The Impact of Technology Transfers on Industry Productivity in China: 1980-95

Sean M. Dougherty *<SMDougherty@alum.mit.edu>*
MIT Science & Technology Initiative and
International Trade Administration
Foreign Commercial Service,United States Embassy
3 Xiushui Beijie, Beijing 100600, China

Abstract

The linkage between foreign technology inflows and total factor productivity (TFP) is examined at the industry level over the period 1980 to 1995. *Appropriate* foreign technology transfers, measured by transfer contracts and foreign direct investment (FDI), are found to have a very strong effect on TFP growth. Relatively labor-intensive industries are best able to independently assimilate new technology.

Domestic R&D is found improve productivity, but to be most effective when closely integrated with technology transfer efforts.

Technology transfers are found to be of comparable importance with ownership in explaining TFP.

Export orientation, while a predictor of differential TFP performance, is not as powerful an indicator as technology transfer.

A newly developed data set of technology transfer contract flows is integrated with factor statistics from the Second and Third Industrial Census to perform the analysis.

1. Introduction

The importation and indigenization of foreign technology represents the best opportunity for developing countries to sustain high rates of economic growth by continually improving productivity. According to the traditional Solow model of economic growth, only through total factor productivity (TFP) improvement can countries sustain growth in the long run. Considerable debate has arisen over the extent to which the Asian Tigers have achieved their impressive growth through advances in intensive growth versus massive increases in capital and skilled labor input. The extension of this debate to China's massive economy has not substantially clarified these questions, partly due to the difficulty in interpreting Chinese statistics. Often the debate has centered around whether China's productivity change has been positive or negative, rather than high or low. Moreover, few studies have focused specifically on the experiences of this enormous giant in introducing foreign technology (*yinjin jishu*).

Gaining an understanding of how well China has adopted foreign technology is critical for foreign providers of technology, domestic Chinese industry, and policy makers in China &

abroad. Foreign providers must be informed about the feasibility of their transfers of technology and the risks associated with fostering competition; recipients need to be aware of what types of technology are most appropriate for their industries and understand the extent to which they need to expend resources on indigenization (*xishou*); and Chinese policy organs should be conscious of the implications of their interventionist policies, just as foreign governments may worry about abetting potentially dual-use capability.

This study[1] focuses on China's industrial sector (*dierchanye*), which is the largest and fastest growing part of the Chinese economy, representing 42% of 1996 gross output. While agriculture (*diyichanye*) initially led the charge of reform after 1978 through improved incentives and more open markets, Industry raced ahead to grow three times as quickly, receiving a full 96% of all foreign technology transferred from 1979 to 1995 by value. This study will attempt to grasp the effects of these transfers of technology on a industry-by-industry basis to make informed judgements about China's development experience. To understand the scope of productive success and failure, this study carefully pieces together the best relevant Chinese statistics currently available and then analyzes the productive elements of technical change.

2. Previous Work

2.1 Technology in China

Only a few studies have systematically examined the impact of foreign technology on productivity in China. Comprehensive studies by Richard Conroy of the OECD (1992) and Gene Tidrick of the World Bank (1986) are somewhat dated now. Conroy reviewed a voluminous amount of Chinese-language materials describing the problems of importation and assimilation, but admitted that "insufficient information is available for Western observers to estimate the overall costs and benefits of the post-1979 technology import program...the information is classified and not available outside of China." His frustration was echoed by Tidrick, who used statistics from the early 1980s to calculate total factor productivity gains (TFP), but had no associated data on technology flows. Both studies concluded that the level of imported technology was often inappropriate for China's level of development and the resources devoted to assimilation & diffusion were far too low.

Several Chinese observers have addressed the same questions, including Shi Qingqi (1992), Chen Huiqin (1997), and Samuel Ho (1996; 1997). Shi's study suffers from a similar problem as Tidrick's—lack of substantial post-reform data. Chen's broad-based study is akin to Conrad's in its review of impressionistic sources and generalized statistics. Ho examines

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the experience of Jiangsu Province in successfully adopting foreign technology using survey data from the late-1980s. Both Chen and Ho's conclusions, in particular that spending on assimilation is far too low (only 1/20th of technology transfer expenses in the 1990s), are quite similar to both Conrad's and Tidrick's.

A study by Zhao Hongxin quantitatively looked at the relationship between technology imports (with capital equipment as a proxy) and indigenous technology spending in China using yearly time-series data from 1960 to 1991 (Zhao, 1995). He found a positive correlation, but his study leaves out the all-important measure of the success of new technology: productivity change.

2.2 Technology and Productivity

An increasing body of literature describes the linkage between various forms of technological progress and economic growth. Relevant approaches consider innovation, trade, knowledge spillovers, export orientation, and explicit technology flows.

2.2.1 Innovation & Trade Literature

Formal endogenous innovation models described by Grossman & Helpman (1991) and Rivera-Batiz & Romer (1991) have received considerable discussion, albeit these studies' focus on product innovation makes them less appropriate in the context of developing countries. Keller's (1996) extension of this work to developing countries considered the absorptive capacity of an economy to be a decisive factor in raising long-term growth. Ideas from these studies have been pursued in a number of other promising directions, including examinations of spillovers of knowledge and export-induced flows of technology.

