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Science and Technology Takeoff in Theoretical and Historical Perspective[1]

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Abstract

This paper documents the pattern of abrupt increase in the R&D expenditure to GDP ratio from below one percent to more than two percent in a number of OECD countries, particularly the larger economies, and in several large developing economies, including China. The endogenous growth literature identifies certain factors that drive an economy's research intensity. These include: (i) a decline in the output elasticity of production labor in relation to technology inputs, (ii) an increase in the marginal product of R&D labor, (iii) growing access to an enlarged knowledge base through international technology diffusion, and (iv) and subsidies to R&D labor, such as an increase in the wage-productivity gap. The paper places these four theoretical conditions in empirical context for China whose R&D-GDP ratio rose from 0.6 percent in 1996 to 1.3 percent in 2003.

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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 statistics show that R&D intensity, i.e., R&D expenditure as a share of GDP, varies widely across counties. Indeed, there exists a clear tendency for R&D intensity to be higher in high income countries than in low income countries.

The historical data on R&D spending in relation to GDP shows a striking tendency. That is the 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.

The next section examines evidence of the phenomenon of S&T takeoff in cross country data; Section 3 looks at the time dimension of S&T takeoff for the larger countries that have completed the takeoff and for several large developing economies whose R&D intensities have reached or now exceed one percent. In Section 4 we investigate the theoretical foundations of S&T takeoff. Section 5 looks at a body of empirical literature that documents changes in the structure of the Chinese economy that

conform to the theoretical requirements for S&T takeoff. Section 6 speculates why the phenomenon of S&T takeoff invariably results in leveling off. Our conclusions and discussion appear in Section 7

2. Cross-country data

The *Human Development Report, 2001* (UNDP, 2001) reports the ratios of R&D expenditure to GDP for 70 countries using data that falls in the time frame of 1987-97. Figure 1 plots these data for the R&D expenditure/GDP ratios in relation to the log of GDP per capita.

One 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 22 OECD economies that are included in the UNDP report, the average R&D/GDP ratio stood at 2.0 percent. Among the other 48 countries, the ratio stood at 0.7 percent. Just two of the non-OECD economies – Israel and Taiwan (China) – reported R&D intensities in the 1990s equal to or greater than two percent.

In Table 1 we report estimates of the statistical relationship between the ratio of R&D/GDP and the log of income per capita. Column (1) in Table 1 shows that estimates, based on the full sample of 70 enterprises, reveal a positive and robust relationship between R&D intensity and the log of income per capita.

In order to test for non-linearity in the relationship between R&D intensity and per capita income, we implement a piecewise regression in which we define low-income countries with levels of per capita income less than $10,000, high-income countries with incomes greater than $25,500, and middle-income countries with incomes lying between

$10,000 and $25,500. The key result from columns (2), (3), and (4) in Table 1 is the tendency for the per capita income in the subsample of middle income countries to exhibit a significantly larger and more robust association with R&D intensity than the association between income per capita and R&D intensity for either the lower or higher income economies. It is this middle income range associated with the steep relationship between GDP per capita and R&D intensity that represents the takeoff stage of the S&T transition.

These results indicate that the pattern of R&D intensification follows an "S" shaped logistic curve. Among the 13 countries with R&D intensities equal to two percent or greater, six have large populations, i.e. more than 45 million in 1999. All but one of the large countries (i.e. Italy) report high R&D intensities equal to or greater than two percent. Eight of the nine OECD countries with R&D intensities less than two percent are smaller countries, i.e. with populations in 1999 less than 45 million. To test the significance of country size as a driver of R&D intensity, we include a dummy for countries with populations over 45 million. Column (5) of Table 1 shows that the estimate of the dummy is positive and significant at the 15 percent level. If we omit Sweden, an extreme outlier, whose R&D intensity is 3.8 percent, the estimate of the size dummy becomes highly statistically significant. We discuss the potential role of size in the S&T takeoff in Section 5.

In the next section, we examine the experience of specific countries that have made the transition from low to high R&D intensity.

