Science and Technology Takeoff in China? Sources of Rising R&D Intensity[1]

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Abstract

China's ratio of R&D spending to its GDP more than doubled from 0.6 percent in 1996 to 1.4 percent in 2005. This paper documents the pattern of science and technology (S&T) takeoff, characterized by an abrupt increase in the R&D to GDP ratio. This abrupt increase, observed in many of the now OECD countries, typically drives R&D intensity from below one percent to the range of two to three percent. The question addressed in this paper is whether China has begun a similar S&T takeoff. The paper reviews several conditions identified in the endogenous growth literature that drives R&D intensification and notes their emergence in China during the past decade. It also speculates why China's R&D intensification appears to be starting at such a low level of income per capita.

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1. Introduction

Economists agree that the sustained growth of living standards requires on-going technological progress. The endogenous growth literature also recognizes that deliberate research and development effort is an important driver of technological change. Cross country data show that R&D intensity, i.e., R&D expenditure as a share of GDP, varies widely across counties. Not surprisingly, these cross country data show a clear pattern in which high R&D intensities are associated with high per capita incomes.

Among the OECD economies, the historical relationship between R&D spending and GDP shows a striking phenomenon in which a country's R&D spending approaches one percent of GDP, abruptly accelerates to the vicinity of two percent, and then levels off in the range of two to three percent of GDP. We characterize this phenomenon of an abrupt one-time increase in R&D intensity as "science and technology (S&T) takeoff." This paper investigates both the statistical regularities of S&T takeoff and the underlying theoretical and empirical conditions that potentially explain this phenomenon of takeoff in which, for the span of a decade, on average, R&D spending rapidly outpaces the growth of GDP.

This paper focuses on growth of R&D spending in China, which suggests that it has begun its S&T takeoff. During the past decade China's R&D intensity has rise from the vicinity of about one-half percent to its present level of approximately 1.4 percent. For the purpose of understanding this phenomenon, we explore the endogenous growth literature that identifies various conditions that motivate firms and whole economies to intensify their R&D spending. In particular, we investigate how these conditions relate to

China and further examine why China's whose level of living standards measured at current exchange rates is but one-twenty-fourth that of the

The next section identifies the stylized facts that characterize the phenomenon of S&T takeoff. In Section 3, we investigate the theoretical foundations of S&T takeoff. Section 4 looks at a body of empirical literature that documents changes in the structure of the Chinese economy that conform to the theoretical predictions for S&T takeoff. Section 5 speculates on why China has begun its S&T takeoff at a relatively low level of income per capita. Section 6 examines why the phenomenon of S&T takeoff results in leveling off. Our conclusions and discussion appear in Section 7.

2. The stylized facts of S&T takeoff

The *Human Development Report, 2001* (UNDP, 2001) reports the ratios of R&D expenditure to GDP for 71 countries using data that fall in the period 1987-97. Figure 1 plots these data for the R&D expenditure/GDP ratios in relation to the log of GDP per capita.

The data suggest two distinct patterns. The first pattern that emerges from Figure 1 is the tendency for richer countries to exhibit ratios of R&D to GDP that are higher than those of lower-income countries. Among the 23 OECD economies that are included in the UNDP report, the average R&D/GDP ratio stood at 2.0 percent. The average for the remaining non-OECD economies is 0.7 percent.

The second pattern that emerges from the reported data is the tendency for larger OECD countries to enjoy higher R&D intensities than smaller countries. The

UNDP/World Bank data show that the seven largest OECD economies enjoy average R&D intensities equal to 2.4 percent,[2] which exceeds the 1.8 average for the 16 smaller OECD economies.

Table 1 documents patterns of rising R&D intensity in the seven largest OECD countries. Five of these countries – the U.S., Germany, France, Japan, and S. Korea – exhibit patterns of a rapid ascent in R&D intensity. When data became available for the U.K. in 1960, its level of R&D intensity had already exceeded two percent. Italy's level of R&D intensity during the 1990s fails to reach two percent. For the other five large OECD countries, the ascent occurred within a relatively short period. For the U.S., the first country for which we can document the rise in R&D intensity from one to two percent, the transition required 10 years. For South Korea, the most recent large OECD country to make the transition, the ascent occurred within a span of just five years. Japan's transition required the longest period; it spanned 19 years. For the five countries, the average duration for the transition of R&D intensity from one to two percent was just a decade.

