

China's technology transformation: Diffusion and intensification of R&D effort in China's firms and research institutes

Project Summary

This proposal builds on an initial round of NSF-sponsored research that has examined the channels through which research and development resources are contributing to technical change in China. Over the period 1995-2003, China raised its R&D/GDP ratio from 0.6 percent to 1.3 percent. This abrupt increase shares features of the historic trajectories of large OECD countries that rapidly raised their R&D intensities from less than one percent to more than two percent. The central objective of the project is to deepen understanding of the factors that are driving the diffusion and intensification of R&D effort in China's economy. To investigate these factors, the project extends its empirical base along two dimensions: (i) for China's 22,000 large and medium-size enterprises, the National Bureau of Statistics has agreed to add the data for 2002-2006 (in addition to the data used previously for 1995-2001), and (ii) the Ministry of Science and Technology has agreed to provide its data base that covers China's approximately 4,500 research institutes for the years 1995-2003. The latter data have never before been used for systematic economic research. Together these data sets cover nearly three-quarters of China's total R&D spending.

The research is based on the theoretical foundations of the endogenous growth literature, including the motives for deliberate investment in R&D and interactions between firm-level R&D effort and R&D spillovers and international linkages (i.e., trade, foreign direct investment, and foreign technology transfer). The data sets are rich in variables that measure these activities at both the individual firm and research institute level and at various levels of industry and geographic aggregation. Among the research issues that the project will investigate are: (i) how complements to R&D, including firm/institute characteristics (e.g., size, profitability, and ownership), international linkages, and R&D spillovers affect R&D effort and returns (ii) the direct contributions of foreign invested enterprises and research institutes to China's rising R&D intensity compared with their indirect contributions that operate through international linkages motivating domestic R&D effort, (iii) the factors that determine the form of ownership restructuring of China's research institutes and the impact of these restructuring outcomes on R&D effort and institute performance, and (iv) the pattern and speed of diffusion of R&D activity from China's technology intensive centers to lagging areas.

A central challenge of this research agenda is to control statistically for issues of endogeneity and selection bias that arise in the analysis of models of R&D, technical change, and ownership restructuring. Access to large panels of microeconomic data that span nine to 12 years will allow for the use of a range of robust panel data estimation methods, including several relatively new techniques that specifically address endogeneity issues in panel data.

This work grows out of research that has been supported by the Department of Energy and the National Science Foundation. That research has generated a body of scholarly work that focuses on the relationship between R&D and imported technology, factor bias, ownership reform, and energy consumption. This proposed project would not be possible without the data set up, the research network, and the intellectual capital provided by the initial project. In addition to on-going collaborations with China's National Bureau of Statistics and researchers from Dartmouth College, the National University of Singapore, and Peking University, the project will be extending its research network to include the National Research Center for Science and Technology Development in China's Ministry of Science and Technology and the National Entrepreneurship Center and a team of researchers from Tsinghua University.

The project promises to sustain and extend its broad impacts in four areas: (i) A deeper understanding of the sources of China's rapid increase in R&D intensity and its impacts on technical change and economic growth in that country that will be disseminated through a continuing progression of published papers that convey these results to the scholarly communities in the U.S. and in China and to China's policy makers, (iii) an expanded appreciation by the staff and leadership in the collaborating Chinese agencies of the research and policy benefits resulting from making their data more broadly available, (iv) continuing improvements in the data sets in order to facilitate their usefulness for research and policy analysis, and (v) the training and participation of young Chinese PhDs, scholars starting academic careers, and staff in important Chinese agencies in the fields of R&D, technical change, and economic growth.

Project description

1. Introduction

This proposal builds on an initial round of NSF-sponsored research that has examined the channels through which research and development resources are contributing to technical change in China. During 1995-2003, China's R&D/GDP ratio rose from 0.6 percent to 1.3 percent.¹ This next phase of our research will investigate the factors that are driving the diffusion and intensification of R&D effort in China's economy. To investigate these factors, we will extend the empirical base of the project along two dimensions. First, the data for China's 22,000 large and medium-size enterprises for the period 1995-2001 used in our previous research will be extended to 2002-2006. Second, a major innovation of the proposed research is to bring on line for research purposes a data base that covers China's more than 4,500 research institutes for the years 1995-2003. During this period these research institutes have been restructured to become more profit oriented and encouraged to develop strong ties with the enterprise sector. We will be able to match the research institutes and the large and medium-size enterprises at considerably disaggregated levels of industry and geographic location. Together these data sets cover nearly three-quarters of China's total R&D spending. These data extensions are important because they enable us to investigate more effectively the sources of China's rising R&D intensity and efficiency by (i) examining the role of complements to R&D personnel, including human capital and R&D spillovers, (ii) investigating the impact on R&D effort of China's growing openness using trade, foreign direct investment, and foreign technology flows, (iii) testing the implications of the restructuring of China's research institutes for the intensity and productivity of R&D effort, and (iv) applying data-intensive but more robust estimation techniques.

In addition to our on-going collaboration with China's National Bureau of Statistics and researchers from Dartmouth College, the National University of Singapore, and Peking University, we are expanding our collaboration to include the National Research Center for Science and Technology Development in China's Ministry of Science and Technology and the National Entrepreneurship Research Center and a team of researchers at Tsinghua.

This work grows out of research that has been supported by the National Science Foundation and the U.S. Department of Energy. Our previous research has focused on six areas: (i) estimates of returns to R&D across Chinese firms of various ownership types; (ii) the role of in-house R&D in facilitating technology transfer; (iii) the factor-bias of

¹China's Tenth Five Year Plan forecasts that the R&D/GDP ratio will reach 1.5% in 2005 (Ministry of Planning, 2005).

in-house R&D and imported technology; (iv) complementarities to R&D that serve to enhance the effectiveness of R&D; (v) factors driving enterprise restructuring and the impact of restructuring on technology development; and (vi) patterns of S&T takeoff in OECD countries and the question of whether China is experiencing such a takeoff. The principal findings of this work are:

(i) Robust returns to R&D are prevalent across Chinese industry, with different ownership types exhibiting different relative strengths in technology development. Among these differences are high returns to foreign invested enterprises (FIEs) engaged in product development. State-owned enterprises (SOEs), while notably inefficient at creating new knowledge (i.e. new products and patents), experience significant performance gains once new knowledge is obtained, perhaps due to weak initial performance and market power (Jefferson et al, 2004; Hu, Jefferson, and Qian, 2004; and Fisher-Vanden and Jefferson, 2005).

