R&D and Innovation in China: Has China Begun Its S&T Takeoff?[1]

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1. Introduction

In 2001, the annual *Human Development Report* published by the United Nations Development Program (2001) featured an analysis of the role of technological change in shaping human development. Among the statistics tabulated in the *Report* are comparisons R&D intensity, i.e., the ratios of research and development spending to gross domestic product, for 76 countries that reported these data. Several aspects of these comparisons stand out. The first is that all of the world's richest 20 countries registered rates of R&D intensity that exceeded one percent. The seven largest of these high-income countries registered R&D intensities that equaled or exceeded two percent. Furthermore, with the exception of but a few countries, all of the countries that did not qualify as "high income" by World Bank standards reported ratios of R&D spending to GDP below one percent.

The largest and richest seven economies share another feature: they all experienced science and technology (S&T) takeoffs. S&T takeoff is defined here as an abrupt increase in a country's ratio of research and development spending to GDP from less than one percent to more than two percent. For these large, high-income economies, this remarkable acceleration in the ratio of R&D spending to GDP occurred on average within the span of a single decade.[2]

Something remarkable has happened to China's R&D effort over the past six

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[1] The author appreciates the helpful data and comments provided by Gao Jian, Albert Hu, Thomas Rawski, and Su Jian. He also appreciates the on-going collaboration with China's National Bureau of Statistics, which has provided access to China's large and medium-size enterprise data set. Nonetheless, any errors are solely the responsibility of the author.

[2] A review of Table A2.2 in the UNDP, 2001, shows that the U.S., Japan, German, the U.K, France, Italy, and S. Korea, all with populations in excess of 47 million, had ratios ≥ 2.0. See Gao (1997) for a comparative discussion of national S&T takeoffs. While S. Korea completed the transition within a mere four years and Japan required 18 years, the U.S, the U.K., Germany, and France all completed theirs within one or two years of the mean duration of 10 years.

years. From 0.6 percent in 1996, China's statistics show its R&D intensity accelerating rapidly to 1.3 percent in 2003. At 1.3 percent, China's R&D intensity is one-half that of the U.S. and substantially greater than what should be expected given the country's level of per capita income.[3]

This paper looks at the issue of whether China has begun its S&T takeoff, which heretofore has been the exclusive preserve of the world's high-income economies. While examining this question, the paper also examines a wide range of issues concerning the state of research and development in China. These include the sectors and regions that are leading China's technological advance, whether the impetus for takeoff is largely coming from the foreign sector or the domestic sector, the underlying causes of China's abrupt increase in R&D spending, and the implications of China's growing R&D intensity for its economic performance.

2. Comparative R&D intensity, composition

With China still transitioning from its central planning legacy, China's government might be anticipated to play an active role in financing and directing R&D. In 1991, the enterprise sector accounted for just 28 percent of science and technology spending, a category that closely tracks with R&D spending. The majority of funding for science and technology and for R&D was provided by the government directly and the state-owned banking system. By 2002, however, these figures had significantly changed as the enterprise sector's funding share rose to over 57 percent, a figure that lies within the range of the largest OECD economies. Among the nation's R&D performers, as contrasted with funding sources, the enterprise sector in 2002 accounted for 61 percent of all R&D spending, followed by the independent research sector, which accounted for 27 percent.[4]

In China, the central government also stimulates R&D though the provision of grants and tax incentives to the enterprise sector. China's National Bureau of Statistics (NBS) conducts an annual census of its approximately 22,000 large and medium size industrial enterprises (LMEs). These enterprises, which account for over one half of China's industrial sales and three quarters of China's industrial R&D spending, receive the majority of these R&D grants and tax subsidies. Over the period 1995 to 2001, government R&D grants as a proportion of R&D spending fell by more than half while the proportion of tax subsidies fell by somewhat more than one-third. These declines indicate that increases in government funding have not driven the abrupt increase in China's R&D spending. To the contrary, these changes in funding shares over the past decade show that the surge in China's R&D intensity has resulted from the rapid growth in enterprise-financed R&D as China has moved

[3] In 2003, the World Bank defined the category of "lower-middle income" countries to include those countries with per capita incomes in the range of $745 to $2,975. With a reported level of per capita income of $890 in 2002, China lies toward the bottom of this range.

