, despite reforms in the NIS, the technological capability of Chinese manufacturing firms is still low relative to firms in developed countries. Jefferson et al (2006) conclude that their findings on productivity growth imply the need for a long list of institutional reforms, of which property rights and corporate governance are key, to enhance the incentives and opportunities to develop and employ new technologies.

Despite these weaknesses, the LME data show that Chinese firms are raising their productivity and extending their capabilities. Jefferson et al (2006) examined labor and capital productivity of entrants, survivors and exiting firms. While labor productivity of entrants was marginally lower than that of survivors, the capital productivity of entrants was 61 percent greater than that of survivors in the 1996-98 period, and more than 150 percent greater in later periods. These findings suggest that the birth and death of firms is an important source of productivity growth. They also suggest that productivity

improvements are due to improving allocation of labor and capital deepening rather than the adoption of new technologies.

Brandt et al (2007) in a detailed study of industry development show rising capabilities in a number of sectors (but not all).¹¹ They too emphasize the importance of intensifying market competition on the birth and death of firms; uncompetitive enterprises, often SOEs, are weeded out and collective, private and foreign-owned enterprises enter. The survivors are building a variety of capabilities as measured by exports net of imports, exports of know-how and higher quality of the parts produced. One area of success is in new industries such as color televisions where China has become a leading global producer. In established industries the picture is mixed. Some firms quickly moved toward international productivity levels. By 2000 China was the world's largest steel producer; both cement and textiles and apparel producers have adjusted to market forces successfully. The auto parts industry also shows success in that production capabilities have been effectively transferred through auto parts supply chains from international car-makers and first-tier component suppliers; however, quality declines rapidly in second-tier suppliers (Sutton 2004).¹² In other industries, high transport costs have segmented markets; others remain inefficient, a pattern due in part to a continuing preference for state ownership and control of large producers.

Our analysis of Zhejiang-area firms' R&D expenditures, new products and processes takes a broad view of what is involved in building technological capabilities, recognizing that such capabilities are incrementally developed and based on tacit knowledge embedded in the skills of the workers and the routines of the firm.¹³

R&D performance in the Zhejiang survey firms is strong (Table 2, columns 2 and 3), as we expected in choosing the industries for study. R&D expenditures cluster around 4-7 percent of total sales in half the firms, up to as high as 10 percent in an electrical equipment manufacturer, and as low as 1.5 – 2 percent in the two general machinery firms and the telecommunications equipment manufacturer in a mature and highly competitive industry segment. These figures are similar in range to those of Jefferson et al 2006 who found that R&D averaged 3.3 percent of sales in 5,050 LME firms in a 1999 sample. Their work also compared inputs and outputs by ownership. They found that the important determinants of R&D effort are profitability, technological opportunities and ownership structure as a proxy for the incentive structures in the firms and their regulatory environment.

In our survey of private SMEs R&D per employee corresponds to the LME findings; it is lowest in a general machinery firm (#1) and highest in an electronics firm (#2); the others are arrayed between 10 thousand and 50 thousand yuan per employee per year (Figure 1). The differences between these two enterprises are of interest. Firm 1 is a former SOE established in the 1960s. In 2000 it was a money-losing SOE which was transformed into a collectively-owned non-state firm through the transfer and sale of its productive assets to managers and employees. Half the work force bought shares and the other half left the company. Since then, this enterprise has become a competitive supplier of low-end machine tools but faces stiff competition in higher value added products.

Management reports investing “heavily” in customer-driven R&D, using the NIS and purchases from foreign firms as well as in house incentives and activities discussed below. Firm 2 is at the other extreme. It is a 1997 startup in the semiconductor industry. Its founders, employed in a SOE, resigned to pursue design opportunities they spotted during China’s IT boom. By 2003 they were able to raise capital cheaply through an A-share IPO on the Shanghai Stock Exchange. This firm has grown rapidly, employing 20 people in 1999 and 600 in 2005. By 2006 40 percent of their customer base was local and 60 percent foreign. Their R&D expenditures include patent purchases, acquisition of a California subsidiary to source information and benchmark their products, and investments of internal resources in profitable products, process development and speculative “long shots”.