3. A time series perspective on S&T takeoff

Table 2 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. India's level of R&D intensity during the 1990s fails to reach two percent. For each of 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. Counties whose R&D intensities by 2000 fell in the range of one to two percent include Belarus, the Czech Republic, Singapore, and Slovenia. 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. Also, in recent years, the R&D intensities of two other large developing economies – Brazil and India – rose to reach or exceed the one percent threshold.

4. The causes of takeoff: 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. Notable contributions to this literature include Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), and Charles Jones (1995). We focus principally on Jones. Like others 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 an R&D sector, which innovates the technologies used in the intermediate good sector. We first model the structure of the R&D sector.

A common feature of much of the endogenous R&D literature is that it shares the assumption of "scale effects," that is, the assumption that a doubling of the level of resources devoted to R&D, say the number of R&D personnel, leads to a doubling of the per capita growth rate of knowledge output, at least in the steady state. Arguing that empirically, this assumption of constant returns to R&D effort is without empirical support (e.g. NSF, 1989), Jones (1995) argues for a model with a more flexible representation of the scale properties. Specifically, he explores the implications of constant or decreasing returns to R&D effect. In that spirit, we introduce flexibility into the R&D function by using the following formulation:

$$\Delta A = \delta' L_A^{\theta} \qquad (1)$$

where ΔA represents increments to the stock of knowledge, δ' represents the productivity of R&D labor, and θ measures the scale effect of increasing numbers of R&D personnel.

Jones speculates that the rate at which scientists discover new ideas may be a function of the amount of knowledge in the economy. If this is the case, then we can specify a function for δ' such that:

$$\delta' = \delta A^{\phi}, \qquad (2)$$

where ϕ measures the degree of externalities across time in the R&D process. When ϕ = 1, this equation reduces to the R&D equation assumed in the Romer, Grossman-Helpman, and Aghion-Howitt models. Alternatively, the case of ϕ < 0 represents what in the productivity literature is called "fishing out," in which the rate of innovation decreases with the level of knowledge. The condition ϕ > 0 corresponds to the case of positive external returns, in which the ability to "stand on the shoulders" of past inventors makes current inventors more productive (Caballero and Jaffe, 1993). A value of ϕ = 0 represents the useful benchmark of constant returns to scale (zero external returns) in which the arrival of new ideas is independent of the stock of knowledge. Substituting (2) into (1) gives:

$$\Delta A = \delta L_A^{\theta} (A)^{\phi}, \qquad (3)$$

Dividing both sides of (3) by A yields an expression for the rate of growth of technical change:

$$\Delta A/A = g_A = \delta L_A^{\theta} A^{\phi-1}. \qquad (4)$$

Differentiating both sides of equation (4) allows solving for the balanced growth path of knowledge, i.e.

$$g_A = \theta n/(1-\phi), \qquad (5)$$

where n is the growth rate of the labor force.

In order to derive the optimal ratio of R&D labor to production labor, Jones specifies the technology for the production of final goods as shown below:

$$Y = L_Y^{\alpha} \int_0^A x_i^{1-\alpha} di \qquad (6)$$

where L_Y represents production labor, α is the output elasticity of production labor, and the x_i are the available intermediate goods. The intermediate sector is composed of an infinite number of firms that produce intermediate goods; each good embodies a technology that lies on the interval [0,A]. All intermediate inputs enter final production with an output elasticity of equal to $1-\alpha$. Innovation corresponds to the development of new varieties of intermediate inputs that provide alternative ways of producing a final consumer good. To close the model, Jones specifies a utility function that exhibits

constant relative risk aversion with time preference (ρ) and intertemporal elasticity of substitution (σ).

Using equations (5), (6), and the utility function, Jones derives the following expression for the decentralized solution to the share of R&D labor, L_A/L, i.e.:

$$S^{DC} = L_A/L = 1/(1 + \psi^{DC}) \quad (7)$$

$$\psi^{DC} = [1/(1-\alpha)][\rho(1-\phi)/\theta n) + 1/\sigma)]/(1 + \zeta) \, . \quad (8)$$

The economic intuition for these results is as follows. A higher steady state growth rate, θn/(1-ϕ), is associated with a larger share of labor in R&D. Notice, however, that the causality runs completely from growth to R&D and not visa versa. A lower rate of time preference (ρ) or a higher intertemporal elasticity of substitution (σ) also leads to an increase in the share of labor devoted to R&D along the balanced growth path. Jones also shows that a wage subsidy to R&D labor, ζ, will increase the share of labor devoted to R&D.