2.2.2 Knowledge Spillovers

Analysis of the flow of knowledge embodied in imports of equipment has recently been pursued for the OECD economies, where data is most readily available. A study by Sakurai *et al.* (1996), using an input-output approach, found evidence indicating that international spillovers of R&D played a major role in TFP improvement, especially from the most advanced to lesser advanced economies.

A broader approach, which looks at the R&D spillovers from developed to developing countries was undertaken by Coe *et al.* (1997), who again find substantial spillovers. Research which examines the dynamics between domestic R&D and foreign technology is thoroughly reviewed by Pack (1997), who notes that increasingly a complementary relationship has been observed between R&D and technology transfers. Pack argues that still little is known about the determinants and forms of technology inflows to developing countries.

2.2.3 Export-induced Flows

In attempting to explain Asia's phenomenal growth experience, the World Bank (1993) examined the role of export-orientation in leading regional development, contending that implicit transfers of technology serve a major role in productivity improvement. Foreign direct investment (FDI) is thought to drive this relationship, but its independent effects are not examined. Related studies of openness have addressed the variable impact of FDI on growth in an alternative selection of countries (such as Balasubramanyam *et al.*, 1996); unfortunately, these studies do not sufficiently narrow their topical analysis to evaluate the importance of technology transfers, *per se*, separate from trade.

2.2.4 Explicit Technical Models
Despite the recent focus on technical learning, few general models of economic growth with explicit *technology* components have even been suggested. In a systematic review of the growth literature, Jan Fagerberg (1994: 1165) concluded that technological explanatory variables outside of research & development and skilled workers had yet to be explored. Some more recent studies have addressed this weakness, such as one by the World Bank (Zhang and Zou, 1995) which tests a formal model treating technology imports as an input to a Solow-style growth equation using a multinational developing country data set. Zhang and Zou found a heavy reliance on wholesale utilization of foreign technology rather than domestic innovation. This study will proceed in a similar conceptual vein, with a focus on China's experience.

2.3 Productivity Measurement
Measurement of productivity changes in China is not as straightforward as in most developed countries which have more mature statistical systems. Approaches from the aggregate level, by sector, on the firm level, and by industry have all been undertaken to distill differing aspects of China's technical progress.

2.3.1 Economy-wide
Aggregate studies of productivity in Asia have been widely popularized (*The Economist*, 3/1/1997) as fierce debate continues about overall productivity gains. The most recent study to focus on China by the International Monetary Fund (Hu and Khan, 1996) found total factor productivity (TFP) growth of four percent per year from 1979 to 1994, contributing 40 percent of China's aggregate economic growth. Unfortunately, this type of study cannot easily identify the *sources* of productivity growth. However, a battery of studies have looked more closely at sub-sectors using a wide range of methods. Nearly all of these studies have focused on methodological questions and the effects of structural reforms on productivity.

2.3.2 By Sector
The most active area of inquiry into China's productivity has been in the state-owned industrial enterprise (SOE) sector, and subsequently as compared with township and village enterprises (TVEs). Because the enterprise reforms of the early 1980s initially focused on SOEs, they were a logical place to start research. Many of these studies inevitably focused on measurement issues, as Chinese statistical practices were still highly underdeveloped.

Heated debates on methodological questions have surrounded measurement of total factor productivity changes which has been found to be positive or negative depending on choice of deflators, weights, and data selection (notably between Jefferson *et al.* and Woo *et al.*). Some consensus seems to have arisen over major methodological questions, which will be discussed at length in the next section (Chen *et al.*, 1988a; Jefferson *et al.*, 1992; Groves *et al.*, 1994; Jefferson and Xu, 1994; Jefferson, Rawski, and Zheng, 1996). On balance, a moderate gain in state enterprise TFP seems likely in the early 1980s, just as slight cooling off appears to have occurred in the late 1980s to early 1990s; collective enterprise performance seems to have been more impressive, albeit somewhat less so by the early 1990s. These studies have found some linkages between the enterprise reforms and changes in productivity, but specific causes have been difficult to identify using their yearly time-series data.

2.3.3 At the Firm-level

Many of the methodological problems of aggregate analysis have been overcome through analysis of firm-level data. Perhaps of greatest value is these studies' ability to clearly differentiate allocative efficiency from technical efficiency, often referred to as x-efficiency. Allocative efficiency refers to a firm's ability to minimize costs, while technical efficiency is the extent to which a firm utilizes the best available production techniques. Technical efficiency gains have been more pronounced than allocative gains in China's post-reform period (Wu, 1996; Li, 1994; Jefferson and Xu, 1994).

Firm-level studies have come to a variety of conclusions, frequently based on the selection of the (sometimes very small) samples, often biased toward better-performing enterprises and special economic zones (see Dollar, 1990; Jefferson and Xu, 1994; Woo *et al.*, 1994; Liu and Liu, 1996, for examples). In an lengthy discussion of firm-level and sectoral studies, Wu Yanrui (1996: 23, 62, 141) argues that the record of efficiency improvement has been a poor one, and that the biggest potential productivity gains could come from changes in the efficiency of use of existing technologies. Production at only *half* of the best-practice technology is common, although some industries seem more capable than others at adopting new technology. While a few firm-level studies do break out their samples by industry branch, they tend to suffer from the above-mentioned selection biases (such as Liu and Liu, 1996; Li, 1994; Jefferson, 1992).