What are the R&D activities in the survey enterprises? The search for new products or design modifications to existing ones? The short answer is both. We found strong evidence that both new products and processes were produced in response to intense market pressures that push the firms to learn through internal processes and external linkages. Between 30 to 50 percent of R&D expenditures were allocated to modifying and testing products, while similar shares were allocated to new product development (Table 2). Generally, firms spent ten percent or less of R&D spending for new *process* development and about ten percent for long-term non-commercial development. In four cases R&D spending was financed entirely from retained earnings while others used a mix of their own funds and various amounts of government funding. Only two acknowledged using any bank finance.

Among these firms we found examples of significant process innovation. Firm 1 expanded its sales by improving old technology, changing its management structure and decision-making processes to be more flexible in response to expanding opportunities. Two other firms even changed what they produced. The pharmaceuticals firm with the high intensity of new product sales (Firm 11) began as a cement producer. The owners then learned about superior market opportunities in commodity chemicals and eventually acquired a dominant position in the global market for a particular dye product as the lowest-cost supplier. Subsequently this firm expanded into pharmaceuticals, learning as it went by hiring the appropriate technical talent. The other pharmaceutical firm (#7) specializes in traditional Chinese medical products. Responding to customer demand it adopted a number of marketing innovations to broaden its customer delivery systems. The fourth case is a telecommunications equipment producer (Firm 3) which responded to intensifying product competition by changing its products to focus its resources on the latest technologies while also increasing both its research and marketing staff. It also developed automated process testing to reduce drastically the time involved in product testing.

Innovations reflect the commercial application of a firm’s knowledge. We asked which of nine sources of innovation were most relevant to each firm (Table 3). Most indicated some form of benchmarking with other firms in terms of R&D and technological change, ranging from scanning for changes that could lead to potential competition to participation in technical meetings so as to keep up with information.

When firms ranked the sources of innovation by importance, the top four by rank suggest the working of market forces: (a) pressure from competitors, both domestic and foreign, (b) demands from customers, (c) imitation of competitors including reverse engineering, and (d) linkages with universities and research institutes. As noted in the previous section there were exceptions where firms reported more important sources to be linkages with foreign firms.

Most of these relatively young firms managed rapid growth in sales, assets and employment based on new products. New product sales in 2005 ranged from 15-30 percent of total sales in four firms to 60-70 percent in three others (Table 2). Considerable industry variation is apparent, with general machinery firms reporting between 20-60 percent new product sales, electronics and telecommunications and electrical equipment reporting between 30-70 percent and between 14 and 57 percent in pharmaceuticals. By comparison, Jefferson et al (2006) ranked electronics and telecommunications at the top of their list with new product sales above 40 percent for reporting firms (and above 22 percent for all firms), followed by electrical equipment at 32 percent (18 percent for all firms). Medical and pharmaceuticals firms ranked ninth with new product sales between 20-24 percent for reporting firms – but with a very high growth rate.

How is technology developed: internally or through transfers through the market or through FDI? The LME studies show that technology transfers are more productive when the recipient firm is also engaged in internal R&D. FDI does prove to be a channel for the transfer of proprietary technology within the firm. Foreign invested firms are less likely, however, to absorb market-mediated technology. Foreign firms appear to prefer to transfer through informal intra-firm channels rather than utilizing technology markets (Hu et al 2005).

The Zhejiang enterprises' acquisitions of foreign assets served two purposes: access to technology and access to foreign markets. Only one enterprise (#10) attracted a foreign investor. Three enterprises (1, 3 and 6) acquired core technologies from foreign firms while three enterprises (2, 5 and 6) either set up or acquired foreign firms for marketing and distribution purposes.

Much of their learning and development of their capabilities resulted from internal processes in response to market pressures. Firm 1 reorganized production, outsourcing much of its parts production in order to focus more on its core capabilities. Firm 2 used its own software to develop a plant to assemble its core product. It outsourced a number of inputs to local suppliers and set up a marketing firm abroad to market the final product. The core technology for firm 5 originated in the local university where the founders were employed. They resigned to focus on development and commercialization. Facing intense product competition and rising costs of inputs from multinational suppliers, they have responded by expanding abroad to take exploit their low cost advantage. Firm 6 adapted its foreign technology to Chinese customer demands and also faces stiff local competition. IPR has become a big issue. The firm's response is

to create barriers to entry with R&D, patenting and a heavy emphasis on brand development.