Other OECD countries that achieved or exceeded the two percent R&D levels prior to 2000 include the Netherlands, Sweden, and Switzerland. The other smaller OECD economies all registered R&D intensities in the range of one to two percent. Also, in recent years the R&D intensities of Singapore and Taiwan have risen above two percent while Brazil's has reached the one percent threshold. In 2000, China's R&D intensity rose to one percent from 0.6 percent in 1996; by 2003, it had risen to 1.3 percent.[3]

[2] These OECD economies with populations in excess of 45 million include the U.S. Japan, Germany, the U.K., France, Italy, and S. Korea.

[3] As a result of the recently tabulated 2004 census, China's 2004 GDP estimate has been increased, thus causing the implied R&D intensity in 2004 to fall from 1.44 to 1.27. In this paper, including in Figure 2,

The key results portrayed in Figures 1 and 2 can be summarized by the following set of stylized facts of S&T takeoff. These are:

- Low and low-middle income countries typically exhibit levels of R&D intensity in the range of zero to one percent.
- High income countries usually exhibit levels of R&D intensity in the range of two to three percent.
- Countries with high levels of R&D intensification, i.e. over two percent, typically make the transition from low R&D intensity, i.e. ≤ 1% to high R&D intensity, i.e. ≥ 2% in about a decade.
- Countries with large populations transition to high R&D intensity with greater regularity than countries with smaller populations.

The relationship between R&D expenditure and GDP per capita is but one dimension of the association between the development of a nation's scientific and technological capabilities and its living standards. While we choose to focus on R&D expenditure as a key input to S&T development, other authors focus on R&D outputs. Notable among these are Bernardes and Albuguerque (2002), who analyze the association between patents and scientific articles and income levels. They find robust associations as well as threshold levels, beyond which the efficient use of scientific output by the technology sector increases. Through its focus on a key S&T input, i.e. R&D expenditure, and the experience of China, this paper contributes to the literature on the association between the development of S&T effort and national income levels.

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we use the original national income figures. While once the historic GDP series has been revises, it will be necessary to revise parts of this paper, the newly revised data will result in a small shift in China's R&D trajectory as shown in Figure 2. We do not anticipate that this will not alter the account of this paper in any meaningful way.

3. The causes of takeoff: a theoretical perspective

An important subject area in the endogenous growth literature focuses on the R&D effort of profit-maximizing enterprises that seek to optimize the allocation of investment between production labor and R&D labor. Like Aghion and Howitt (1992) who model the role of deliberate technical change in the endogenous growth process, Jones (1995) assumes an economy with three sectors. These are a final goods sector, an intermediate goods sector, which embodies various vintages of technology, and a knowledge producing R&D that innovates the technologies used in the intermediate good sector. This model model yields the following comparative statics that identify the conditions under which R&D personnel rise as a share of total labor:

- The factor income share of technology-intensive intermediate inputs rises in relation to that of production labor,
- The productivity of R&D labor rises (holding constant the supply of technological opportunity),
- The scale effects of available knowledge grows, i.e., an enlarged base of technological opportunity enables the efficiency of R&D activity to rise, and
- Subsidies to R&D labor increase, including, possibly, a rise in the productivity of R&D labor in relation to its wage.

The following section examines a range of empirical conditions that potentially alter the values each of these four factors that drive the increase in R&D intensity.

4. The empirical conditions for takeoff

In this section we examine a variety of empirical finding that relate to the theoretical predictions for S&T takeoff derived in the previous section. In particular, our analysis focuses on China. With its R&D/GDP ratio having risen from 0.6 percent in 1996 to 1.3 percent in 2003, among the countries shown in Figure 2, China appears to be the most firmly established in making the transition to rising levels of R&D intensity. Because of its R&D trajectory and the availability of relevant data, we focus on China to illustrate the empirical conditions of S&T takeoff.

Decline in the relative importance of production labor: Structural change that causes a decline in production labor's output elasticity will, as a consequence, cause a rise in the output elasticity of the technology-intensive intermediate inputs, which require the input of S&T personnel. A decline in the income share of production labor relative to technology-intensive intermediate inputs could result either from an increase in the marginal product of intermediate inputs relative to production labor (holding the relative quantities of production labor and intermediate inputs fixed) or an increase in the demand and production of intermediates relative to the supply of production labor (holding the relative marginal products constant). Why across nations should a rise in living standards be associated with a decline in the relative factor income share of production labor?