2.3.4 By Industry-branch

Only a few studies have addressed aggregate productivity changes *by industry* for the state, collective, and private sectors, which is what this study will attempt to do. The most comprehensive previous series of work is by the US Census Bureau (McGuckin and Ngugen 1989, 1992, 1993). In their analysis of the National Industrial Census (*PCDZ*, 1988), they examine TFP trends across 39 industries from 1980-85. They find improving productivity for manufacturing and declining productivity for extractive and energy industries. In a regression analysis, they find support for several possible explanatory variables for the productivity trends, including the number of computers and engineers, ability to retain profits, and payment of bonuses (1992: 263). Additionally, across their series of studies (1989, 1992, 1993), they test nearly all possible permutations of productivity measurement techniques for sensitivity. McGuckin & Ngugen find a relatively simple production model best describes the Chinese economy; this model will be discussed next.

3. Research Design

3.1 Linking Technology and Productivity

This study will attempt to fill a large gap in the empirical literature linking foreign technology transfers and productivity by using: (1) newly available statistics from China's Industrial Census, and (2) tortuously uncovered flows of technology by industry branch. Insights into the flow and structure of the linkage between technology and productivity will be sought. Through this examination of the technology-productivity linkage, the relative importance of technology transfers relative to other productivity-enhancing factors will be estimated. Given varying levels of capital intensity, technical updating, R&D expenditure, assimilation effort, economies of scale, and technical capability, the extent to which technology transfers independently or interactively produce industry-wide productivity gains will be examined.

This study is more comprehensive in scope than previous work and ideally more definitive, principally because of the use of more systematic data, but also as a result of the inclusion of the foreign-invested sector and smaller enterprises. The extended time period covered in this study—almost the entire post-reform period—should make it more thorough than many previous published productivity studies. Representing the first known attempt to link the Second and Third Industrial Census, this study also suggests techniques for longitudinal analysis in the midst of changing standards.

Since the precise form of the linkage between foreign technology and productivity has yet to be well established, and the goal of this study is not specifically theoretical, only a modified Solow growth model will be tested. The Cobb-Douglas form growth accounting equation will be used, employing a gross-output production function with constant returns to scale and calculated input shares, all of which were found by McGuckin & Ngugen (1992, 1993) to be highly robust. Technology is assumed to be exogenous, contributing linearly to technical efficiency. The impact of foreign technology transfers on productivity will be assessed at the two-digit Chinese SIC industry branch level over the period 1980 to 1995.

3.2 Primary Data

To determine the impact of technology transfers on productivity, this study utilizes growth rates in industry-level *aggregated* figures across the years 1980, 1985, and 1995. By looking at changes over an extended time period, many of the difficulties with prior time-series analytical work are reduced, as results become less sensitive to choice of deflators and intermittent data collection errors. Moreover, data for intervening periods at the industry level are not comparable, due to changes in industry coding and typically low quality control[2].

The necessary components for productivity measurement are taken from the Second and Third Industrial Census, as opposed to yearly industrial statistics, which are widely acknowledged to be inflated with large yet indeterminate fraudulent figures (*shuifen*). For

[2] 1984 data for most variables is available in the Second Industrial Census, but these figures would add little incremental value to this analysis. The author attempted to acquire comparable data for 1990, but the substantial upward drift in collective statistics cannot be deterministically removed from figures on the four-digit SIC level.

example, after the completion of the Third Industrial Census, official 1991-94 industrial output was proportionally revised downward by the State Statistical Bureau by over ten percent (compare *TJNJ*, 1995 and 1996).

Technology flows are based on technology transfer contract statistics and foreign direct investment (FDI) by industry sector, using an intertwining collection of the most complete data available. Contract statistics are based on a comprehensive official study for 1979-90 and newly obtained updates for 1991-94. FDI is based on investment actually made from 1980-95, sourced from the Third Industrial Census.

3.3 Coverage

All independent accounting enterprises at the township level and above are included in this analysis. This includes some smaller-sized enterprises, with an average output of five million *renminbi*, contributing 44% to output in 1995. Previous detailed studies have primarily been limited to large and medium sized enterprises (*dazhongxingqiye*). An exception is Field (1992), who looked at the changing structure of industry, and cautioned about substantial upward bias in the sub-township category, so these enterprises are not included in the present analysis.

The State, Collective, and foreign-invested sectors have all been included here. In contrast, nearly all previous detailed studies have limited their analysis to the State and Collective sectors. Of course, foreign enterprises contributed less than one percent of output in 1980 and 1985, but by 1995 they contributed almost 18%. Most studies whose data extends into the 1990s have continued to ignore foreign enterprises, but they probably suffer from a selectivity bias acknowledged by Jefferson *et al.* (1996: 168), where the best performing firms are the most likely to undergo conversion to forms such as joint ventures. Through the inclusion of foreign enterprises, the overall progress of Chinese industry is estimated.