Assuming that rising living standards do not significantly affect discount rates or measures of relative risk aversion, our focus is on the production side of the economy. Focusing on the parameters on the production side in Equations (7) and (8), we derive the following comparative statics in which the R&D personnel rises as a share of total labor:

- The factor income share of production labor falls in relation to that of technology intensive intermediate inputs (i.e., $\partial S^{DC}/\partial\alpha < 0$).

- The productivity of R&D labor rises ($\partial S^{DC}/\partial\theta > 0$),
- The scale effects of available knowledge grow ($\partial S^{DC}/\partial\phi > 0$),
- Subsidies to R&D labor increase ($\partial S^{DC}/\partial\zeta > 0$).

The following section examines a range of empirical conditions that potentially alter the values of α, θ, ϕ, and , ξ and thereby cause a rise in S^{DC}.

5. 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. China appears to be on an S&T takeoff trajectory – its R&D intensity having risen from 0.6 percent in 1996 to 1.3 percent in 2003 – and because of availabile relevant data, we focus on China to illustrate the empirical conditions of S&T takeoff.

Decline in the output elasticity of production labor (α): Structural change that causes a decline in production labor's output elasticity will, as a consequence, cause a rise in 1-α, the output elasticity of the complementary technology-intensive intermediate input, which in equation (6) includes capital goods. In equation (6), holding the marginal productivities of physical labor and intermediate inputs constant, a shift in demand and production that motivates an increase in x/Y relative to L_Y /Y will translate into a decline

in $\alpha/(1-\alpha)$. Why across nations should a rise in living standards should be associated with a decline in $\alpha/(1-\alpha)$, the relative factor income share of production labor?

A stylized fact of development 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, more 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 the rise in the technology intensity of production translates into a reduction in $\alpha/(1-\alpha)$?

Based on data for the population of China's nearly 22,000 large and medium-size enterprises, Table 3 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 rising technology content and a greater share of total industrial sales. The table shows that form 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, i.e., a decline in $\alpha/(1-\alpha)$. 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.

A high income elasticity of demand for technology-intensive goods need not translate into equivalent increases in the technological intensity of production n countries experiencing rising incomes. The demand for technology intensive goods can in part be satisfied by imports. In the case of China, however, while smaller developing countries may import technologically sophisticated electronic and telecommunications equipment and other high-tech goods, including electrical machinery, instrumentation, and automobiles, multinationals are clamoring to set up production for these R&D intensive industries in close proximity to China's burgeoning consumer markets. This phenomenon of the commercial desire to set up production in close proximity to large markets may explain why S&T takeoff has not occurred in certain smaller OECD countries, such as Norway, Australia, New Zealand, and Belgium. In the larger OECD economies, large populations create the potential for manufacturers to establish scale economies with the associated scale, learning, and productivity gains.[2]

Increasing elasticity of innovation w.r.t. R&D labor (θ): Because $\theta = (\partial g_A/\partial L_A)(L_A/g_A)$, estimates of θ are difficult to compute. In part, this difficulty arises from the fact that derived as a residual, g_A is difficult to interpret as pure technological change. Moreover, even if g_A is a proper measure of the rate of

[2] 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.

technological progress, a range of factors, in addition to variations in the input of R&D labor, L_A, will affect the rate of technological advance.

For empirical purposes, however, at the firm level, estimates of the output elasticity of R&D labor, controlling for other inputs, yields useful information about the magnitude and significance of θ. If we control for the appropriate range of inputs, an increase in output associated with an a given level of R&D labor input represents an increase in productivity that can be interpreted as an increase in the firm's (short-term) rate of technological change. A rise in R&D labor's marginal product, however, should be expected to motivate the allocation of new investment to R&D human capital leading to an increase in L_A/g_A. For reasons given above relating to difficulties in estimating and interpreting g_A, the ratio L_A/g_A is also difficult to measure. Rather than attempting to directly estimate changes in θ or its components – the marginal product of R&D capital (w.r.t. g_A) or an average measure of L_A/g_A – we identify the factors that motivate increases in the conventional marginal product of R&D labor and therefore lead to some combination of changes – rising marginal product and/or rising intensity of R&D labor – that increases the output elasticity of R&D labor.