A regular feature of the development process is that as living standards rise, the composition of goods and services shifts from those that are low in technological content to goods and services that are more technologically intensive. Automobiles substitute for bicycles; consumer electronics become ubiquitous, medical services and the equipment that supports them become more sophisticated. This pattern of technology intensification that accompanies rising living standards mirrors Engel's Law. As incomes rise, not only is the income elasticity of demand for non-agricultural goods greater than one; also, technology-intensive goods enjoy comparatively high income elasticities. Goods with low-technology content (e.g. bicycles, handicrafts, rudimentary medical care) exhibit the attributes of inferior goods. The rise in the demand for technology-intensive goods leads to a rise in the demand for human capital relative to unskilled labor. What evidence can we find that in the Chinese economy the rise in the technology intensity of production?

Based on data for the population of China's nearly 22,000 large and medium-size enterprises, Table 2 shows two basic findings. The first is that three key categories of intermediate goods – electronic and telecommunications equipment, electrical equipment and machinery, and instruments and meters – exhibit a greater share of total industrial sales as well as rising technology content. The table shows that from 1995-2000, as China's R&D to GDP ratio rose from 0.6 to 1.0 percent, the R&D expenditure to value added intensities rose substantially in each of these industries. Over the same period, each of these intermediate goods industries increased their share of total sales in Chinese industry, indicating a decline in the share of expenditure dedicated to production labor in the final goods sector and an increase in spending on intermediate goods. In conclusion, the high income elasticity of demand for technology intensive goods has, in China, led to a substantial increase in the demand and production of technology-intensive intermediate inputs relative to production labor.

Increasing efficiency of R&D labor holding the supply of technological opportunity constant: The value of the marginal productivity of R&D labor may rise from the accumulation of a broad assortment of complementarities, including IT equipment, education, and the purchase of outside technology. In their paper that focuses on the role of complementarities in determining returns to R&D labor in five Chinese cities and Seoul, Korea, Jefferson and Zhong (2004), to estimate the significance of the contribution of a set of potential complements to enhancing the marginal product of R&D personnel using the following production function.

$$\ln V_i = \alpha_0 + \alpha_1 \ln L_i + \alpha_2 \ln K_i + \alpha_3 \ln R_i + \alpha_4(\ln R_i * \ln Z_i) + \Sigma\alpha_1 \ln LOC_i + \Sigma\alpha_1 \ln IND_i + \varepsilon_i. \quad (1)$$

In Equation (1) V represents value added, L and K are total labor and the net value of fixed assets respectively, R is R&D personnel, Z is a vector of complements to R&D personnel, and LOC and IND are location (i.e. metropolitan area) and industry group dummies. Jefferson and Zhong use data collected from a World Bank survey that covered 300 firms in each of the six cities, i = 1…1,800. Estimates of Equation (1) indicate that three groups of complements shown in Table 3 – human capital, R&D networks, and institutional quality – and their constituent measures each exhibits significant effects on the returns to R&D personnel[4] Because

The results in Table 3 are of interest, since in China's economy the incidence of these complementary factors, with the possible exception of the number of competitors,[5] has grown significantly over the past decade. The growth of these complements to R&D

[4] Given that estimates of Equation (1) are based on a single cross section in the year 2000, estimates of α_3 and α_4 may suffer from upward bias associated with omitted variables misspecification (e.g. complements Z_j, $j \neq i$. Potential complements to R&D personnel that did not significantly enhance the productivity of R&D personnel include purchase of a domestic license, the export-sales ratio, member of a business association, firm's market share, import market share, and imported equipment. While some of these affected the firm's productivity, they did not act on productivity through their interaction with R&D personnel.

[5] While the sheer number of enterprises in China's industrial system has declined, the vast majority of these are small household enterprises (geti qiye). As a result of the rapid establishment and growth of foreign-invested enterprises, and the conversion of non-state enterprises the level of effective competition is likely to have grown over this period.

can be expected to shift out the marginal productivity schedule of R&D, motivating new investments in R&D human capital, until the returns to R&D equilibrate toward the long run (risk-adjusted) return on investment. In either case, whether the accumulation of these complements is raising the marginal returns to R&D labor or raising the proportion of R&D workers in the labor force, the result will be an increase the value of the output elasticity of R&D personnel.

Increasing scale effects associated with and expanding supply of technological opportunity: Jones (1995) focuses on scale effects as a key feature of the innovation process. That is, when innovation results in substantial knowledge spillovers over time, the spillovers may replenish and expand the pool of technological opportunity, thereby creating scale effects. Alternatively innovation may suffer from diminishing returns, i.e. the "fishing out" effect in which the depletion of technological opportunity diminishes returns. Arguably, for China, the scale effects of the body of knowledge exist and are growing.