3.3.1 By Branches of Industry

For consistency, 1995 Chinese SIC definitions at the two-digit level are used to define industry sectors (*CSIC*, 1995). These definitions are roughly in accordance with ISIC Revision III, 1988. Data from the Third Industrial Census use these definitions consistently, except in the reporting of technology vintages. The Second Industrial Census utilized newly implemented (1985) four-digit industry codes based on ISIC Revision II (only the township and larger Census statistics are reported consistently at all four-digits). For longitudinal comparison, all required data from the Second Industrial Census had to be manually converted to the 1995 Chinese SIC definitions using a correspondence table (*CSIC*, 1995: 49-107). For all critical productivity-related variables, conversion was direct and discrete: no disaggregation was necessary. However, some ratios, such as the proportion of productive capital for 1980 and 1985, and the implicit gross output deflator for 1985, were slightly imperfect[3].

Technology transfer statistics were found to use several different industry standards. The core set of statistics, from 1979 to 1990, conform to the 1985 Chinese SIC definitions, and were converted accordingly. Data from 1991 to 1994 conformed to a still unidentified numbering system, whose categories *are* traceable to specific two-digit industries using cluster comparison across three open sources. Transfer data were not available beyond the two-digit level in either the 1979-90 or the 1991-94 data set. Because differences between 1985 and 1995 Chinese SIC standards principally affect four-digit sub-sectors which map discretely to alternative sectors, this study assumes that the transfer recipient firms in each two-digit sector remain similarly classified after conversion. In the regression analysis by all 37 sectors, disaggregation is required for the 1991-94 data, which will be described below.

Two industries, miscellaneous mining and miscellaneous industry, are not included in the 1995 Census results due to their small representation. They will be excluded from examination here. Of the remaining industries, specialized machinery and coal energy do not have matching technology transfer data, and thus will be excluded from the regression analysis.

3.4 Quantifying Productivity

This study uses total factor productivity (TFP) as its principal measure of productivity, which includes both allocative and technical efficiency components. The largest share of TFP change in China is presumed to be technical efficiency improvements, as suggested in prior firm-level studies (Wu, 1996). Alternative single-factor measures of productivity (such as labor and capital productivity) are not capable of controlling for tradeoffs between inputs. TFP is favored because it is a *whole* measure of productivity: output obtained given a marginal cost-weighted set of inputs.

The Cobb-Douglas form growth accounting equation will be used, employing a gross-output production function with intermediate inputs (Gullickson, 1995: 38):

$$\dot{TFP} = \frac{\dot{Y}}{P_Y} - w_I \cdot \frac{\dot{I}}{P_I} - w_L \cdot \dot{L} - w_K \cdot \frac{\dot{K}}{P_K}$$

TFP is the residual after the weighted set of inputs have been removed from gross output. This form of the growth equation has been found to be appropriate for the Chinese situation (Jefferson *et al*., 1996), where intermediate inputs make up a large share (around 70%) of gross output. In industry-level analysis, intermediates are even more important, especially in

[3]In almost all cases, missing four-digit industries represented less than 10% of the two-digit destination industry output. As these measures only involved ratios, the distortion is expected to be insignificant.

the context of China, where use of the firm method means that transactions outside of a firm are often duplicated in gross output (McGuckin and Ngugen, 1992).

Constant returns to scale are assumed, so the three weights sum to unity. Weights are calculated using cost factor shares, as well as with fixed weights derived in other researchers' frontier studies, to test sensitivity. The rates of change are calculated using the tourquist method:

$$\dot{X} = \ln(X_t) - \ln(X_{t-1})$$

3.4.1 Measurement of Variables

The correct measurement of input and output is critical to the outcome of this study and must be described in some detail. This study borrows popular techniques used in recent studies of Chinese industry to addressing most of the methodological questions, particularly those dealing with the principal sources of bias.

Price deflators have evolved slowly, only recently improving with the support of the Urban Survey Team at the SSB (Jefferson *et al.*, 1996). Producer price indices (PPIs) exist for 15 industry categories (*TJNJ*, 1996: 196), and a fixed capital deflator has recently been developed (*GDZC*, 1997). Previously, constant price statistics relied upon the application of ex-producer price tables, at times inconsistently applied (Field, 1992). This study uses both sets of prices alternatively, all converted to a 1995 base. PPIs will be referred to as **explicit** price indices, while constant price derived deflators will be called **implicit** price indices.

The means of measurement and adjustments for bias for each factor are as follows:

- *Gross Output:*

  Gross output is taken directly from both the Second and Third Industrial Census. For 1980 and 1985 current price output is inflated to 1995 prices (*PCQB*, 1988). 1995 output is taken in current prices (*PCZY*, 1997).

  Implicit price indices are derived using the ratio of output in current prices to output in constant prices, chaining three pairs of figures by industry: (1) 1985 output in current and 1980 constant prices with approximate conversion to 1995 SIC codes (see above for discussion), (2) 1995 output in current and 1990 prices, and (3) 1990 output in 1980 and 1990 constant prices (*GYNB*, 1991). Calculated implicit and PPI-based explicit price deflators are defined as in Table 1.