The value of the marginal productivity of R&D labor may rise from the accumulation of a broad assortment of complementarities, including education, IT equipment, 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), use the following estimation equation to the significance of the contribution of a set of potential complements to enhancing the marginal product of R&D personnel.

$$\ln V_i = \alpha_0 + \alpha_1 \ln K_i + \alpha_2 \ln L_i + \alpha_3 \ln R_i + \alpha_4 (\ln R_i * \ln Z_i) + \Sigma \alpha_1 \ln LOC_i + \Sigma \alpha_1 \ln IND_i + \varepsilon_i. \quad (9)$$

In Equation (9) V represents value added, K and L are the net value of fixed assets and total labor, 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. Estimates of Equation (9) indicate that three groups of complements shown in Table 4 – human capital, R&D networks, and institutional quality – and their constituent measures each exhibits significant effects on the returns to R&D personnel.[3]

These results are of interest, since in China's economy the incidence of these complementary factors, with the possible exception of the number of competitors,[4] has grown significantly over the past decade. The growth of these complements to R&D can be expected to shift out the marginal productivity schedule of R&D, motivating new investments in R&D human capital, which cause the returns to R&D to move back toward the long run (risk-adjusted) return on investment. In either case, whether the accumulation of these complements is raising the marginal product of R&D labor or its output intensity, the result will be an increase the value of the output elasticity of R&D personnel.

[3] Given that estimates of Equation (9) are based on a single cross section in the year 2000, estimates of α_3 and α_3 are likely to 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.

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

Increasing scale effects associated with the amount of knowledge (ϕ): A key issue on which Jones focuses is the scale effect of the body of knowledge on the innovation process, that is the existence of knowledge spillovers over time, which implies $\phi > 1$, versus the "fishing out" effect, which implies that $\phi < 1$. Arguably, for China, the scale effects of the body of knowledge exist (i.e., $\phi > 1$) and are growing.

A key reason for believing that scale effects exist in the case of China is the opening of its economy to the international stock of knowledge, which has significantly expanded the effective pool of knowledge available to China's emerging R&D establishment. The measure of g_A shown in equation (4) refers to the stock of knowledge created by L_A within a closed economy. While scale effects may be absent or even negative in the case of new knowledge generated by China's internal R&D, the effective body of knowledge that serves as the "shoulders" on which China's R&D personnel stand effectively expands as foreign knowledge enters the economy and as China's R&D personnel are able to access overseas knowledge. In order to represent the effect of additions of foreign knowledge, in equation (3) we could represent the body of effective knowledge as Af, where f is a scalar ≥ 1 representing the ratio of the total (domestically and foreign produced) knowledge to domestically produced knowledge. 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.

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 4, 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 (forthcoming), 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.[5] Westphal reports on the pervasive role of reverse engineering in the Korean economy, abetted by an extensive government spending on the training of Korean scientists and engineers both at home and abroad, during the period of its S&T takeoff.[6] We do not have documentation of substantial reverse engineering of imported equipment in China, however, critics of China's enforcement of intellectual property rights cite the high incidence of reverse engineering of imported 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

[5] NBS/MOST (2003, 1999).
[6] Westphal (1990).

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 (ξ): The fourth factor shown in equation (8) with the potential to increase the ratio of R&D to production labor is wage subsidies to R&D personnel. Equations (5) and (6) are derived under the assumption that wages equate to marginal products. The research of Jefferson and Zhong (2004), however, indicates that this may not be the case.

Table 5, 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.[7] For the purposes of this section, the key finding 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 producer surplus for firms setting up R&D operations than their counterparts in Seoul. 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 in the near term. Because productivity remains relatively low in China's traded goods section, the pressure to raise

[7] The data in Table 5 show that the estimated marginal productivities are substantially larger than reported wages for the sample of Korean firms and 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 argues that there is not reason to expect the magnitude of any estimation bias to vary across cities, i.e. it should not affect the *relative* size of the estimated wage-productivity gaps.