(ii) In-house R&D is required for effective domestic and foreign technology transfer. Relative to China's domestic firms, foreign invested enterprises rely less on market-mediated technology transfer; technology transfer for FIEs is largely achieved internally (Hu, Jefferson, and Qian, 2004).

(iii) Alternative sources of technology transfer exhibit different factor biases that support distinct firm objectives. Autonomous technical change (driven by time and the investment process) drives neoclassical *growth*. In-house R&D emphasizes *efficiency* by focusing on comparative advantage, i.e., labor-using and capital and energy-saving technical change. Imported technology is oriented toward *new product* development (Fisher-Vanden and Jefferson, 2005).

(iv) Complements, such as human capital, foreign direct investment, IT spending, networks with other R&D performers (firms, institutes, and universities), and technology parks are significantly associated with returns to R&D. These complementary factors largely account for differences in measured returns to R&D in China across firms and across cities (Jefferson and Zhong, 2004).

(v) Selection bias infuses the Chinese enterprise reform process (with the more productive and profitable firms selected for restructuring); restructuring improves performance, but, most notably, contributes to a more labor-using factor bias (Su and Jefferson, 2004; Jefferson and Su, 2005), thereby raising the returns on assets.

(vi) Six of the seven largest OECD countries have abruptly increased their R&D intensities, doubling their ratio of R&D expenditure/GDP from one to two percent within a relatively short period of time (e.g. on average within a decade). China, having doubled its level of R&D intensity in seven years to 1.3 percent in 2003, may be in the midst of a similar S&T transition (Gao and Jefferson, 2004).

The acquisition and set up of an extraordinary data base, the establishment of a research network with strong internal complementarities, and the intellectual capital resulting from our team's joint research effort make this next phase of our research feasible. The central focus of this research project will be to extend our understanding of the factors that are giving rise to the seemingly historic acceleration in the diffusion and intensification of China's technological development. Specifically, this analysis focuses following factors relating to China's R&D intensification: (i) firm-specific factors and market concentration, (ii) knowledge spillovers, (iii) international linkages, (iv) ownership restructuring, and (v) the speed of diffusion of R&D activity across regions. In section 3, we describe the analytical foundations for enlisting these factors as part of our research focus. We first describe patterns of R&D activity and rising R&D intensity in China's economy.

2. China's rising R&D intensity

China's abrupt doubling of its R&D/GDP ratio is shown in the lower-right quadrant of Figure 1.² Apart from China, Figure 1 exhibits three striking features. The first is the rapid rise in R&D intensity in all of the OECD economies shown in the figure, which together represent six of the seven largest OECD economies. The second striking feature is that once the R&D/GDP ratios of these countries reached one percent, they ascend rapidly to two percent. Excluding the U.K. for which we do not have data, the ascent for the five large OECD countries occurs on average within a decade. Moreover, according to some researchers, South Korea, a latecomer that shares critical attributes with China, has reduced the time required to make the leap from imitation to innovation (Amsden, 1992 and 2001; Kim, 1997). Finally, Figure 1 shows that once R&D intensity reaches two percent it typically levels out off and fluctuates within the range of two to three percent.

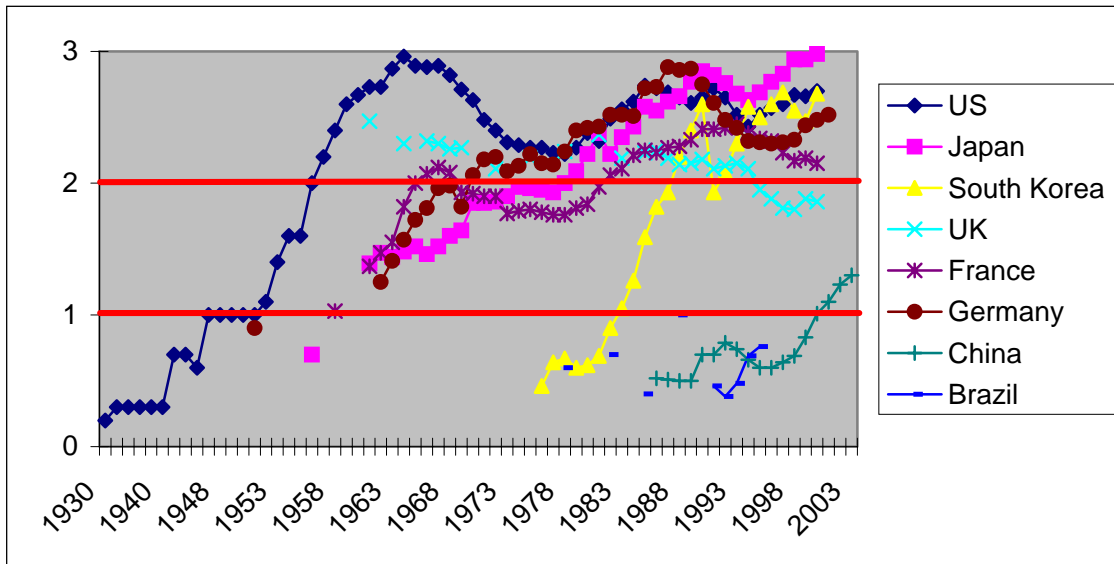


Figure 1. Historic R&D/GDP (GNP) in 8 Countries (Gao and Jefferson, 2005)

In this project, our focus is on the behavior of China's enterprises and research institutes and changes in the market and institutional environment that are driving R&D intensification in the Chinese economy. Since the early 1990s, the enterprise share of R&D spending in China has risen from less than 30 percent to approximately 60 percent in 2002 (NBS/MOST, 2003, p. 6-7). This rapid rise in the enterprise's share of total R&D funding strongly suggests that the enterprise sector, not government spending, has been a key driver of China's rise in R&D intensity.