These enterprises also develop their capabilities through internal knowledge-sharing processes. Discussions among workers and informal knowledge sharing with other firms are among the top four sources of innovation in three firms and incentives are specifically used to encourage such learning. Nine firms use rewards for new ideas in the forms of bonuses, stock options or promotions. These rewards vary in part because of the nature of each firm's operations. Six of the firms met regularly with production workers to discuss new products and processes; four of these firms had bonus systems for suggestions or improvements in these respects. All nine had one or more ways to reward non-production employees for meritorious performance. Two noted an annual evaluation of R&D staff as the basis for bonuses, two rewarded project teams for improvements, three gave stock options to key staff and one had this under consideration, and three gave bonuses and sometimes other recognition for patent or copyright development.

As these findings imply the quality of their human capital is fundamental to these firms' learning and innovation records. Table 2 (sixth column) summarizes skill levels. Skilled employees, ie with a diploma or further formal education, were 25-45 percent of total employees in three firms and 80-100 percent in three others. Among senior managers, everyone had a B.A. or even higher education in four cases; in three cases 80 percent or more had a similar skill level, in two others the proportion was 50 percent or more.¹⁴ Research staff had less formal education and production staff even less. In only one enterprise did as many as half the employees have a B.A.; this level of educational attainment in the others clustered around 5 percent of employees.

Improving the quality of their human capital is also important. Six firms provided orientation training for new employees at all levels of employees including management. Six firms noted specific provisions for continuing education of management, researchers or production staff. In one case, the training was on demand for all groups, in three it was from one to four weeks yearly, in two firms management and research staff had over one month of training each year. Four of the six firms noted they sponsor further formal education or refund tuition for some employees, and four noted they use external staff, including foreign experts, for training. Three of the four firms which did not give information by groups of employees indicated they provided training both in-house and external beyond that on first employment and one sponsored further formal education. These training figures seem modest, given that most of these firms are relatively technology intensive and face strong competitive challenges.

In summary, in this section on Chinese enterprises we see in the literature that exporters are dependent on foreign partners and suppliers. These enterprises operate within an institutional context which still has weaknesses rooted in central planning. Productivity improvements in LMEs depend more on resource allocation than on new technologies. Industry studies also paint a picture of intense competition and creative destruction with productivity rising and quality improving as uncompetitive firms die and new firms enter an industry. Our study of SMEs also found incentive problems but shows

rising capabilities among fast growing startups that leverage the assets of foreign firms more through links initiated by the Chinese firms than through FDI. They also leverage the network of technical institutions in Zhejiang and beyond. Most notably, however, is the strong emphasis on internal learning processes and the development of their own stocks of human capital. We examine the evidence of outputs from these activities next.

Outputs of R&D and Innovation

What are the outputs of innovation? If China is successfully making the transition from imitation to innovation we should expect to see growth in patenting activity and other outputs. The studies of LME behavior show that patent applications have growth through time. Hu and Jefferson (2006) show LME patent applications growing in the 1987-99 period at an annual average rate of 15 percent; this rate accelerated to 23 percent between 2000 and 2004.¹⁵ Patents are of two kinds: incremental and design innovations called “utility” patents, and those with an element of novelty. Foreign and domestic firms filed similar numbers of patent applications for novel innovations but in the post-2000 period foreign firms were far more successful in securing patent grants. Patent applications have grown strongly, but from a low base.¹⁶

Firms in our survey also created intellectual property and differentiated products (Table 2, column 8). One of the larger firms began with five patents in 2000 which grew to 80 in 2006. Two other larger firms produced several patents each year, while three medium-sized firms and one smaller one managed between three and ten each year. Only two firms reported any foreign patenting. Patent intensity (Table 2) is consistent with the findings of Jefferson and his co-authors; our survey of private firms showed patent activity at 5-6 patents per year among reporting firms. Jefferson et al (2003) found 7.31 per year for private firms.

Trademarks are concentrated in five firms in the pharmaceutical, electronics and telecommunications and electrical equipment producers. Two large firms showed steady increases in the number of trademarks in recent years to a stock in each case of between 140 and 170. Another large firm had only one recent trademark but it was highly important to the firm’s brand. One had a few trademarks from an earlier period and one had just acquired several. Assuming the non-reporting firms had nothing to report, the trademark activity is narrowly concentrated as yet. Branding activity, reported in Table 3, is associated with the larger firms in both pharmaceuticals and electronics. One smaller electrical firm had also achieved some success with branding, led by a particularly ambitious manager with goals and aspirations to differentiate the firm’s product in the national market.