  Concerns about measurement of gross output include duplicated transaction and spurious innovations (Jefferson *et al.*, 1996). The use of the firm method in Chinese growth accounting, where transactions inside a firm are not duplicated, but transactions between firms may be duplicated, adds extra weight to inter-firm transactions, which can distort output to the extent that structural changes are taking place in an industry. Fortunately, proliferation of small firms has taken place primarily below the township level (Field, 1992); the share of enterprises at and above the township level has actually declined slightly.

Table 1 1980-95 Price Deflators by Sector

Code	Industry	Implicit	Explicit	Code	Industry	Implicit	Explicit	Code	Industry	Implicit	Explicit
B 06	Coal	3.783	4.457	C 19	Leather	1.759	3.620	C 32	Ferrous mfg.	3.712	4.156
B 07	Oil & gas	6.946	7.418	C 20	Wood prod.	1.877	4.432	C 33	Non-ferrous mfg.	2.993	4.156
B 08	Ferrous	2.775	5.383	C 21	Furniture	1.382	4.432	C 34	Metals	1.527	2.457
B 09	Non-ferrous	3.021	5.383	C 22	Paper	2.104	3.707	C 35	Machines	1.609	2.457
B 10	Non-metallic	1.837	5.383	C 23	Printing	1.641	3.707	C 36	Spec. machines	1.538	2.457
B 12	Logging	3.860	4.432	C 24	Cultural	1.408	2.417	C 37	Transport equip.	1.578	2.457
C 13	Food proc.	2.904	3.295	C 25	Petroleum	3.929	7.418	C 40	Electric mach.	1.406	2.457
C 14	Food mfg.	2.351	3.295	C 26	Chemical	2.218	2.830	C 41	Comm. equip.	1.135	2.457
C 15	Beverages	2.658	3.295	C 27	Medical	1.237	2.830	C 42	Instruments	1.076	2.457
C 16	Tobacco	2.556	3.295	C 28	Fibers	1.660	2.830	D 44	Electricity	3.873	3.554
C 17	Textiles	2.047	2.849	C 29	Rubber	1.683	2.830	D 45	Coal energy	5.663	4.457
C 18	Garments	1.435	2.829	C 30	Plastics	1.529	2.830	D 46	Running water	3.843	3.554
				C 31	Non-metals	2.246	4.156				

Sources: *PCZY*, 1997; *TJNJ*, 1996; *GYNB*, 1991; *PCZL*, 1988.

Spurious innovation became of considerable concern during the progress of price reforms in the 1980s, where new products could be sold at market prices. However, Jefferson (1989) found that the rankings of industry performance were not significantly affected by output distortions. Furthermore, spurious innovation—manifested by false new products—is primary a transitional problem during price reform, and becomes less of an issue when measuring changes over the elapsed period 1980–95.

- *Intermediates:*

Intermediate industrial materials are calculated from the difference in gross output (GO) and value added (VA) in current prices in each year.

The Second Industrial Census only provides net output (NO), which is based on Soviet accounting concepts. 1980 and 1985 NO is adjusted according to the formula: VA + interest = NO + depreciation + major repair funds (*Manual*, 1990). Interest (*lixi*), according to the State Statistical Bureau, was negligible until the 1990s, so it is ignored. Depreciation (*zhejiu*) is available by industry, but major repair funds (*daxiulijijin*) are not. Thus, major repair funds are assumed to be the same for each sector as in the aggregate, one-half of depreciation (as in Jefferson *et al.*, 1992). Because the Third Industrial Census computes value added directly, no adjustment is required for 1995 intermediates.

The new intermediate goods deflator, which began in 1989, is combined with the PPI index for the Building Materials industry before 1990 to inflate 1980 and 1985 intermediates to 1995 constant prices.

- *Labor:*

Only productive labor is used as labor input. Sufficiently detailed breakdowns of worker types are available for 1985 and 1995. The proportion of productive labor in 1980 is assumed to be the same in 1985 and is adjusted accordingly. Many state-run enterprises employ workers for social services and other non-production related activities (Chen *et* *al*., 1988). Because the additional workers do not contribute to measured output, they are excluded from labor input.

No poll data exist for China on numbers of hours actually worked. The official work week through 1995 was 6 days, although many workers rarely put in the supposed 48 hours. While the work week officially shifted to 5½ days starting in 1995 (and subsequently to 5 days), implementation has lagged considerably, with many businesses not abiding by the regulations in mid-1997 (*China Daily*, 4/3/97). Despite policy changes, there are arguments that actual hours worked have gone up and down. In this study, labor will be only measured in numbers of production-related workers.

- *Capital Stock:*

A productive assets ratio is derived using the ratio of productive to total gross fixed capital stock for each year 1980, 1985, and 1995. These breakdowns on production-related gross fixed capital stock are available for all three years (*PCQB*, 1988; *PCZH*, 1997). The productive assets ratio is then applied to net fixed capital, which excludes official depreciation.