In China, while substantial knowledge spillovers may result from R&D spending by domestic and foreign R&D activity, one key element that is inseparable from the factors determining the supply of technological opportunity is the increasing openness of China's economy. Keller (2004) identifies key sources of international technology diffusion as including imports, exports, and FDI. In the case of China, and other rapidly globalizing economies, the effective body of knowledge has become rapidly augmented through channels into the international economy, thereby expanding the opportunities for domestic R&D personnel to imitate and innovate technological advances. In effect, the opening of China's economy has substantially expanded the effective pool of knowledge.

These FDI flows and the R&D effort that it motivates causes the effective body of knowledge that serves as the "shoulders" on which China's R&D personnel stand to effective expand.[6]

Using the same World Bank survey, Jefferson and Zhong (2004) test the impact of measures of international technology diffusion on returns to Chinese R&D labor. As shown in Table 3, these firm-level measures of access to foreign technology include foreign direct investment, location in an industrial park or export processing zone, and purchase of a foreign license. Jefferson and Zhong find that each of these three measures significantly interacts with R&D personnel to enhance the productivity of R&D labor.

Further evidence of the increasingly important role of foreign technology in China's economy is demonstrated by Hu, Jefferson, and Qian (2005), who find substantial complementarities between in-house R&D labor and foreign technology transfer. While the impact of purchases of imported technology depends substantially on its interaction with in-house R&D, purchases of foreign technology substantially raise the productivity of in-house R&D. The authors calculate a 25 percent increase in the stock of purchases of disembodied imported technology (e.g. blueprints, licenses) during 1996-1999.

Finally, a further channel of international technology diffusion is equipment imports. During 1996-2002, as a portion of GDP, machinery and equipment imports rose by 230 percent.[7] Westphal reports on the pervasive role of reverse engineering in the Korean economy, abetted by extensive government spending on the training of Korean scientists and engineers both at home and abroad, during the period of its S&T takeoff.[8] We do not have documentation of substantial reverse engineering of imported equipment

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[6] See Caballero and Jaffe (1993).
[7] NBS/MOST (2003, 1999).
[8] Westphal (1990).

in China, however, critics of China's enforcement of intellectual property rights cite the high incidence of reverse engineering of imported goods, both producer and final goods.

Taken together, these factors suggest the growth of a substantial body of knowledge to complement the knowledge that is created within China's enterprise system. By effectively expanding the body of available knowledge from which China's R&D workers can imitate and create new knowledge, this diffusion is likely to be expanding the magnitude of scale effects relative to their size if China's R&D workers were instead operating in a closed economy.

Rising R&D wage subsidies: Jones' endogenous growth model focuses on a fourth factor with the potential to increase the ratio of R&D to production labor: wage subsidies to R&D personnel. In a competitive equilibrium, we generally assume that labor's wage and value of marginal product are equal. The research of Jefferson and Zhong (2004), however, indicates that this has not been the case for R&D labor in China.

Table 4, column (1) shows estimates of the value of marginal product of R&D labor in Seoul, Korea and five Chinese cities. Column (2) reports the average levels of reported compensation received by these R&D personnel in each of the six cities.[9] The the key finding in this table is that while in Seoul firms employing R&D labor face a ratio of the value of marginal product to wage of 1.81, for employers in the Chinese cities, the ratio lies between three and five. These differences suggest a substantially greater

[9] The data in Table 4 show that the estimated marginal productivities are substantially larger than reported wages for the sample of Korean firms; they are multiples for the Chinese firms. In principle wages and marginal products should equate. One reason for the large disparities that persist even in the case of Seoul, where labor markets in skilled labor should be relatively efficient, is that the wage data do not include benefits. Also, the simple OLS methods used by Jefferson and Zhong (2004) on a cross-section of data may have resulted in upward bias of the estimates of marginal productivity, say due to omitted variables misspecification associated with fixed effects, such as managerial quality. While the wage-productivity gap may be overstated, the authors argue that there is no reason to expect the magnitude of estimation biases to vary across cities, i.e. it should not affect the *relative* size of the estimated wage-productivity gaps shown in Table 5.

employer surplus for firms setting up R&D operations than their counterparts in Seoul. These numbers suggest that while a firm investing in R&D in Seoul could hire one R&D worker for $20,000 and expect in return a stream of R&D services valued at $37,000, in Shanghai the same investment would, in 2000, have employed four R&D workers who together would have generated nearly $100,000 in R&D services.

One possible source of this disparity that may be motivating Chinese firms to invest heavily in R&D labor, is the lag between the rising productivity of China's R&D workers and the wages that they command. Because productivity remains relatively low in China's traded goods section, the pressure to raise the compensation of R&D workers may be limited. However, as China's most skilled workers become increasingly integrated with an international labor market (i.e. become more "tradable"), the size of the wage-productivity gap should diminish. During the transition, however, investors in Chinese-based R&D enjoy a considerable subsidy.