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.

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 predict a rising proportion of R&D labor in the total workforce. It also provides some intuition as to the question of whether China's rising R&D intensification is the early stage of an R&D takeoff.

An aspect of the takeoff that is equally as 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.

A critical insight that grows from this analysis is the transitory nature of key factors that are initially motivating the takeoff. These include the four following transitions:

- 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 suggests that there is a certain 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 4, 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 the advanced economies 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, 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 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.

Figure 1

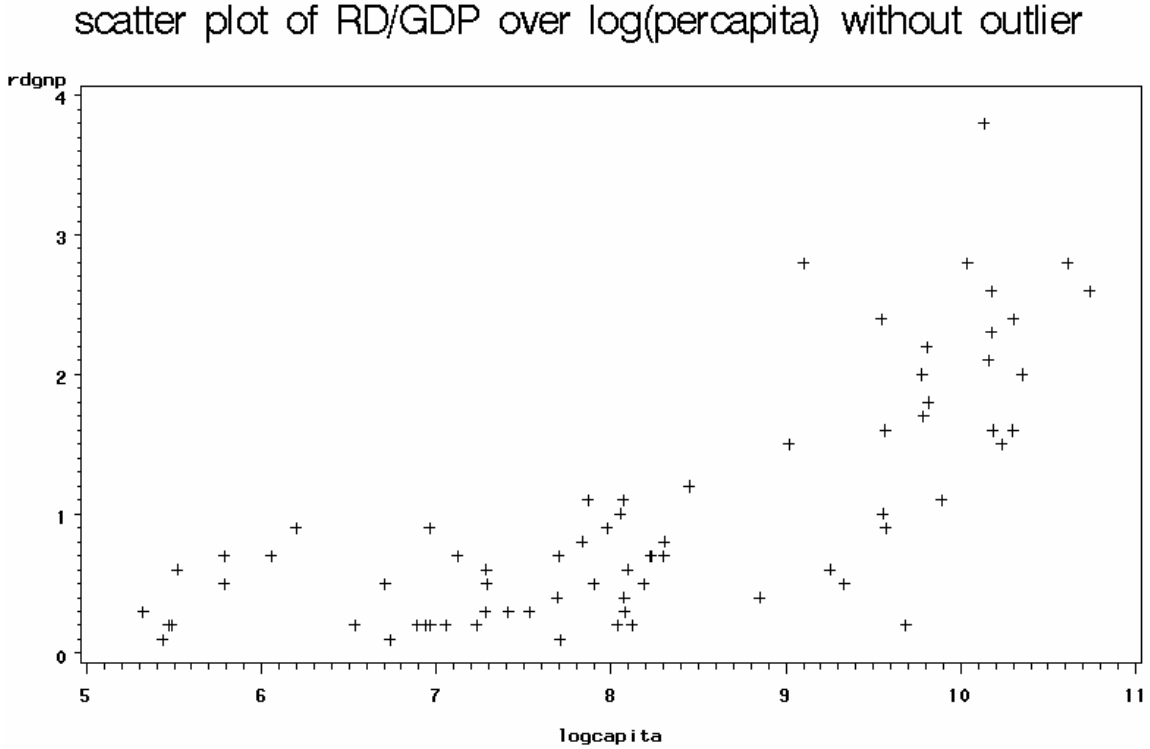

Table 1
RD/GDP versus log(GDP/capita)

Variable	(1) All observations	(2) Low income < $10,000	(3) Middle income $10,000 < x < $25,500	(4) High income > $25,500	(5) High income >$25,500, large country dummy
Constant	-2.447 (6.33)	-0.955 (-2.10)	7.715 (3.49)	-10.327 (1.40)	-8.941 (1.33)
ln(gdp/capita)	0.420 (9.03)	0.209 (3.40)	2.943 (3.70)	1.208 (1.70)	1.062 (1.62)
Population > 45 million	n.a.	n.a.	n.a.	n.a.	0.440 (1.63)
Adj. R-square (observations)	0.538 (70)	0.187 (46)	0.494 (13)	0.173 (9)	0.315 (9)

Table 2. 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	Has not achieved S&T takeoff	*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.