[4] NBS (2003), p. 7.

toward a market economy.

3. One China, two economies

Large and growing income disparities within China suggest that different regions may be contributing in substantially different ways to China's technological transformation. Not surprisingly, China's eastern provinces dominate the country's R&D spending. Furthermore, within the eastern region, the cities of Beijing and Shanghai and Guangdong and Jiangsu provinces account for two-thirds of that region's R&D spending. While covering less than 15 percent of China's population, these four sub-jurisdictions account for nearly one-half of the nation's total R&D spending.

Table 1. Regional comparisons, 2002
(billions of yuan)

	R&D expenditure	% total
Total	128.8	100.0
Mid-region	20.9	16.2
Western region	17.0	13.2
Eastern region	91.6	71.1
Of which:	-	-
1. Beijing	22.0	17.1
2. Guangdong	15.6	12.2
3. Jiangsu	11.7	9.1
4. Shanghai	11.0	8.7
Total 1 - 4	60.3	47.1

Source: NBS (2003), p. 20

Moreover, the technological disparity between the coastal provinces and the interior provinces is not only large – favoring the coast – it has also been growing to the advantage of the coastal region. As we find from our LME data set, during the latter half of the 1990s, along virtually every dimensions of technological progress, e.g., R&D intensity, firm productivity, profitability, patents, new product sales, and the intensity of foreign direct investment (FDI), China's coastal LMEs continued to expand their dominance over their counterparts in China's interior.

Even within the coastal region, research shows remarkable disparities among major cities in their range of R&D capabilities and the returns they generate to R&D. As part of a World Bank study on innovation in East Asian cities, my research with Zhong Kaifeng (2004) compares the R&D capabilities of five Chinese cities and Seoul, South Korea. The index of R&D capabilities shown in Table 2, based on surveys of 300 firms in each of the six cities, summarizes differences reported by the firms in each city with respect to openness, human capital resources, R&D networking, and institutional quality across the six metropolitan economies. The index shows Seoul as the city with the greatest overall R&D capabilities, followed by Shanghai, Guangzhou, Beijing, Chengdu, and Tianjin. The attached graph, which maps the series in columns (1) and (2) onto a scatter plot, shows a robust relationship between the metropolitan indexes of R&D capabilities and metropolitan wide returns to R&D.[5]

Table 2. Comparison of Seoul and 5 Chinese cities

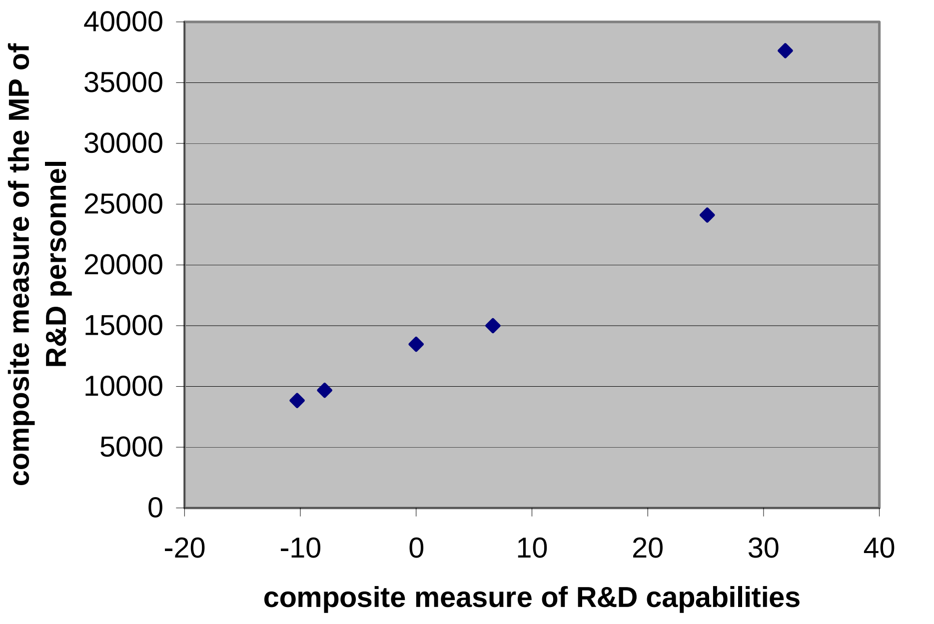
City	Index of R&D capabilities (1)	Estimated returns to R&D personnel ($) (2)	R&D personnel wage ($) (3)	ratio (2):(3)
Seoul	31.9	37,639	20,847	1.8
Shanghai	25.2	24,086	5,655	4.3
Guangzhou	6.6	14,984	3,249	4.6
Beijing	0.0	13,479	3,494	3.9
Chengdu	-7.9	9,676	3,102	3.1
Tianjin	-10.3	8,818	1,569	5.6