While many papers have used the official depreciation rates of capital to approximate capital services, direct estimates of the capital accumulation rate are conceptually superior (Collins and Bosworth, 1996: 145). Values for capital stock in China suffer from notorious problems of valuation, as they often include non-productive assets and have not been adjusted for inflation. An ambitious effort made by Chen *et al.* (1988b) to correctly value Chinese capital stock suggested that price changes on pre-1980 capital were small. Officially, the SSB began releasing a fixed asset deflator starting in 1992 (*GDZC*, 1997). This deflator is used in conjunction with the machinery building industry PPI for price adjustment. Pre-1980 capital stock is adjusted using the 1980 deflator. Post-1980 capital stock deflators are derived using a technical updating-weighted combination of yearly price indices.

- *Factor Input Weights:*

Factor weights represent an input's respective marginal cost of production, or production elasticity. In a market economy, these weights can be calculated directly using factor cost shares. The distortion of prices in the Chinese economy suggests this approach will introduce bias. However, the sensitivity of productivity to the specific value of these weights is a matter of some dispute (Tidrick, 1986; Chen *et al.*, 1988; Shi, 1992; McGuckin and Ngugen, 1993). Calculation of weights by directly estimating a frontier production function is the ideal approach, but with aggregate-level data this is not possible. Jefferson (1991) uses a special city-level data set to make cross-section estimates of elasticities for a three-input model, and his estimated weights were tested in this study. Attempts to apply frontier estimates directly to industry-level data by Guckin & Ngugen (1993) yielded figures strikingly similar to cost shares. Test use of the Jefferson's weights in this study did not substantively affect TFP ranking by industry.

The existence of substantial variation in cost shares by sector (see Woo *et al.*, 1993; Guckin and Ngugen, 1989) suggests that differences in factor intensity would be hidden unless input weights are calculated by industry sector. Without low-level data by sector, this type of estimation is not feasible. This study will use the 1995 cost shares, when the distortion of prices would be expected to be less than during the mid-1980 setting of earlier estimations. The weight (elasticity) for intermediates is assumed to be their share of gross output, with capital and labor cost determining their respective weights.

Capital cost is defined as the total of all profits and taxes (*PCZH*, 1997). Labor cost is defined as total salary and benefits, for all workers; this includes workers not considered in labor input, which is intentional. Non-production workers provide benefits to Chinese (mostly state) enterprise workers which other firms must provide in basic salary. As constant returns to scale is assumed, capital and labor weights are their respective proportions of value-added share of output.

3.5 Technology Transfer Figures

The sophistication of technology transfers is very difficult to measure quantitatively, as full information on patterns of adoption are probably necessary. Alternative measures such as the deepening of capabilities, proximity to the technological frontier, and indigenization have all been suggested (Felker and Weiss, 1995). Unfortunately, all of these measures describe the receipt as opposed to the flow of technology.

For the purposes of this study, the relative *value* of technology transfer flows will be used as the primary measure, although there are numerous more informal paths of transfer, such as movement of employees, establishment of foreign research institutes, academic exchange, and intra-firm knowledge transfers. Additionally, due to imperfect markets for technology, some transactions may be mis-valued or unreported. But in China, only limited information about the *inward* movement of technology is available, so *valued* measures of aggregate flows must suffice. Specific possible value-based measures include equipment vintages, high technology imports, technology transfer contracts, and foreign direct investment.

3.5.1 Possible Measures

Vintages of technology by decade of origin are available in the Industrial Census. In the Second Industrial Census, 1985 imported equipment in use is described by vintage for each two-digit industry (*PCJY*, 1989). The Third Industrial Census surveys similar indicators, but does not publish them by industry in the volumes released to date[4]. Without comparable measures in 1995 or 1980 sources, no longitudinal analysis is possible. In any case, vintages are not ideal due to their limitation of coverage to embodied equipment, so other options are considered, as shown in Table 2.

Previous time-series studies of China have used capital good imports as a proxy for technology (Hu, 1996 and Zhao, 1995). Such imports certainly embody technical content, but are a highly imperfect measure of technology transferred, as licensing and inter-company

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[4]The SSB's Consultancy appears willing to produce tables similar to the 1995 results using the Third Industrial Census data for a service fee.

Table 2 **Technology Flows** *Figures in millions of US dollars*

Year	Total technology transfers	High-tech imports	Machine & transport imports	FDI Utilized	Year	Total technology transfers	High-tech imports	Machine & transport imports	FDI Utilized
1979	3,433	n/a	n/a	3,114*	1988	3,464	8,132	16,700	10,226
1980	1,239		8,120	3,114*	1989	2,909	6,853	18,210	10,059
1981	221		5,870	3,114*	1990	1,439	6,967	16,840	10,289
1982	396		3,200	3,114*	1991	3,459	9,439	19,600	11,560
1983	531		3,990	1,981	1992	6,590	10,712	31,312	19,200
1984	1,381		7,250	2,705	1993	6,109	15,909	44,987	38,960
1985	3,590	4,734	16,230	4,647	1994	4,106	20,595	51,564	43,220
1986	3,741	4,985	13,780	7,258	1995	13,033	n/a	52,638	48,130
1987	2,981	5,319	14,610	8,452	1996	15,250		n/a	54,004