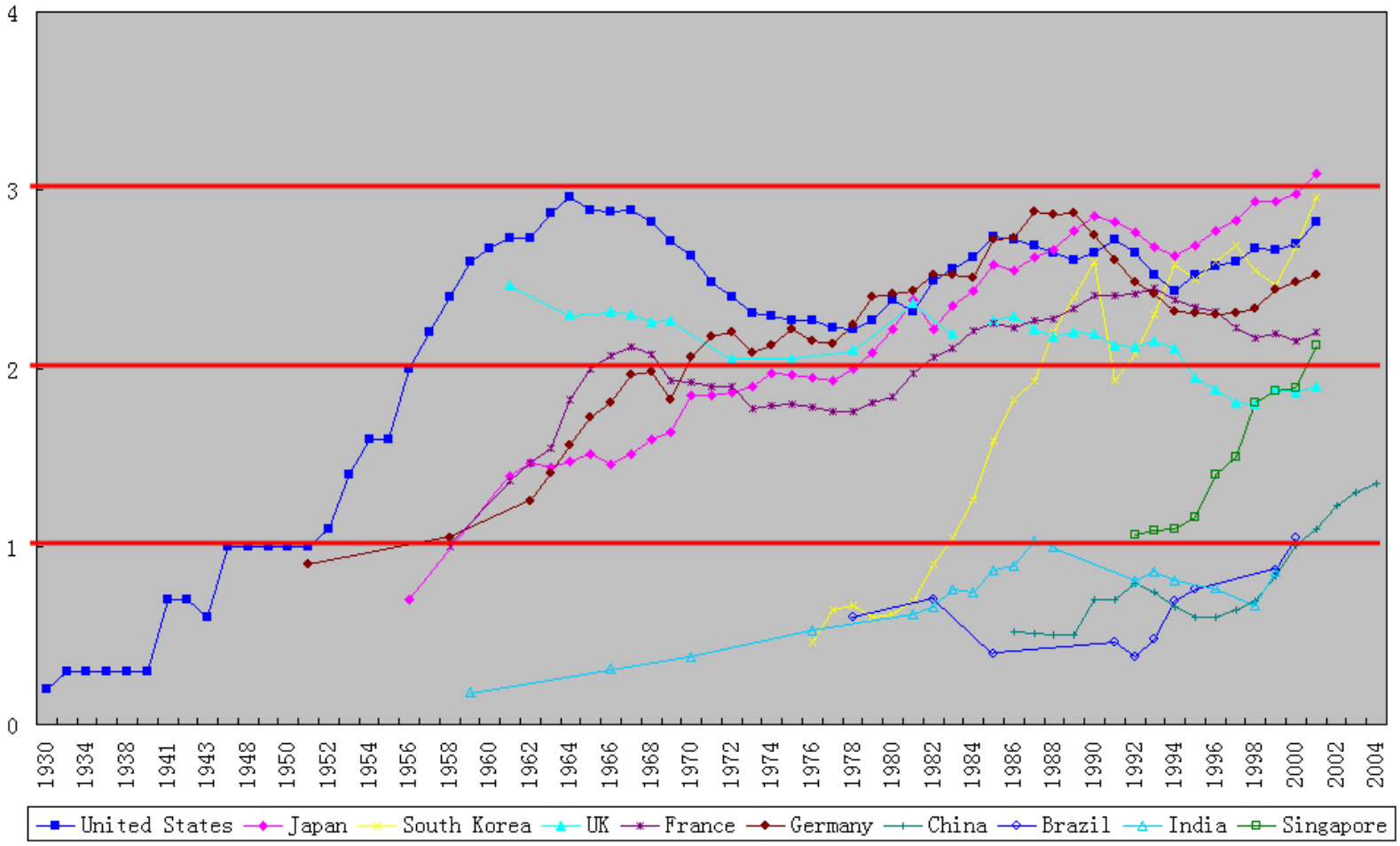

Figure 2. Historic R&D/GDP (GNP) in 10 Countries

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

Table 3. 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 4. World Bank study	
Significant impact on the measured productivity 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)

Table 5. 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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