Source: Adapted from Jefferson and Zhong (2004), Table 9.

We draw two additional conclusions. The first is the importance of a range of complementarities for enhancing the effectiveness of R&D. The measure of innovation potential entails far more than a measure of the volume of R&D spending or number of R&D personnel. R&D capabilities depend on a range of factors that play a complementary role with R&D resources, so as to enhance their effectiveness. The complementary factors include the quality of training of R&D personnel and their managers, R&D networks with research institutes, universities, and overseas collaborators, and the institutional context of R&D, including the forms of corporate governance and public policy. By continuing to expand this set of R&D complements, China's cities can further enhance the quality and intensity of firm-level R&D. An additional conclusion of this study prepared for the World Bank is that by performing more like Seoul than the other Chinese cities, Shanghai has established a leading role in China's technological transformation. While China's R&D capabilities stand out, the rapid rise in returns to R&D across China's major cities has created a substantial gap between the revenue and cost associated with the hiring one additional Chinese R&D worker. The differences between these costs and benefits, shown in Table 2 (the last column), are creating powerful incentives for the outsourcing of multinational R&D operations to move to China, often Shanghai, while leapfrogging Seoul and other Asian cities.

[5] The "goodness of fit" for the regression for this plot is $R^2 = 0.919$ (see Jefferson and Zhong, 2004, Table 15).

Figure 1: relationship between composite measures of city R&D capabilities and returns to R&D



Source: Jefferson and Zhong (2004)

4. Is China's S&T takeoff a foreign driven phenomenon?

In his *Foreign Affairs* article, "The Myth Behind China's Miracle," George Gilboy (2004) argues that China's technological advance is largely driven by the dominant role of foreign investment. Gilboy characterizes China's domestically owned firms as hampered by:

> …an "industrial strategic culture" that encourages them to seek short-term profits…(and) forego investment in long-term technology development and diffusion….Most Chinese industrial firms…have not increased their commitment to developing new technologies…. R&D expenditure as a percentage of value added at China's industrial firms is only about one percent, seven times less than the average in countries of the OECD. (p. 43).

To test Gilboy's claim that firms with foreign-owned firms dominate R&D operations in China, we turn to our data set for China's industrial LMEs. According to the LME census data, in 2001 total R&D expenditure within China's domestic industrial LME sector was approximately four times that of the foreign funded enterprise (FFE) sector, which we define as including both foreign firms and overseas investment from Hong Kong, Macao, and Taiwan (HMT). That is, in 2001 domestic firms accounted for 78 cents of every R&D dollar spent by the enterprise sector[6]. Moreover, in 2001, while the ratio of R&D to value added in China's domestic LMEs had reached 3.3 percent, well above the one percent figure cited by Gilboy. In the foreign firms, this measure of R&D intensity stood at just 2.6 percent. This finding is broadly consistent with a recent OECD report that states, "…foreign firms that invest in China appear to have engaged in only limited levels of R&D activity and their role in the innovation process seems even more limited. (OECD, 2002, p. 267)