5. Why has China begun its takeoff so early?

Figure 1 indicates that in the cross section of countries, R&D takeoff begins in the range of $8,000 in purchasing power parity (PPP) adjusted 1999 dollars. In that year China's PPP income per capita was just $3,600.[10] We speculate on the reasons for this appearance of an early takeoff.

High rates of literacy. At 16.5 percent, China's adult illiteracy rate in 1999 was approximately twice that of Singapore, similar to those of Brazil (15.1%) and Turkey (15.4%) with substantially higher incomes, and well below that of India (43.5%).[11]

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[10] UNDP (2001), p. 52-54.
[11] UNDP (2001).

These comparatively high rates of literacy in China are leading to a high incidence and rate of growth of demand for and utilization rate of technology intensive goods and services, such as telecommunications services, computing, and medical services. The paucity of installed infrastructure for earlier generation technologies, such as land telephone lines, early vintages of automobile assembly lines, and early computing technologies, both hardware and software, open the door for the rapid dissemination and adoption of new vintages of technologies. Certain key sectors, such as telecommunications, exhibit a substantial degree of technology leapfrogging.[12]

Market size. The commercial motive to produce in close proximity to large markets may explain why S&T takeoff has not occurred in certain smaller OECD countries (e.g. Norway, Australia, Belgium, Austrialia, and New Zealand) while it has occurred in all but one of the largest OECD economies.[13] Moreover, in the larger OECD economies, large populations create the potential for manufacturers to establish scale economies with the associated scale, learning, and productivity gains[14] Likewise, in China, multinational have been clamoring to set up production for technology-intensive industries in close proximity to China's burgeoning consumer markets and its abundant supply of low-wage, but now increasingly skilled, labor supply. While the Chinese government's "markets for technology program" focuses push international firms toward accelerating the shift of design, R&D, and component production toward China, it is likely that even in the absence of this program, the sheer scale of supply and demand conditions in China would

[12] See the example of Japan's adoption of basic oxygen steel production in the 1950s and 1960s in Ruttan, 2001, p. 159.
[13] 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 burgeoning demand.
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motivate rising investment in electronic goods, telecommunications, and automobiles. Commenting on the decision by Airbus to assemble its A320 plan in China, one analyst was quoted, "Everything else being equal, you would never choose to put a production line in China."[15]

Proximity to dynamic economies. Arguably China's greatest asset in making its transition from plan to market and in accessing the capital, technology, and talent needed to move along the trajectory from low to middle-income economy is its close physical and cultural proximity to Hong Kong and Taiwan and to a lesser, but still significant degree, to Korea, Japan, and S.E. Asia. One measure of this importance is the fact that approximately one half of the accumulated FDI in China has originated with Hong Kong, Taiwan, and Macao. Another is the concentration of FDI in specific regions within China, such as Taiwanese investment in Dongguan (Guangdong Province), which has become the primary source of many PC components. Singaporean investment in the Shanghai area and Korean investment in China's northeast region have also spurred technological advance. This close proximity has at once served as a channel for technology transfer and access to the human capital that can use it not only within the foreign sector but also generate spillovers to China's domestic sector through joint ventures, licensing, and contracting.

The four factors associated with the endogenous growth process have been central to the intensification of R&D across all countries that have achieved S&T takeoff. But not all emerging economies have experienced S&T takeoff. We suggest that China's high literacy rates, its perceived potential, and its proximity to dynamic economies have

[15] "Airbus, China and Quid Pro Quo," M. Landler and K. Bradsher, New York Times, March 15, 2006, p. 4.

driven China's S&T takeoff along an earlier and steeper trajectory than would have been the case if China did not enjoy these particular characteristics.

6. Factors leading to leveling off

This paper documents a set of structural changes in the Chinese economy that are associated with the early stages of the abrupt intensification of R&D in China. The documentation is intended to map into an empirical context a theoretical framework that identifies the conditions that lead to a rising proportion of R&D labor in the total workforce. It also provides some intuition regarding the question of whether China's rising R&D intensification represents the early stage of an S&T takeoff.

An aspect of the takeoff documented in Figures 1 and 2 that is equally fascinating as the initial abrupt acceleration of R&D intensity is the tendency for countries that have passed through the two percent R&D/GDP threshold to then moderate their spending, so that R&D intensities remain in the vicinity of two to three percent.