Conclusion

We have argued that if China is making the transition from imitation to innovation we should expect to see institutions that promote technical advance and firms that develop new capabilities, technologies and products. A striking feature both of the studies in the literature and our survey is the increasing competitive pressure on firms that encourages learning. Intense product competition and demanding customers encourage rising R&D spending and the development of new products and processes, imitation of

competitors, linkages with foreigners and local research institutions, and increased emphasis on incentives and development of human resources in their own organizations. We found evidence of some new inventions measured by novel patents granted, but most innovations were adaptations and process innovations. Both Gary Jefferson and Loren Brandt and their co-authors point out how productivity is rising because of the creative destruction of firm entry and exit rather than the adoption of new technologies. Our survey emphasizes the reliance by enterprises on internally-generated processes to promote learning. This behavior will continue to evolve and it would be helped along by further reform to protect property rights and remove distortions created by regulatory uncertainties and the lack of a level playing field with SOEs. Our work in Zhejiang also suggests that at least one provincial government seems to understand the importance of firms making their own decisions based on market signals.

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Table 1. Selected Indicators of Firm Performance, 2005

Firm No.	Industry (1)	Employees (number) (2)	Assets, 2005 (RMB m.) (3)	Annual sales (RMB million) (4)	Brand (5)	IPO (6)
1	General machinery	2,300	60	672	No	No
10	General machinery	700	200	400	No	No
2	Electronics	600	1,200	630	Yes	Yes
8	Electronics	1,500	587	600	No	No
5	Electrical equipment	600	30	300	No	No
6	Electrical equipment	348	168	100	Yes	Not yet
3	Telecom equipment	440	220	220	No	No
9	Telecom equipment	285	500	300	No	No
7	Pharma	1,900	1,155	866	Yes	Yes
11	Pharma	1,900	400	1,200	Yes	Not yet

Source: Authors' interviews, firms' annual reports for data in all tables and Figure 1.

Table 2. Selected Indicators of Firms' Learning, 2005

Firm No.	Industry	R&D (% of sales)	R&D (per employe)	New product sales, (% total sales)	Skilled employees, (% total) /b	Obtain foreign technology?	Patents (stock and flows)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	General machinery	1.4	0.004	60	80-90	Yes	19
10	General machinery	1.5	0.009	20	25	Yes from foreign investor	No
2	Electronics	6	0.063	30	100	No	5-10/yr. since 2000
8	Electronics	6	0.035	70	N.A.	No	83 in 2005
5	Electrical equipment	10	0.050	40.	91	Acquired from MNE suppliers	3-5 software copyrights /yr
6	Electrical Equipment	4	0.013	N.A.	N.A.	Imported from foreign suppliers	6/yr.
3	Telecom equipment	7	0.035	N.A.	N.A.	Yes. R&D system adapted from foreign partner	3 since 2003
9	Telecom equipment	2	0.025	67	25	No	6 process patents
7	Pharmaceuticals	5	0.023	14	44	No	50
11	Pharmaceuticals	20 /a	0.016	57	N.A.	No. Active local learning	None

Source: Same as Table 1.

Notes: The ten firm numbers range from 1-11, missing #4 which declined to be interviewed.