Again according to Gilboy, "Chinese firms are taking few effective steps to absorb the technology they import and diffuse it throughout the local economy, making it unlikely they will rapidly emerge as global industrial competitors." (p. 38) Once again, our LME data set shows a different picture. In 2001, 1,460 LMEs, over 80 percent domestically owned, recorded purchases of imported technology. Furthermore, the FFEs purchased virtually nothing in China's domestic technology markets. In conclusion, except for their parent companies from whom they transfer technology, the FFEs are substantially less connected with local technology markets than their domestic counterparts. The key conclusion of this section is that while FFEs are contributing to China's openness and rapid export growth, they do not constitute the leading edge with respect to China's rising R&D intensity – at least not directly.

5. Causes of R&D takeoff

There is insufficient space here to analyze the range of underlying causes of S&T takeoff generally and the specific phenomenon in China. Moreover, since surprisingly little research exists on the topic, a discussion of the causes of S&T takeoff is at best highly speculative. Still, some preliminary discussion may be useful. As living standards rise, we anticipate that the composition of goods and services will become more technologically intensive. Automobiles substitute for bicycles; consumer electronics become ubiquitous, medical services and the equipment that supports them become more sophisticated. Within China, the electronics and telecommunications industry is illustrative of China's high-tech leading industries. Within our LME data set, during the last half of the 1990s, the ratio of R&D spending to value added in this sector accelerated by 250 percent to reach 7.5 percent. The overall impact on Chinese industry of the growth of R&D intensity in this sector was magnified by the fact that its market share in total industry sales doubled over this period. While other developing countries may import technologically sophisticated electronic and telecommunications equipment and other high-tech goods, including electrical machinery, instrumentation, and automobiles, in China multinationals are clamoring to set up production for these R&D intensive industries in close proximity to the country's burgeoning consumer markets. This phenomenon of the commercial

[6] Accounting for the fact that in 2001, 61 percent of China's foreign funded enterprises were domestically owned, we can reapportion a proportional share of the FFE research and development spending to the domestic side of the ledger. The domestic share of China's LME industrial R&D spending then rises to 91 cents on the dollar.

desire to set up production in close proximity to large markets may explain why the S&T takeoff has occurred in all of the largest OECD economies.[7]

A second aspect of the takeoff phenomenon focuses on patterns of adopting new R&D operations and learning-by-doing in established R&D centers. Table 3 shows during 1995 to 2001 increasing rates of adoption of R&D activity by China's industrial LMEs. During this period, the proportion of LMEs performing R&D rose from 20.2 to 29.1 percent, a rise of nearly one-half. Over the same period, the number of high performing LMEs with R&D to value added ratios in excess of 10 percent grew from 620 to 1,553. All but 267 of these are domestically owned LMEs. As established R&D performers gain experience and access to foreign technology, rising returns to R&D motivate firms to move more resources into their R&D operations thereby causing industrial R&D intensity to rise.[8]

Table 3

Distribution of R&D/VA(r), proportion of all LME enterprises (%)[1]

Year	0	$0<r\leq1$	$1<r\leq2$	$2<r\leq4$	$4<r\leq6$	$6<r\leq10$	$r>10$
1995	79.8	7.2	3.2	3.4	1.4	1.7	3.3
2001	70.9	6.7	4.0	4.8	3.0	3.5	7.1
% increase	-11.1 (45.6)	-7.5	22.8	40.8	108.0	110.8	119.1

Source: NBS-LME data set.