Sources: *KJNJ*, 1991-94; *TJZY*, 1997. ** Based on period 1979-1982 aggregate.*

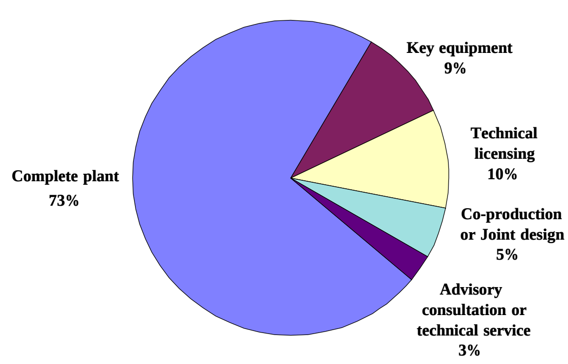
contacts are not included. Limiting imports to their high technology content is probably better, but there is still a focus on equipment, to the exclusion of all non-embodied technology. Furthermore, Chinese scholars suggest that technical content in high technology imports is exaggerated (Tian, 1995).

Technology transfer contract statistics are probably the best alternative measure. The Ministry of Foreign Trade (MOFTEC) requires that all transfers of industrial property rights or know-how be registered through its organizations, and until 1996, approved as well (Markel, 1997). Contracts include embodied technology such as production lines and key pieces of equipment, and disembodied technology such as technical licenses, engineering services, and co-production (Conroy, 1992: 184). A breakdown of such technology transfers from 1979 to 1995 is shown in Figure 1.

With funding constraints representing a significant barrier to additional transfers, the rise of foreign direct investment (FDI) has increasingly become an important source of technology acquisition, particularly as a result of FDI's considerable spillover effects (Zhao, 1995). Technology acquired by foreign-invested enterprises is *not* included in technology transfer contract statistics (Conroy, 1992: 191). While the technology content of some small-scale labor intensive projects in FDI flows has been questioned by Chinese scholars (Jiang, 1996: 14), there is strong consensus that significant amounts of both equipment and know-how are transferred through FDI. Enterprises short of funds for technology transfers are often able to use FDI to acquire bargain access to advanced production processes and techniques.

Figure 1

Forms of Technology Transfer 1979-1995



Sources: *Fourty Years*, 1991; *JJNJ*, 1992-96.

3.5.2 Technology Transfer Contracts

Technology transfer contracts are compiled by MOFTEC's Technology Import-Export Division, Department Five. Broad summaries of transfers are published in MOFTEC's Yearbook (*CFERT*, 1988-97) and the Economic Yearbook (*JJNJ*, 1981-96). After 1990, more detailed information has been released in the Science & Technology Yearbook (*KJNJ*, 1992-95). Regretfully, none of these sources consistently show the two-digit industry-level figures required for this study.

A compressive report on technology transfer, *Forty Years of Technology Transfer* (1991), was used to identify 1979 to 1990 two-digit Chinese SIC industry-level flows. All data are valued in current US dollars, and are converted at the 1995 average exchange rate to *renminbi*. Figures over the period 1980 to 1995 for imported technology are assumed to approximately match gains in quality minus depreciation.

Less detailed data, matching the *KJNJ* and *JJNJ* in totals, were obtained for the years 1991-94 from MOFTEC-supplied sources (*Contract Summaries*, 1997). These figures use only 15 industry branches[5], which complicates the full utilization of 1979-90 figures and productivity measures. For regression analysis, the 1991-94 data are proportionally disaggregated to all 37 branches using the 1979-90 industry shares. Because 56% of the value of the 1979-94 technology flow was acquired in 1979-90, some variance is lost, just as the data gain a stronger emphasis on technology which has had more time to be absorbed. In all cases, technology flows are assumed to have a lagged effect of at least a year on productivity. The proportion, as opposed to the value, of technology transfers in new net fixed investment is used to measure the flow of transfers into an industry.

Unfortunately, soft technology content is not available by industry. The flow of technical know-how has been a subject of particular concern for domestic analysts (Chen, 1997). Rhetoric has emphasized the need for more soft technology, but proportionally the soft content has actually dropped from over 20% to close to 15% over the past 17 years. Officials attribute the problem to difficulty in obtaining financing for disembodied technology.

The primary recipients of the technology are medium and large size SOEs, although there has been increasing private participation (*SSTCC*, 1996: 55). The presence of spillovers to smaller firms and to the Collective sector, who often lack sufficient funds for acquiring foreign technology is expected (Chen, 1997; Conroy, 1992; Jefferson *et al.*, 1992). Advances in productivity in industries dominated by non-SOEs should demonstrate spillover effects.

Most technology has come from OECD countries, principally the United States, Japan, Germany, France, and the United Kingdom, and often represent current-generation technology (*Forty Years*, 1991). An even larger number, but not value, of contracts come from Hong Kong and Taiwan, whose investments are often on a much smaller scale.

[5]This is still superior to the limited information available in the *KJNJ* and *JJNJ*, which use an inconsistent selection of less than 12 industry categories for classification.