(a) as share of profits

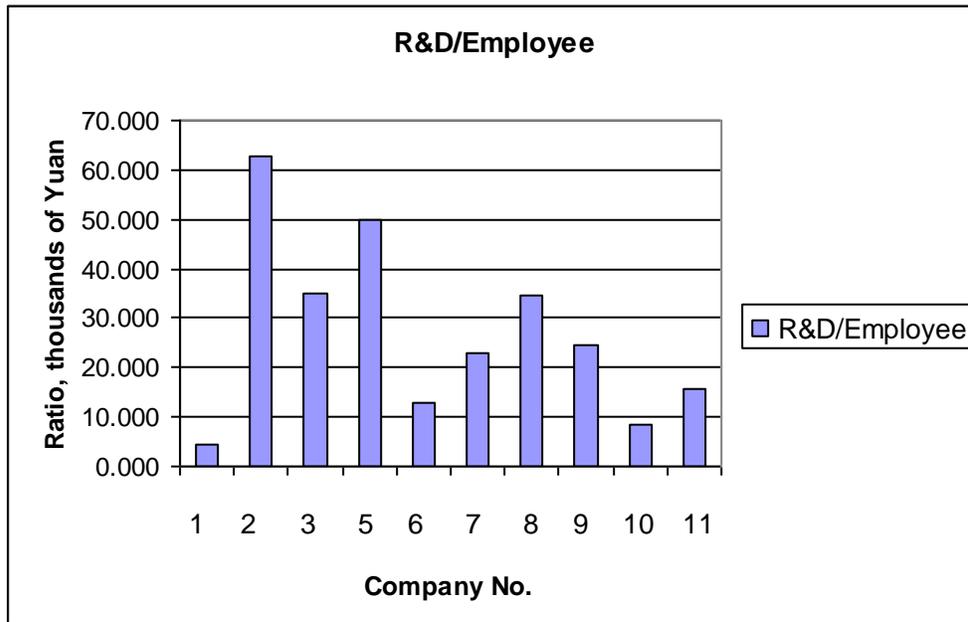
(b) employee qualifications of diploma or more

N.A. = not available

Table 3. Sources of Innovation

	Number of times mentioned	Number of times appears in top four
Government incentives	4	1
Links to R&D parks, universities etc.	7	6
Suppliers	2	0
Discussion among workers	6	3
Imitation of competitors, including reverse engineering	6	5
Pressure from competitors, domestic and foreign	8	7
Licensing or purchase of technology from competitor	4	2
Demands from customers	7	7
Informal knowledge sharing with technical staff in other firms	4	3

Source: Same as Table 1.

Figure 1. R&D expenditures per employee, 2005

Source: Same as Table 1.

Endnotes

¹ China's level of annual spending also has overtaken that of Japan (OECD 2006). Of course, firms and economies can grow rapidly even if they are not among the first to innovate. What matters is being among the first successful imitators so that they capture some of the rents available from innovation.

² "A module is a subset of a product's functional structure, and interfaces are standardized and interdependencies among modules are reduced as much as possible. (Liu, 2005, 11).

³ Tian (2007) has used a large sample of Chinese firms from 1996 to 1999 to examine the different sources of FDI technology spillovers and which have favorable effects.

⁴ Bhidé (2006) makes a similar point: that we should not overdo the production side of innovation. He argues that consumers, whether individuals or firms, who are prepared to try new goods and services, and managers able to adapt their organizations to innovations can be significant drivers of innovation.

⁵ These new machines were developed to "automate manual procedures previously used to attach surface-mounted integrated circuits to large, complex circuit boards".

⁶ Since foreign firms also supply high value-added exports which rely on high value-added imports, particularly of technology, the export pattern may be a misleading indicator of growing capability of domestic firms.

⁷ In 1999, China's high and medium technology exports were 21 percent and 18 percent, respectively, while OECD averages were 21 and 38 percent, and East Asia's 33 and 20 percent, respectively.

⁸ The outputs of these investments were relatively modest: science and engineering publications were only 10,070 in 1996, a number that tripled to 29,186 in 2003, but was still a modest share of the 2003 OECD total of 583,913 publications (OECD 2006).

⁹ See also the closely related paper by Lipsey and Bekar (1995).

¹⁰ A full account of the incident can be found in Fifield and Cookson (2006).

¹¹ Industrial capability is measured by the ability to sell abroad in a growing array of products and sectors. Such measures reflect unit costs and quality as well as knowhow which helps in determining new products.

¹² Sutton (2004).

¹³ Puga and Trefler (2005) document constant incremental innovations in low-wage countries such as China and India.

¹⁴ The differences between the number of firms noted and the total of ten firms interviewed reflects inadequate information or non-responses to these questions.

¹⁵ In their examination of the reasons for these increases in a country in which intellectual property protection is still weak and find these factors: increased competition from foreign firms that emphasized to Chinese firms the strategic value of patenting; increased R&D in China; and increased non-state ownership of Chinese firms along with a more patent-friendly legal environment.

¹⁶ Relative to China's vast population, the figures are quite low. Only five patents were granted to residents per million population in 2002, similar to close to zero for India and four for Brazil. The rates rise to 48 for Central and Eastern Europe and the CIS, and 248 for the OECD, the latter number including 302 in the United States, 633 in South Korea and 852 in Japan (Hu and Jefferson 2006).