In the previous section, we saw that FFEs are not directly and substantially contributing to China's rising R&D intensity. But the foreign sector does play a key role in motivating rising R&D intensity through at least two indirect channels. First, my research colleague, Albert Hu, and I (2004) find that the R&D intensity of domestic firms is rising most quickly in industries that are rich in foreign direct investment.[9] The market competition and proliferation of product variety associated with high industry FDI participation create pressures for domestic firms in these FDI rich industries to mount extensive and effective R&D programs to hold their own against foreign competition.

A second channel though which the foreign sector contributes to rising R&D intensity is through the access to foreign technology it provides for domestic firms.

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[7] The desire to serve large and fast growing consumer markets creates a premium for the establishment of production centers that can benefit from learning-by-doing and learning-by-using in close proximity to fast expanding markets.

[8] Measured in terms of productivity gains, cost reductions, or increased profitability, research on returns to R&D consistently show substantial returns to Chinese-based R&D. See Hu and Jefferson (2004a), Jefferson, Bai, Guan, and Yu (2004), Jefferson and Zhong (2004), Fisher-Vanden and Jefferson (2004), and Hu, Jefferson, and Qian (2004).

[9] Hu and Jefferson, (2004b) find that R&D intensity in China's domestic firms rose most rapidly over 1995-2001 in industries that exhibited the highest rates of FDI participation in 1995.

Chinese firms are finding that in-house R&D is needed to access and absorb effectively these technologies from abroad. Research shows that the firms that purchase imported technologies invariably also support in-house R&D operations. In-house R&D shares strong complementarities with technology imports, enabling domestic firms to capture higher returns to their own R&D spending.[10] Our research also finds that domestic firms that combine in-house R&D with imported technology are more likely to be active exporters.[11] By creating incentives for domestic firms to perform R&D while also enhancing the impact of R&D by combining it with foreign technology transfer, China's fast growing foreign sector is creating powerful incentives for Chinese firms to acquire the technological capabilities needed to compete on world markets.

5. What is the significance of R&D and innovation for China's economy?

Gilboy's analysis focuses largely on the role of R&D innovation in supporting China's export sector. Yet, high-tech exports account for barely more than four percent of China's total GDP.[12] The story of China's technological transformation is far more subtle than the development and export of high-tech goods.

During the era of central planning, a mantra of China's political leadership was to catch up with the West. One way in which it pursued growth and a rise in living standards was to emphasize capital-intensive growth, which involved the establishment of an extensive set of capital-intensive industries, including steel, petrochemicals, and heavy machinery and transportation equipment. An unfortunate result of this capital-intensive pattern of growth was that, in the absence of market signals, the allocation of China's scarce supply of capital was highly wasteful. Moreover, the pursuit of capital intensive growth that was fundamentally inconsistent with China's underlying comparative advantage in labor, not capital, created further inefficiencies that rendered Chinese industry incapable of competing on world markets.

Recent research suggests that this pattern of development is changing. Two studies indicate that at least since the mid-1990s, innovation in China has tended to be labor using and capital and energy savings.[13] Chinese enterprises increasingly appear to be concentrating their R&D resources on installing new processes that are relatively intensive in their use of labor. One implication of this emphasis on the development and use of labor-intensive production processes is that China is using its relatively

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[10] Hu, Jefferson, and Qian (2004a) show this result within the context of a production function. Fisher Vanden and Jefferson find this result using a cost function approach.

[11] Fisher-Vanden and Jefferson (2004).

[12] UNDP, 2000, calculated from the data on p. 199.

[13] Using a translog cost function approach, Fisher-Vanden and Jefferson (2004) find that in-house R&D is labor using and capital and energy savings. Jefferson and Su (2004) find that privatized enterprises invest in labor using technologies far more than unconverted state-owned enterprises.

scarce resources – i.e. capital and energy – far more efficiently than it would if it were continuing along its capital and energy-intensive growth path.