The population of industrial large and medium-size enterprises (LMEs), which has served as the empirical foundation for our research, exhibits two distinct trends. The first is the increasing incidence of R&D activity. Between 1995 and 2001, China's LMEs reported an 11.2 percent decline in the proportion of non-R&D performing firms (i.e. a 45.6% increase in the proportion of R&D performers) (Hu and Jefferson, 2004). At the same time, the proportion of firms reporting ratios of R&D/sales in excess of one percent rose from 6.6% to 15.1%. During 1995 to 2001, the number of high performing LMEs with R&D sales ratios in excess of three percent grew from 544 to 1,581. All but 275 of these are domestically owned LMEs.

² The guidelines that China's NBS uses to compute measures of R&D expenditure are consistent with those set forth by the OECD (Frascati, 2002).

China's 4,500 research institutes (RIs) are important elements of this proposed project for the following reasons. First, while China's GDP rose by 55 percent during 1996-2002, the R&D expenditures administered by these institutes more than doubled. Secondly, China's RIs were extensively restructured, as most lost their government support and were effectively privatized. Third, a substantial portion of the institutes were acquired by enterprises, including LMEs, thereby contributing to the rise in reported LME research intensity. Finally, whereas during 1996-2002 the proportion of basic research in overall R&D spending rose from only 5.0 percent to 5.7 percent, the proportion of spending for research institutes rose from 6.5 percent to 11.6 percent. While some of this increase is due to the tendency of the enterprise sector to acquire the more commercially oriented research institutes, overall spending on basic research in the research institute sector rose nearly four-fold during 1996-2002 ((NBS/MOST, 2003, p. 29). Careful scrutiny of a policy that has induced a fundamental shift in the research orientation of one of the major R&D sectors in China promises to provide interesting academic insights and important policy lessons.

A final statistical perspective that is important as background to this project proposal is the geographic distribution of R&D activity in China. Not surprisingly, China's eastern provinces dominate the country's R&D spending. Furthermore, even within the eastern region, the cities of Beijing and Shanghai and Guangzhou and Jiangsu provinces account for two-thirds of the 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. If China is experiencing an S&T takeoff, it appears to be highly concentrated in several regions along the coast.

We do not in this proposed project attempt to explain the pattern of "takeoff" shown in Figure 1 for the OECD economies.³ However, having reached the one percent R&D/GDP ratio associated with takeoff for the OECD economies, China's rising R&D/GDP ratio does raise the question of whether China has begun a takeoff that will cause its R&D intensity to rise to two percent within a relatively short period of time.⁴ The analysis will provide insights into the sources of China's rising R&D intensity and may help our understanding more generally of the factors that are leading to rising R&D intensity in other developing economies, such as Brazil (shown in the Figure) and India (not shown).

3. Theoretical perspectives

Our analytical perspective begins with a description of the behavior of the firm where, for the purposes of this narrative, we use the term "firm" to include commercially-oriented research institutes. We begin with the now widely-held premise that intentional investment in R&D, in which entrepreneurs respond to market incentives, is critical for technical change. Following on the work of Romer (1990), Aghion and Howitt (1992), and Grossman and Helpman (1994), we start with a firm that seeks to maximize its present value by optimally distributing human capital between

³ Gao and Jefferson (2005) emphasize two conditions that may drive the observed S&T takeoff: a high income elasticity of demand for technologically intensive goods and market size and/or human capital that motivates investment in R&D (e.g., Romer, 1990) and FDI.

⁴ This abrupt change for China has occurred at a lower level of per capita income than it has for any of the countries that have previously exhibited this takeoff phenomenon. In 2000, Brazil's R&D/GDP ratio achieved 1.05% (NBS/MOST, 2003, p. 521). Depending on whether one uses the exchange rate conversion method or PPP, Brazil's per capita income is 2-3 times that of China. With a population of 180 million, Brazil qualifies as a "large" economy.

production workers and R&D workers.⁵ As the efficiency of R&D workers rises relative to production workers, firms reallocate human capital investment from production to R&D and thereby become more R&D intensive.

The present value of investment (PVI) can be represented as:

$$PVI = f_1(\Pi, r, L_R, \beta), \quad (1)$$

where Π represents the profitability of the innovation and r is the interest rate that discounts the value of future innovations. At the firm level, R&D personnel, L_R , enters into the innovation process with positive but diminishing returns, while β represents the factors both within the firm and within its economic and institutional environment that serve as complements to R&D activity, thereby increasing its efficiency. A key hypothesis of this analysis is that differences in returns to R&D across firms and research institutes, and therefore in the propensity to adopt and intensify R&D effort, results from factors that enter as complements to R&D labor.

Also, with a comparatively fixed supply of R&D personnel that fits the firm's R&D requirements, an increase in the demand for R&D labor may lead to higher average wages, w , and will thereby lower the net return to the project. However, the larger the firm's total work force, L , in relation to L_R , the greater the opportunity for effectively reassigning labor, or human capital investment, from production to the R&D function. That is:

$$w = f_2(L_R, L), \quad (2)$$

Taking the partial of (1) w.r.t. L_R , equating the resulting marginal revenue and marginal cost functions [i.e. equation (2)], and solving for L_R gives the following R&D demand function:

$$L_R = f_3(\Pi, r, w, \beta, L)\epsilon, \quad (3)$$

where ϵ has been added to capture the stochastic nature of the relationship, resulting from omitted variables and uncertainty.

The literature on R&D and growth typically avoids discussion of the distinction between the demand for an innovation, say based on the characteristics embodied in Π which describes the economic profit associated with a potential innovation, and the demand for R&D resources, which serve as a channel to the innovation or at least a means for increasing the probably of successfully securing an innovation outcome. As a result, equation (3) is in effect a reduced form, whereby the firm is solving the following two problems simultaneously:

- (i) Whether or not to adopt the innovation, conditional on the probability of success and the cost associated with the R&D resources required to secure the innovation, and
- (ii) The optimal level of R&D effort, conditional on the expected benefits associated with the innovation.

The logistical S-shaped curve, also called the diffusion curve, is typically used to describe the diffusion of technical change, i.e. new products and new process innovations.⁶ The adoption literature provides two interpretations of this well-established pattern of adoption. Neoclassical or equilibrium models of adoption view the adoption decision as based on optimizing decisions in which the decision is driven by a fully-informed comparison of

⁵ Other authors take a more macroeconomic perspective on inducements to technical change. See Atkinson and Stiglitz and Acemoglu (2002).