The previous analysis regarding the sources of the initial increase in R&D intensity also provides the critical insight for understanding the causes of the leveling of R&D intensity. These all have to do with the transitory nature of the conditions that initially motivate the takeoff. The four transitions are:

- The transition from the consumption of final goods that are low in technology content to those high in technology content. The shift from bicycles to automobiles, for example, underscores the asymptotic limit to the growth of technology intensity. Once automobiles have fully substituted for bicycles, the rate of technological intensity grows only as fast as that of the automobile.

- The accumulation of complements to R&D. As shown in Table 3, these consist largely of investments in physical infrastructure and human capital. Typically, the transition from low-income to middle-income status involves catch-up investments in physical technology and more expansive investment in universal education at intermediate levels in higher education. At higher levels of income investment in physical infrastructure and human capital accumulation advance more slowly.

- Accessing the world's knowledge base. With rising flows of FDI, technology imports, and the capacity to absorb foreign technology, domestic R&D workers increasingly gain access to the international knowledge base. The effective body of accumulated knowledge grows rapidly, thus elevating the productivity of domestic R&D labor. Once the takeoff economy has integrated with the international economy, its knowledge frontier converges to that of the advanced economies and grows at the same rate as that of the other advanced economies.

- Exploiting the wage-productivity gap. Initially, the rapid rise in the productivity of R&D labor, driven by the three factors described above, drives a wedge between marginal product and wage. Eventually, with the integration of the takeoff economy into the world economy, wages in the tradable goods sector rise and factor price equalization prevails.

The theoretical factors that drive the S&T takeoff are also those that account for the leveling off of R&D intensity, including the tendency for the advanced economies to share a similar set of conditions: a similar level of technology-intensity in consumption and production, the creation of a similar set of physical infrastructure and human capital complements to R&D labor, a more or less identical international technology frontier, and comparable wages for R&D personnel. The equalization of these four factors across the advanced economies causes these countries to converge within a similar range of R&D intensity, thus bringing an end to the phenomenon of S&T takeoff.

7. Conclusions

This paper focuses on four economic conditions that plausibly account for the abrupt increase in R&D intensity in a number of OECD economies and in certain developing economies, now including China, whose R&D intensities have risen quickly in recent years to equal or exceed one percent. In addition to the factors emphasized here, other factors certainly relate although perhaps in not such a broad, generic way. Among these are government policies, including direct R&D spending as well as subsidies to R&D effort. Also, geography and natural resource endowments are likely to matter, which may explain the relatively weak level of R&D intensification in the Australian, New Zealand, and Norwegian economies – all comparatively small and major agricultural and raw material exporters. In addition, China's close proximity to Hong Kong, Taiwan, South Korea, and Japan are likely to provide it with an advantage relative to other developing economies, including Brazil and India. Finally, we see in Figure 2 the similar timing of the takeoffs of France, Germany, and Japan suggesting that spillovers may be at play. In this context, the simultaneous increase in R&D intensity in China, India, and Brazil, which together represent 40 percent of the world's population, may have a mutually reinforcing effect on the process of R&D intensification in these countries.

An important caveat in this analysis is the recognition that our focus on R&D intensities, as measured by R&D labor and expenditure shares, says little about the quality of R&D. For example, in relation to its OECD counterparts, China's expenditure on basic research is but 20 to 30 percent of the proportion of total R&D spending on basic research these advanced industrialized economies.[16] While the quality and composition of R&D effort may change as overall R&D intensity rises, we have not specifically investigated this association and do not intend to infer a particular qualitative dimension to the phenomenon of S&T takeoff other than that documented in the paper.

[16] See NBS/MOST (2001), pp. 250-251.