That China is beginning to develop and invest in relatively labor intensive and capital and energy-saving technologies, with the support of research and development, is an enormous achievement in its quest for economic efficiency and political stability. One consequence of greater efficiency and profitability is that retained earnings, the principal source of firm R&D spending in the OECD economies, is becoming more available to finance China's continuing rise in R&D intensity. At a time when funding for R&D from the Chinese government and banking sectors is in relative decline, growing firm efficiency and retained earnings are critical to sustaining the growth of China's R&D investments and its technological advance. This fundamental orientation – Chinese enterprises learning to capitalize on China's comparative advantage – is critical for establishing the foundation of an efficient, sustainable national R&D program while also moving China's economy up the technology ladder to expand its presence on international markets across an increasing variety of goods and services.[14]

6. Caveats and conclusions

Large differences in relative prices between China and the U.S., such as differential wages for R&D personnel, and differences in the emphasis of R&D on basic versus applied research, complicate comparisons of R&D intensity between China and the U.S. With R&D intensity in the U.S. operating at a level approximately twice that of China, it is difficult to translate this factor of two into an economically meaningful comparison.[15]

While cross-country comparisons of R&D intensity are difficult to interpret, there is, however, little uncertainty that China is presently engaged in a stage of its development in which the growth of R&D expenditure is rapidly outpacing GDP growth, itself virtually without international comparison. These growing R&D

[14] A particularly buoyant account of China's move up the technology ladder into foreign export markets is provided by Fishman (2004). A key point in that article is the ability of domestic producers to outcompete FEEs by establishing labor- intensive workshops that produce high-end domestic products and export goods of similar quality and at lower cost.

[15] The conventional measure of GDP, which appears in the denominator of these intensity comparisons, is the exchange rate adjustment measure of GDP. However, while GDP of the U.S. is eight times the size of China's exchange-rate adjusted GDP measure, using a purchasing power parity (PPP) measure that adjusts for differences in relative prices, the magnitude of the U.S. measure of GDP falls to less than twice that of China. Substituting the PPP measure of GDP in China's measure of R&D intensity should substantially reduce the ratio, although implementing similar PPP adjustments to R&D expenditures in the numerator will likewise tend to enlarge that measure. If after making these measurement adjustments, the relative U.S.-China R&D intensities still stood in a ratio of 2:1, the outcome would be sheer coincidence.

resources are devoted to important purposes, including the exploitation of China's underlying comparative advantage that entails a focus on labor-using and capital and energy-saving technologies. At the same time, many of China's large and medium-size enterprises are using their in-house R&D capabilities to absorb imported technologies, which enable these firms to move up the technology ladder and produce goods for the export market.

Relative to a decade ago, R&D has become extensively and deeply embedded in China's enterprise system. A virtuous circle seems to be emerging in China's R&D process. R&D in support of production for domestic consumption and export sale that is consistent with China's comparative advantage promotes efficiency and profitability; efficiency and profitability raise living standards and creates surpluses for the creation of more R&D investment. At the same time, China's growing R&D capabilities are being reinforced through a growing set of complementarities that include the competition and demonstration effects of FDI rich industries, R&D networks, advanced training, and favorable R&D policies.

As well as policies, such as training and incentives for the repatriation of overseas talent, that overarch China's S&T system, the Chinese government is also emphasizing policies to extend its technology ladder into specific spheres of global technological advance. These include its focus on strategically important sectors, such as integrated circuits and computer software, telecommunications, and biotechnology and the formulation and coordination of industry standards to support these areas of technological advance.[16] While these are important initiatives, the essential pillars of China's current technological transformation are a reorientation toward its underlying comparative advantage and the complementarities that have developed between the in-house R&D operations of growing numbers of Chinese firms and the competition and technology transfer that are fostered by the increasing openness of the Chinese economy. The confluence of these conditions appears to be motivating an intensification of China's R&D effort that substantially exceeds our expectations, based on history and international comparisons, for an economy, which has only recently graduated from the ranks of the world's low income nations.

[16] See Dahlman (2001) and Suttmeier and Yao (2004) for extensive discussions of the technology policy choices facing the Chinese government.

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