⁶The literature in this field was framed by Ryan and Gross (1943) and Griliches (1960), who formulated and demonstrated the empirical robustness of the "S"-shaped diffusion curve. For a review of the original research in this field, see Ruttan (2001).

the relative returns between the new technology and the old technology.⁷ In the formulation of equation (3), equilibrium models place relative weight on the information embodied in Π , the profitability of the new technical innovation. Evolutionary models of adoption describe technology diffusion and adoption as an evolutionary process rather than as an optimizing event. The process consists of diverse economic agents, uncertainty, and complex feedback mechanisms.⁸ For evolutionary models, differences in firm characteristics, based on ownership structure, size, and financial condition are likely to affect whether firms are early or late adopters. Also, the quality of information available to potential adopters is assumed to be highly variable; the firm's information reflects information networks and demonstration effects embedded in the firm's environment. Furthermore, trial and error are important as the firm experiments with various packages of R&D inputs to locate, acquire, and master heretofore unused technologies.

Given the extraordinarily uneven diffusion of R&D activity across China's regions, which we have documented in section (2) and elsewhere (Jefferson and Su, 2002, and Hu and Jefferson, 2004), our focus is not only on factors driving the adoption of R&D activity at the individual firm level, but also on the patterns of spatial adoption of R&D activity.⁹ One approach to investigating patterns of diffusion and adoption of R&D activity is to apply models of international technology diffusion to interregional technology diffusion. In particular, Caselli and Coleman (2001), who investigate the cross-country diffusion of computer technology, Eaton and Kortum (1999) who look at the speed of adoption and convergence, and Keller (2004), who reviews the literature provide the theoretical foundations for this important spatial extension to our analysis of China's R&D intensification.

To accommodate this evolutionary view of the firm that has been implicitly incorporated into recent models of technology diffusion, we incorporate into equation (3) a variable, F , which captures heterogeneous firm characteristics. Given the emphasis of the evolutionary approach on the firm's environment, we also include in equation (3) the potential for R&D spillovers, i.e., R^* . R&D spillovers potentially affect the firm's R&D decision by impacting one or more of the following three factors: (i) the profitability of the firm's existing innovations, (ii) the returns to new R&D, and (iii) the information available to the firm regarding the costs and benefits of R&D. Incorporating firm-specific characteristics (F) and R&D spillovers (R^*), we explore in more detail the arguments of the expanded R&D demand function defined as,

$$L_R = f_4(\Pi, r, w, \beta, L, F, R^*)\varepsilon, \quad (4)$$

Four of the arguments in equation (4) form the analytical and empirical focus of this research project. They are: (i) factors that shape the profitability of new technologies (Π); (ii) factors that determine the efficiency of R&D inputs (i.e. efforts to acquire technology) (i.e. β); (iii) the role and measure of R&D spillovers (R^*); and (iv) firm characteristics (F). Below, we briefly explain the theoretical basis for the factors identified in equation 4, identify the relevant literature, and report on some of our findings.

Technological opportunity and the profitability of innovation (Π). The profitability of an innovation depends not only on the degree of intrinsic technological opportunity embedded in the industry, but also on market conditions, such as competitiveness and the aggregate demand for the product. Linkages through trade and FDI that expand exposure to international market demand and the international technology frontier are also important. We review these.

⁷ See Lissoni and Metcalf, 1994.

⁸ See the research agenda outlined by Dosi and Silberberg, 1984.

⁹ Jaffe and Stavins (1994) model and estimate a diffusion function for energy conservation materials in the U.S.

(i) Industry classifications are typically used in studies of innovation to differentiate technology opportunity across industries. In our work – Jefferson et al (2004) and Hu and Jefferson (2004) – we find substantial industry differences in R&D effort and R&D outcomes, including the association between R&D effort and industry productivity, new product development, and patenting.

(ii) The domestic market environment, which determines levels of competition and the appropriability of rents to innovation, is often summarized by concentration ratios. Although in their review of the literature on innovation and market structure Cohen and Levin (1989) conclude that “concentration contributes little to an explanation of the variance in R&D intensity,” (p. 1077), we find a non-linear relationship in which rising concentrations encourage R&D effort although with diminishing returns.¹⁰

(iii) International linkages reinforced by China’s recent accession to the WTO and on-going integration with international markets leads us to expect that Chinese firms and research institutes are facing a widening sphere of technological opportunity. Grossman and Helpman’s observation (1990) that growth theorists need to improve their understanding of “how the international economic environment impinges upon the incentives that firms in specific countries have to invest in the creation of knowledge.” (p. 86) is particularly true for China. We focus on two areas of openness that shape the market environment within which the firm operates: trade and foreign direct investment (FDI)

- Trade. The link between trade and R&D is modeled by Romer (1990) and Grossman and Helpman (1990), who show that the returns to research will rise when trade promotes growth in the relevant sector. Trade creates opportunities for scale economies in production, which brings production efficiencies, higher returns to innovation, and a larger base for learning by doing and using. It also allows for greater R&D payoffs to new product development diversification. On the input side, trade also allows for a wider variety of quality intermediate inputs and capital goods (Romer, 1994). By virtue of its size and economic diversity across and within provinces and the recent acceleration of trade activity associated with the lead up and accession to the World Trade Organization, China provides a natural experiment for examining the impact of the growth of trade on research activity. In support of the trade-innovation link, Sokoloff and Khan (1990) find that the introduction of water transport in the U.S. was followed by increasing patenting activity in counties contiguous to the waterways.

- Foreign direct investment. A common theme of the FDI literature is that multinational corporations establish foreign invested subsidiaries, so that the parent company can transfer proprietary technology internally within the firm, with less risk of the technology being lost through market failure associated with weakly enforced technology contracts. Foreign subsidiaries, therefore, may promote R&D effort in one or a combination of two ways. Industries with concentrations of FDI may engender more technology spillovers through labor mobility or demonstration effects. Alternatively, if, as research generally shows, FDI firms enjoy a competitive advantage, then domestic firms – and other foreign subsidiaries – will need to invest in R&D to survive or maintain market share. In preliminary research, Hu and Jefferson (2005) find that in industries that are FDI-rich, domestic Chinese firms tend to increase their R&D intensities most rapidly. Whether R&D effort is motivated by technology opportunity or the threat of competing innovations, China’s domestic LMEs located in 3-digit industries with the highest FDI concentrations in 1995, exhibited the largest increases in their R&D intensities over the period 1995-2001.