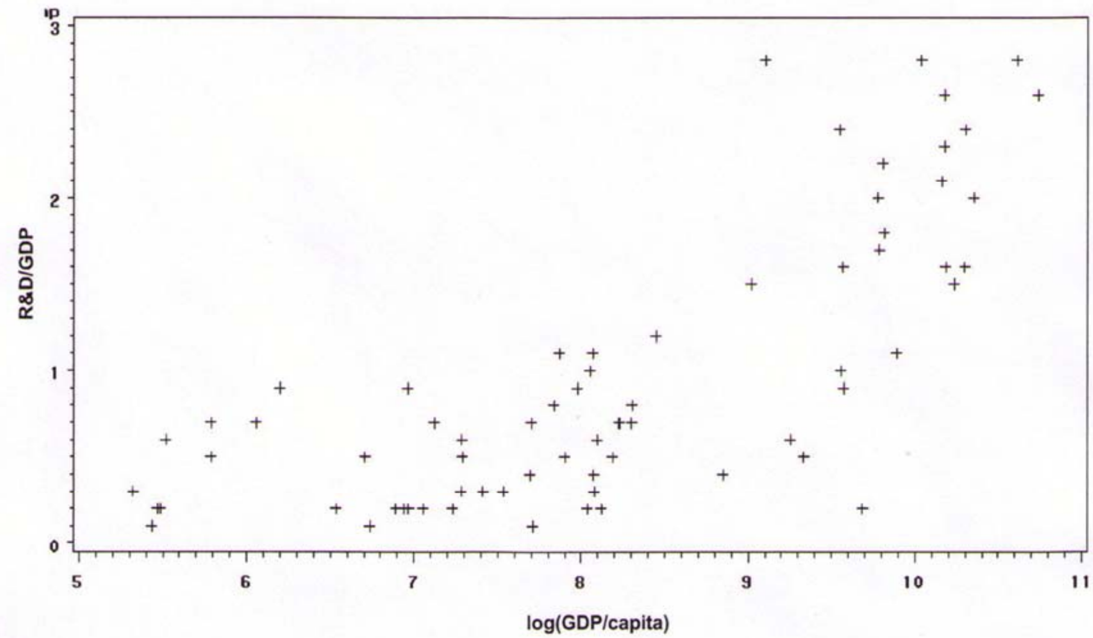

Figure 1
Scatter plot for country observations R&D/GDP versus log(GDP/capita).
data source: UNDP (2001), pp. 52-54