The above list of factors may expand the access of a firm to technology opportunity, its incentive to pursue these opportunities, and its ability to appropriate returns from R&D. Below we focus on other forms of complementary

¹⁰ Jefferson et al, 2004. The robustness of this finding diminishes when we add industry dummies.

inputs to R&D which match up with R&D personnel (or expenditures) to make these basic R&D inputs more efficient.

Complements to R&D inputs (β). For the reasons described below, we classify the factors that shape the efficiency of R&D inputs as “complements” to the basic unit of R&D input, i.e. L_R .¹¹ By matching up with R&D personnel, these factors substantially enhance the returns to R&D workers. Using some of our research results, we illustrate how the role of complements has emerged as an important factor in our research results.

R&D capabilities across metropolitan areas. The role of complements in R&D activity is demonstrated by Jefferson and Zhong (2004), who show that across five major metropolitan economies in China and Seoul, S. Korea the range of R&D complements and R&D productivity vary significantly and are highly related. Using a World Bank data set based on 300 firm surveys each conducted in Shanghai, Guangzhou, Beijing, Chengdu, Tianjin, and Seoul, the authors construct an index of R&D capabilities that summarizes complementarities to R&D. They combine these 12 measures of R&D complements into four broad categories – openness, human capital resources, R&D networking, and institutional quality. For the purposes of this research proposal, the key finding of this study is that a wide range of factors, including shares of public and foreign ownership, manager’s education, proportion of workers with foreign experience, purchases of foreign licenses, all complement R&D personnel in ways that enhance the returns to R&D personnel.¹² In order to understand the effectiveness of core R&D resources, it is necessary to examine the contributions of the factors that complement them.¹³

These research findings are consistent with a large body of cross-country research points to four types of complements to R&D labor: human capital, trade and FDI that are specific to the firm, foreign technology transfer, and government policy.

(i) **Human capital.** Human capital is a widely acknowledged and used measure of R&D effectiveness. It is probably the most fundamental measure that distinguishes R&D personnel from production personnel. For successful innovation, the complementarity of human capital with unskilled labor is decisive. Barro (1991) and others who use measures of educational levels or occupational classifications of scientists or engineers as proxies for human capital find these to be a highly predictable determinants of innovation success.

(ii) **Firm-specific trade and FDI.** In the previous section, we identified spillover effects of trade and FDI as potential indicators of technology opportunity. Trade and FDI that are specific to individual firms may also enhance – and complement – in-house R&D effort. While the literature focuses on the impact of trade and FDI on firm

¹¹ While our taxonomy distinguishes between factors that expand technology opportunity and R&D complements, both are complements. In fact, all of the factors examined in this study can be broadly construed as potentially complements to R&D activity.

¹² The paper emphasizes two other notable findings: Shanghai exhibits R&D capabilities and returns that seem more similar to those of Seoul than to any other Chinese city, and the proportional difference between the marginal return and marginal cost of one R&D staff person in China is much greater than it is in Seoul, thus making China a more attractive location than Seoul for locating R&D operations.

¹³ Because the data set used for this research is largely based on a single cross section, it was not possible to use the conventional panel data set estimation techniques to control for endogeneity or to correct for measurement error. Hence these results should be seen more as evidence of interesting correlations rather than robust estimates of causality.

productivity,¹⁴ fewer studies study the interaction of these factors with R&D performance. Using the LME data set, Jefferson and Zhong (2004) find that the greater the share of foreign ownership, the more productive and profitable R&D personnel. Jefferson et al (2004) find that foreign invested firms are particularly efficient at generating high returns to new product development.

(iii) Foreign technology transfer. Access to foreign technology should considerably enhance the range of both imitation and innovation possibilities. Consistent with findings by Basant and Fikert (1996) for Brazil and Ferrantino (1992) for India, Hu, Jefferson, and Qian (2004) find that in-house R&D and imported technology purchases interact as robust complements. While the former is necessary for effective foreign technology transfer, the latter substantially increases the payoff to domestic in-house R&D. Fisher-Vanden and Jefferson (2005) find that Chinese firms use imported technology to support new product development. The hypothesis that trade drives the use of imported technology, and hence product development, has yet to be tested.

(iv) Government policy. Economists agree that as a result of the extensive technology spillovers associated with research and development, from a social perspective firms under-invest in R&D. This is likely to be particularly true in China where property rights and patent law are still irregularly enforced. The Chinese government provides direct grants to firms, principally LMEs, and tax subsidies to a wide range of firms.¹⁵ Whether these substitute for or complement private R&D effort is a matter of empirical investigation.

R&D spillovers (R*). A key insight of the literature on endogenous growth through knowledge spillovers is that productivity and R&D decisions of individual firms is affected by the myriad R&D decisions made by other firms in the technology or geographic neighborhood of the optimizing firm. Romer (1990) and Easterly (2001) emphasize that R&D spillovers may cause aggregate investment in knowledge that exhibit non-decreasing return to scale thereby allowing firm-level investment in innovation to be a sustainable process in the long run. Grossman and Helpman (1990) treat knowledge capital as “a (public) input into R&D, so that at any point in time fewer resources are needed to invent a new variety of product the greater is the state of scientific understanding.” This view receives empirical support from Jaffe (1986), and Hu and Jaffe (2001).

One issue in the literature (Branstetter, 2001) is the relative importance of domestic and international spillovers. Using the three sources of technology development in our data sets – R&D, purchases of domestic technology, and purchases of imported technology – Hu and Jefferson (2004) have begun to investigate this issue.

Concentrations of R&D activity in certain industries or geographic areas may generate spillovers through demonstration effects. As well as providing access to knowledge and a more ample supply of R&D personnel, concentrations of R&D may enable non-adopters to understand the function of the R&D operation and the associated innovations that are possible using R&D resources. It is unlikely that we can distinguish among the channels through which R&D spillovers operate, but theory and evidence suggests that the sign of these impacts will generally be positive.¹⁶ One possible outcome, however, is that through competitive effects, R&D concentrations skew the distribution of firm productivity, generate more exits and consolidation, and thereby increase market concentration. This is a testable hypothesis.

Firm-specific characteristics (F). Our research identifies several firm-specific factors that affect the demand for

¹⁴ See, for example, Aitken and Henderson (1999) and Keller (2004).

¹⁵ See Liu, 2000, Simon, 1989, and Dahlman, 2002.

¹⁶ The way in which R&S spillovers affect individual firm R&D effort will be a key focus of the small firm survey that is proposed in this study (conducted by research associates at Tsinghua University).

and effectiveness of R&D resources. Evolutionary models of adoption suggest that heterogeneous firm effects significantly impact on the probability and timing of adoption. Among the firm-specific factors that we assess are:

(i) Size. In general, the research concerning the implications of firm size for R&D effort yields ambiguous results, that are confounded by related characteristics such as liquidity, diversification, and market structure (Cohen and Levin, 1989). Within our sample of China's LMEs, we find a size-R&D intensity elasticity that is significantly smaller than unity (Jefferson et al, 2004).

(ii) Profitability. Because of the riskiness associated with innovation, R&D tends to be financed out of retained earnings. Consistent with these findings, Jefferson et al, (2004) estimate of their R&D effort function confirms the association between Chinese firms with higher retained earnings ratios and higher R&D intensity.

(iii) Governance. The latter half of the 1990s and first half of this decade have been particularly active periods for China's enterprise and research institute restructuring. Our research results consistently show that ownership and ownership conversion, whether measured as formal ownership classification or assets shares, affect R&D productivity. (e.g. Jefferson, Bai, Guan, and Yu, 2004 and Jefferson and Su, 2005).

This structure, theoretical perspective, and set of empirical findings provide the analytical framework for our research program. Specifically, this background provides the framework motivating a set of specific hypotheses on which we focus our data and econometric work.

4. The hypotheses, data, and econometric strategy

Based on the literature on panel data estimation, our own research, and the theory and modeling strategies described in the previous section, we describe in this section a set of specific hypotheses that will focus our research, the data used to test these hypotheses, and estimation strategies to implement tests of our hypotheses using these data.

Hypotheses. Our research will focus on the following set of specific hypotheses, which relate to our broad inquiry into which features of China's economy are most important in explaining the country's abrupt rise in R&D spending:

(i) Conventional measures of R&D effort set the stage. How important are the conventional or baseline conditions that are the usual focus of studies of R&D effort? These include firm-specific measures, such as formal education and experience, firm size, and ownership structure (e.g. FDI), and measures of market structure, including market size and concentration ratios.

(ii) R&D spillovers matter. If R&D spillovers matter, how do they operate-directly through complementary purchases of domestic and foreign technology or through proximity – industry or geographic – proximity to clusters of R&D activity or concentrations of market transactions of domestic or foreign technology? What is the effect of large concentrations of R&D intensive firms and research institutes operating in the same industry or geographic neighborhoods?

(iii) International effects operate on R&D intensity both directly and through indirect channels that intensify R&D in domestic firms. What is the effect on foreign and domestic firms of directly engaging in trade, FDI, and foreign technology transfer? What are the impacts of operating in industries or geographic areas in which there are high concentrations of these activities?

(iv) Restructuring raises R&D effort, linkages, and returns. Does restructuring result in more horizontal linkages between research institutes and LMEs? Are R&D spillover effects stronger among restructured firms and institutes? With restructuring do we observe more international linkages, controlling for the impact such linkages may

have on the propensity to restructure?

(v) The speed of diffusion across regions in China is significantly determined by the factors identified above. What impacts do R&D spillovers, international linkages, and ownership restructuring have on the pattern and speed of diffusion of R&D activity across regions? Do government policies, such as R&D grants and tax subsidies, speed or retard the diffusion of R&D activity?

Our estimation equations will involve various functional forms based on equation (4). As a demand equation for R&D effort, L_R can be measured using a variety of variables that are available in our data sets. These include R&D personnel, R&D expenditure, counts of R&D projects, or formally designated R&D units within the firm. With the appropriate time lags, we can also embed equation (4) into knowledge production functions, in which we estimate the impact of the relevant arguments on the production of domestic and foreign patenting activity, new product development, or export intensity. Finally, equation (4) can be embedded in a production, cost, or profit function in which we control, as needed, for other factor inputs and prices. We examine the key data sources below.

Table 1. NBS-LME and MOST-RI Data (partial list of variables)

LMEs (firm and 2-4-digit levels)	Research institutes (institute and 2-3 digit levels)
Technology activity	
R&D expenditure and personnel; S&T expenditures (basic, applied, experimental); S&T personnel; internal R&D units; new product development, patents (domestic and foreign); published scientific articles (domestic and foreign); various measures of productivity.	
Technology opportunity and profitability	
Industry classifications (construction of concentration ratios using LME data)	
Aggregations of export activity and foreign/overseas investment activity	Associations with domestic and foreign research organizations.
Complements to R&D	
Degrees (Ph.D.s, MAs, undergraduate degrees, occupational levels)	
Firm-specific exports, FDI, purchases of imported technology	Technology acquisition – domestic and foreign Sources of R&D funding – government, enterprises, non-profit, foreign, other
R&D spillovers	
R&D (S&T) expenditures and R&D (S&T) personnel at the firm at the city/country or district level	
Firm characteristics	
Sales, assets, employees, industry, location, profits, level of subordination, number of formal R&D units within the firm.	
24 formal ownership classifications, including state, collective, foreign/overseas, shareholding, and private.	Transformed to an S&T enterprise; incorporated into an existing enterprise; transformed into a central or provincial gov't unit or a large-size S&T enterprise
Assets owned by state, foreign, and other (i.e. non-st domestic).	Assets owned by the government, enterprises, foreign sources.

Data. While much of our attention has focused on R&D personnel as the measure of R&D adoption, our data sets include a variety of technology variables that measure technology activity. As shown in Table 1, these include R&D

expenditure, the establishment of formal R&D units, new product development, domestic and foreign patenting, and measures of single factor, multi, and total factor productivity. Our LME and research institute data sources contain many variables that are identical. Others, however, are specific to one data source or another, sometimes representing intrinsic differences between the structure and functions of firms and those of research institutes. In the following table we identify a limited subset of the several hundred variables that are included in the data sets.