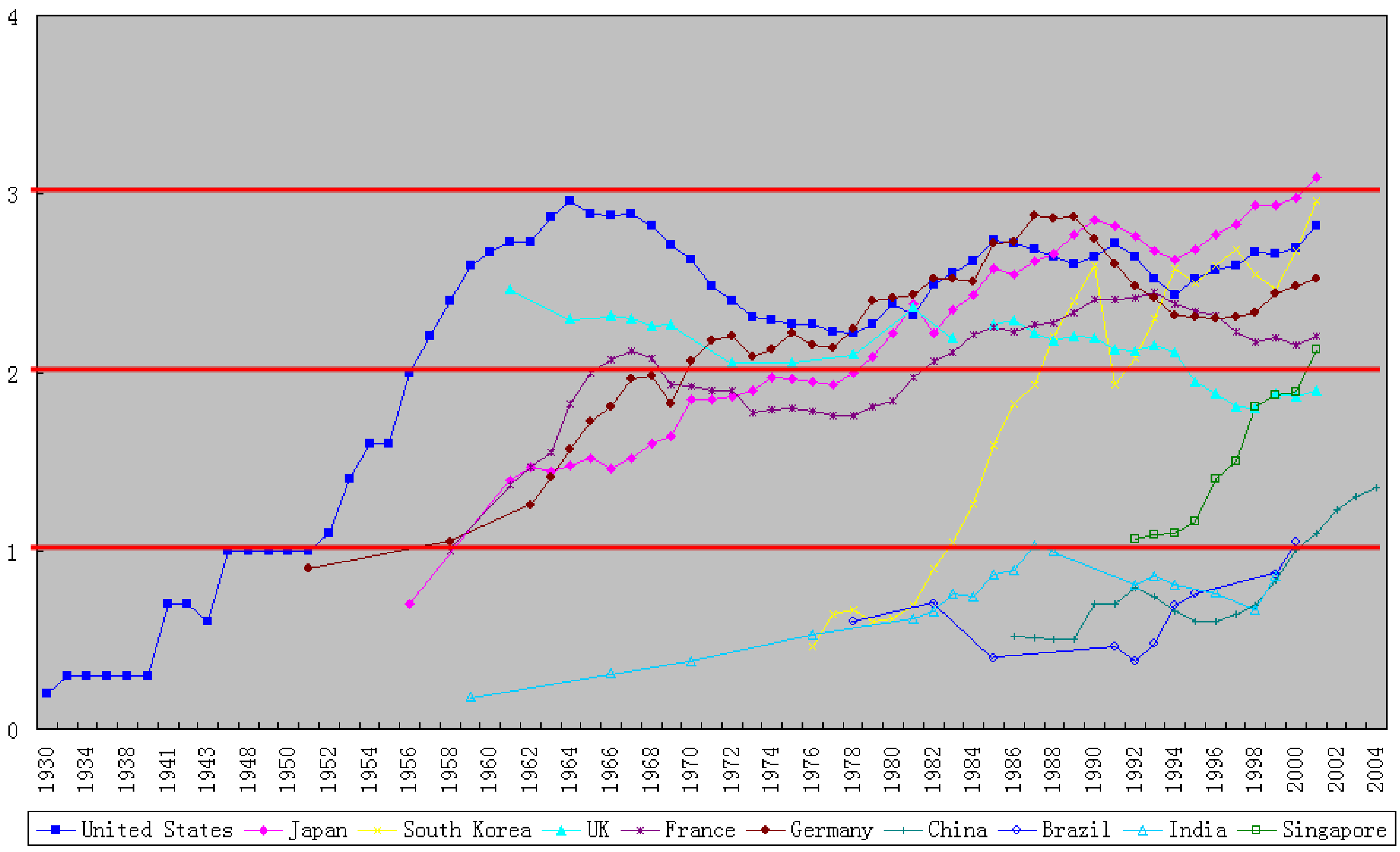

Figure 2. Historic R&D/GDP (or GNP) in 10 Countries

(R&D/GDP ratio (%) on the vertical axis)

Table 1: Historical documentation of S&T takeoff

Country	Dates for rise from 1%/ to 2%	Source (title and page number)
U.S.	1947/1956	Data are R&D/GNP. Xu, S.Y., Qiu, X.Y., Mu, Z. C., and Cao, X: *Macro-Policy for Science and Technology--- An International Comparative Analysis for China's R&D*, Tongji University Press, 1993, p97.
W. Germany	1961-1970	Christoph- Friedrich von Braun: *The Innovation War*, Carl Hanser Verlag, 1998, p. 29; and Xu, S.Y., Qiu, X.Y., Mu, Z. C., and Cao, X: *Macro-Policy for Science and Technology--- An International Comparative Analysis for China's R&D*, Tongji University Press, 1993, p 147.
France	1958-1967	Data are R&D/GNP. Xu, S.Y., Qiu, X.Y., Mu, Z. C., and Cao, X: *Macro-Policy for Science and Technology--- An International Comparative Analysis for China's R&D*, Tongji University Press, 1993, p 39.
Japan	1959-1978	Lihua Zhang: *S&T System and Policy Study After World War II in Japan*. Chinese Science and Technology Press. 1992, p. 96.
Singapore	1992-2001	*China Statistical Yearbook on Science and Technology 2000,* China Statistics Press, p.231. *China Statistical Yearbook on Science and Technology 2003,* China Statistics Press, p.521.
Italy	< 2.0%	*Science and Engineering Indicators* 2000, NSF, p. 112.
S. Korea	1983-1988	Data are R&D/GNP. Zhou, Jizhong. *International Science and Technology and Economic Cooperation*, Science Press House, 1993, p. 89.
OECD	1967-1983 1.2%-2.1%	Estimated weighted average of 12 EC countries. Source: Chris Freeman and Luc Soete, *The Economics of Industrial Innovation* (3rd Edition), MIT Press, 1997, p. 300.

Table 2. The role of changing industry composition (LME database)				
Industry	R&D/VA 1995 (%)	R&D/VA 2000 (%)	R&D/VA 2000/1995	Sales share 2000/1995
Elec. and telecom. equipment	2.97	7.34	2.49	1.91
Elec. equip. and machinery	1.71	4.98	2.91	1.15
Instruments and meters	2.86	4.65	1.63	1.28
Total industry	1.52	1.98	1.29	1.00

Source: Jefferson, Bai, Guan, and Yu (2003). Note: VA = value added.

Table 3. R&D complementarities	
impact on the measured productivity of R&D personnel*	sign
R&D Complementarities	
1. Human capital	
Level of management's education	+
% of workforce with foreign experience	+
% of workers using the internet	+
2. R&D network	
Receive external R&D assistance	+
Provide design or R&D services	+
IT assets/total fixed assets	+
3. Institutional quality	
Share of public ownership	-
Number of competitors	-
Purchase of outside technology	+
International technology diffusion (openness)	
Share of foreign ownership	+
Industrial park/export processing zone	+
Purchase a foreign license	+

Source: Jefferson and Zhong (2004): *The relevant estimates are statistically significant at the 5% level or better.

Table 4. Comparative producer surplus, R&D personnel			
	(1)	(2)	(1):2)
Country/ city	MP of R&D personnel ($)	R&D personnel wage ($)	ratio
Seoul	37,639	20,847	1.81
Shanghai	24,086	5,655	4.26
Guangzhou	14,984	3,249	4.62
Beijing	13,479	3,494	3.86
Chengdu	9,676	3,102	3.12
Tianjin	8,818	1,569	5.62

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