Econometric issues. We will need to address a number of econometric issues in testing the hypotheses and the underlying theories we have discussed above. The potential endogeneity of the complementary factors, the heterogeneity of Chinese firms, and the non-random nature of our enterprise sample caused by entry and exit that in turn related to firm performance are the primary sources of bias. The design of our empirical research will center on employing various econometric tools to correct such biases. Only when such potential biases are properly addressed will we be able to make causal inference regarding the complementary factors and R&D. The availability of large panels of data, particularly with the additional data to be acquired with the proposed grant, provides us with a variety of possibilities.

(i) Fixed effects. The conventional measure of dealing with the potential correlation between unobservable/un-measurable firm heterogeneity and the regressors is to exploit the time dimension of panel data and perform a “demean” procedure to rid the error term of the firm specific effect under the assumption that the latter is time invariant. An analytically equivalent approach is the Least Squares Dummy Variable estimator (Greene 1993, p. 466). In Fisher-Vanden and Jefferson, we are not able to identify with confidence a set of appropriate instruments within our data set. Instead we have managed to obtain fixed effects estimates by incorporating into our estimation procedure a dummy for each of the N firms that appear in the panel data set.

(ii) Instrumental variable approach. A problem with the fixed effects solution is that it eliminates the firm specific effect along with most of the variation of the variables, as in short panels – large N and short T – most of the variation resides with the cross-section dimension. In addition it also exacerbates the problem of measurement error and relies on the assumption that the firm specific effect remains unchanged over time. Alternatively, one can use the IV approach (See for example, Jaffe 1986). The basic idea is to use industry level variables to approximate the environment in which firms operate. When used as instruments, these industry level variables will be correlated with the business environment that affects firms’ business decision and yet uncorrelated with the specific characteristic of any particular firm. We have had success with this approach in our EINT paper and Hu and Jefferson (2004)

Recent developments in the panel econometrics literature suggest two additional approaches are available to address the econometric issues that we face.

(i) The Arellano – Bond dynamic panel estimator (Arellano and Bond, 1991). Arellano and Bond, building on the earlier literature on the General Methods of Moments (GMM) estimation and dynamic panel data estimators, propose a GMM estimator that provides a different venue to address the firm heterogeneity and endogeneity problem. According to this approach, the equation to be estimated is first differenced to rid the error term of the firm specific effect. Under certain conditions, Arellano and Bond show that lagged predetermined variables can serve as effective instruments for the first differences of the regressors. To address the issue of high degree of autocorrelation in the regressors, Blundell and Bond (1998) suggest a system GMM estimator that includes an additional set of moment conditions that are based on the assumption that past levels are uncorrelated with current first differences of the endogenous but predetermined regressors.

(ii) The Olley-Pakes approach. Olley and Pakes (1996) develop an innovative method to estimate a production function and deal with the endogeneity generated by firm specific effect and the sample selection bias in an integrated

framework. The major identifying assumption is that firms' investment is monotonically increasing in the unobservable firm productivity. The latter can then be expressed as a function of investment, capital and other state variables by taking the inverse of the investment function. By also making a firm's liquidation decision a function of the unobservable productivity, a two-stage semiparametric estimator is used to obtain consistent estimates of the output elasticities of the production inputs. Levinsohn and Petrin (2003) propose an alternative estimator in the same spirit. Instead of using investment, they assume that the intermediate input is increasing in the unobservable firm productivity. This approach is less taxing on the data since many firms do not invest every year thereby forcing researchers to discard these observations when using the Olley – Pakes estimator.

With a data set that spans the diverse population of Chinese large and medium size enterprises and the additional years of data we are going to acquire, these techniques provide us with powerful tools and ample opportunities to deal with the methodological difficulties that have plagued similar studies in the OECD literature.

5. Work program

The research project is designed to extend three years, i.e. from July 1, 2005 through June 30, 2008. The project includes three critical components. The principal elements of the work program will consist of the following.

- (i) Extension of our work with the National Bureau of Statistics
- (ii) Establishment of our research collaboration with the Ministry of Science and Technology
- (iii) Extension of our research collaboration with Tsinghua University
- (iv) Interaction of our core research team (Jefferson, Hu, Su, Fisher-Vanden, and Gao) with these organizations, including research at Brandeis.
- (v) Coordination with the U.S. Department of Energy grant.

Extension of our work with the National Bureau of Statistics. During 2000-2002, with support from our initial NSF grant, 12 NBS staff and their supervisors visited Brandeis to conduct our research collaboration. The research template that we have developed involves extended visits by two NBS researchers at a time – one from each of the collaborating departments – with each pair staying for six weeks. During these visits, the NBS staff members work intensively with Jefferson and with graduate student research assistants. While the visitors are generally well-trained in basic statistical methods, they have had little formal training in economics and econometrics. Our approach has been to team each visitor with a Brandeis Ph.D. candidate in order to work on two parallel projects. We meet formally on Monday, Wednesday, and Friday mornings to analyze the work assignments from the last session and plan assignments for the next meeting.

This has been a successful model in terms of exposing our Chinese colleagues to the realm of economic, econometric, and policy analysis; it has generated jointly-authored manuscripts and publications in both English and Chinese. The collaborative process has also been useful for us for the purpose of gaining a deeper understanding of the content and methods of collection of the data and for understanding the occasional counterintuitive result. For the next three years, the NBS has entered into the following formal agreement.

- (i) Data preparation. Continue to collect, format, and make available in a timely matter both sets of economic/financial and S&T panel data for the period 2002-2006. The NBS will also make available portions of the 2000 S&T census, as needed, to extend the national overview study beyond the LME sector to include agriculture, the services, and the small-scale industrial enterprise sector.

(ii) Collaboration. During the summers of 2005-2007, the NBS will resume providing release time for members of its staff to participate in the research collaboration at Brandeis.

Start up collaboration with the Ministry of Science and Technology (NRCSTD). A major innovation of this project is to bring into the research realm the extraordinary set of data on China's research institutes that has been compiled over the past two decades. Initially, the directors of NRCSTD balked at allowing any of the individual institute level data to leave China. They were willing to collaborate but required that we provide the necessary econometric programs, which they would implement on-site. After discussing the drawbacks (indeed impossibility at this initial stage) of such an approach, our NRCSTD colleagues have agreed to select, based on appropriate statistical criteria, a subsample of the data that they will bring to Brandeis for analysis. A member of the NRCSTD staff is expected to visit Brandeis this summer to jointly analyze the data. Within NRCSTD, we will be collaborating with Liu Xielin, one of China's foremost authorities China's national innovation system.

While at this time the NRCSTD has agreed only to provide the data through 2003, they have agreed that if the initial round of collaboration is successful, they will update the data set annually through the end of our NSF research collaboration. Our colleagues in the NRCSTD are genuinely and enthusiastically engaged in this research project. They have for some years been anxious to undertake this type of enterprise.

Collaboration with Tsinghua University. Professors Gao Jian and Jefferson are presently completing a paper that provides an historical perspective on the S&T takeoff experience of the OECD economies. Professor Gao has taken a leading role among China's researchers who focus on the emerging role of R&D within China's enterprises system. His research on enterprise-level technological innovation and capabilities led to his receiving first-prize from China's Ministry of Education for his contribution to "China's scientific and technological progress."¹⁷ Under this project, Professor Gao has several responsibilities. These are:

(i) In collaboration with Jefferson and Gao Xudong, Assistant Professor at the School of Management at Tsinghua, design and implement a survey of at least 20 firms and research institutes. The purpose of the survey will be to clarify the role of the factors that motivate the adoption of R&D. This survey will help to strengthen the motivation and design of the overall research program using the large panels of LMEs and research institutes. The survey results will also provide the basis for a scholarly article.

(ii) In his capacity as Vice Director of the National Center for Entrepreneurship Research Center, Gao Jian will also coordinate with the NBS and NRCSTD/MOST to organize a workshop during the summer of 2005. The purpose of the workshop will be to report on and discuss our research findings, to make modifications to our research plan as recommended, and to create a broader network of Chinese researchers that work in the area of innovation and technical change in China. We anticipate also inviting several U.S. scholars who work in the area of research and development.

(iii) Coordinate with other Tsinghua faculty, including Gao Xudong, Xue Lan, all of whom specialize in R&D and innovation in China, The purpose of this coordination will be to establish closer coordination between our research design and findings and China's S&T policies and programs. This function is to ensure the policy relevance of our research program.

Interactions of the core research team with NBS, Most, and Tsinghua. We have two venues for our research collaboration. One is at Brandeis, where interactions will occur principally during the summer months, when we have

¹⁷ Professor Gao was the Chinese expert of the first and second Seminar on Technological Innovation in China and United States co-sponsored by the U.S. and Chinese NSF's

travel money for all of the key participants to travel to Brandeis one or more times during the span of the 3-year project.. The second critical venue is in Beijing, where we plan to conduct field research, hold a workshop jointly with NBS and MOST, and coordinate with MOST staff as they replicate and extend on-site programs that we have developed at Brandeis.

Coordination with the Department of Energy grant. Karen Fisher-Vanden at Dartmouth College has received a U.S. Department of Energy grant (DE-FG02-04ER63930). The grant covers the following costs that overlap with the proposed NSF-sponsored research. NBS data (a smaller sample of approximately 3,500 energy intensive LMEs) and a portion of the travel for NBS staff; one month of support for Jefferson to manage empirical analysis at Brandeis, travel for Jefferson and Fisher-Vanden, and Brandeis graduate student support.

Phasing of research. We outline the sequencing of our research program.

- (i) May-August, 2005. Enterprise and research institute survey
- (ii) June-July, 2005. MOST staff comes to Brandeis
- (iii) July 2005: NBS staff come to Brandeis University
- (iv) May or June, 2006, Workshop at Tsinghua
- (v) June 2006-August 2007. Jefferson is on sabbatical; one semester in China.
- (vi) June-July 2006: NBS and MOST staff come to Brandeis
- (vii) June-July 2007: NBS and MOST staff come to Brandeis
- (viii) Throughout: research papers are prepared, submitted, revised, published in English-language journals and Chinese language sources.

Summarizing, we anticipate five broad impacts of the proposed activity:

(i) A deeper understanding of the sources of China's rapid increase in R&D intensity. Through the intellectual capital created within our broad network and the stream of publications that will result, we expect to establish the baseline reference in the literature on China's rising R&D intensity and to provide an important set of insights that will help to explain the phenomenon of abrupt increases in R&D activity as observed across the OECD economies and that appears to be emerging in several developing economies. Results are being published and circulated in both English and Chinese language publications, so that they can be accessible to Chinese and foreign scholars and policy makers.

(ii) An expanded appreciation by the staff and leadership in our collaborating Chinese agencies regarding the research and policy benefits resulting from expanding the access of researchers to the vast statistical resources that the Bureau collects on a regular basis. While the NRCSTD begins this collaboration with a deep intellectual interest in the research enterprise, their appreciation for specific research applications for the data they collect will likely expand.

(iii) An upgrading of the data quality. As a result of our collaborative work, the NBS has remedied a number of data deficiencies. The most significant problem we identified was the disappearance of firm identifiers for up to 10 percent of the LMEs in any given year. We surmise that this was principally due to a change in formal ownership classification resulting in the assignment of new IDs. For other enterprises, mergers or exits led to the disappearance of IDs. As a result of the complications that this feature of the data posed for addressing some of our research questions (particularly those relating to the impact of ownership reform), the NBS began in 2004 identifying the cause of all ID changes and linking the IDs across consecutive years. Other improvements in data collection and formatting will result from the participation of the NBS and MOST staff in our research program.

(iv) Young Chinese Ph.D. candidates and tenure-track academics are being trained and networked in China-related fields of research. Through their participation in the research program, overseas Chinese PhD students and junior faculty are gaining access to the vast statistical network of China's NBS data and an extensive research and policy network that is focused on carefully applying up-to-date research methods for analyzing the data. Two senior researchers for this project, Albert Hu and Jian Su, now on the faculties at the National University of Singapore and Peking University respectively, were former Ph.D. students at Brandeis. Their dissertations were substantially based on the NBS data. This experience is shaping the careers of Chinese scholars and expanding the supply of researchers, experts, and research collaboration in the important fields of R&D, technical change, and economic growth.

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Note: Citations in bold types were prepared in relation to NSF grant (#SES-9905259); papers with an asterisk (*) can be viewed at <http://people.brandeis.edu/~jefferso/index.html>

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