3.5.3 Foreign Direct Investment (FDI) Data

FDI is an indicator of technology transferred to foreign-invested enterprises through transfers of assets, infusions of cash, and other types of investment. By combining FDI flows with technology transfer contracts, the vast majority of imported technology value is captured (Conrad, 1992; Chen, 1997). Foreign invested enterprises, nearly non-existent in 1980 and 1985, represented well over 10% of fixed investment by 1995.

Because FDI gives a foreign firm a vested interest in the outcome of a venture, foreign investors often make crucial production and marketing knowledge available to recipient enterprises. Investing firm's strong desire and capability to produce with best-practice knowledge and equipment often enables rapid transfers of both embodied and disembodied technology. Labor mobility and informal contacts among managers further allows diffusion of technical knowledge to entire industries (World Bank, 1993).

After China opened its doors to foreign investment, FDI quickly overtook technology transfer contracts in terms of overall value. The implications of transfers through contracts and through FDI are thought to be quite different, especially in their interaction with domestic R&D and assimilation efforts (see Pack, 1997).

The Third Industrial Census gives accumulated foreign capital investment actually used by industry branch (*PCZH*, 1997). These FDI figures include investment from Hong Kong and Taiwan. Investment is converted to 1995 prices using the same methods as those used for fixed capital input. The proportion of FDI in newly acquired fixed capital over the elapsed period 1980-95 is used to measure the relative size of foreign sector technology flows.

3.5.4 Other Variables

A selection of additional variables discussed in the literature on technological progress are included to control for externalities. These measures include vintage of starting technology, average contract size, capital-to-labor ratio, state share of value added, presence of engineers, technical updates, assimilation spending, research and development, and export orientation. They are defined as follows:

- *New Technology Vintage:*

  The vintage of starting technology in 1985 is used to estimate the disposition of an industry with respect to installed imported new equipment. While five years of the analysis period 1980-95 overlap, a full 84% of technology transfers by value were made subsequent to 1985. The imported equipment included in this measure are reflective of the extent to which foreign technology was adopted early on.

  The proportion of undepreciated and undeflated 1980s-vintage equipment to total imported equipment is used as the primary measure of the technology base (*PCJY*, 1989). Compatible data is not available from the Third Census, as corresponding tables do not divide equipment by sector, but rather by type and application. Furthermore, the tables only use quantities, as opposed to values of the equipment, which is highly misleading as a result of the substantial–yet indeterminate–cost differential between domestic and foreign equipment.

- *Average Contract Size:*
  The average size of technology transfer contracts in thousands of US dollars is used to reflect the scale of each import. Licensing contracts tend to be relatively small, while whole sets of equipment tend to be quite large.

- *Relative capital-labor ratio:*
  The ratio of fixed capital to productive labor in 1995 is used to represent the capital intensity of an industry (*PCZH*, 1997). To make the figure relative, it is divided by the overall average industry ratio to create an index centered around 100. The measure is reflective of the actual capital or labor intensity of an industry in 1995, and thus does not necessarily mean that the industry cannot be operated under alternative input ratios.

- *State share of value added:*
  The proportion of value added contributed by state-owned enterprises in 1995 is used to reflect SOE's overall presence in an industry branch (*PCZH*, 1997). The literature on ownership and enterprise reform has indicated that SOEs are expected to exhibit low entrepreneurial activity, as these enterprises lack management flexibility and often have burdensome obligations to the state. While their performance seems to be improving, they are believed to lag behind both Collective enterprises and foreign-invested firms. Ownership structure is often assumed to be the most important factor determining TFP in China, but it is quite possible that technology plays a more dominant role (see Woo, 1994: 432).

- *Engineers:*
  Human capital is a central element in most of the endogenous growth models. Technical workers are required to operate, understand, and assimilate technology. Presence of engineers should be a prerequisite for successful acquisition of new technology (Zhao, 1995 and Jefferson, 1994). These workers may also be thought of as a bottleneck: the complete lack of any technical staff is prohibitive for technological acquisition. The proportion of engineers in productive labor in 1995 is used to measure their industry branch-level presence.

- *Technical Updates:*
  Technical updates reflect spending on upgrading and improving existing fixed capital. While much of this spending is thought to be unfocused, a small fraction may be used for the indiginization of imported technology (Chen, 1997). Some researchers have treated updates as innovation expenses, but this is almost certainly an exaggeration (Zhao, 1995). Technical updates over the whole period 1980-1995 are measured (*GDZC*, 1997).

- *Assimilation Expenses:*
  Spending on the assimilation of imported foreign technology is available for large & medium enterprises in 1993. The ratio of assimilation expenditures to technology transfers in 1993 is used to measure the effort devoted to absorbing and indigenizing

technology (*KJNJ*, 1994). Because the overall level of these expenditures is so low (less than 5% of technology transferred), research and development expenditures are hypothesized to be a more relevant measure of this effort.

- *Research and Development:*

  Chinese research and development (R&D) spending is low even by developing Asian standards, at less than one percent of overall output in Industry. While at times not closely tied with production, applied research, including advancing current technology and backwards engineering of existing technology, is essential for domestic industries to digest foreign technology. In China, research activities have historically not been well integrated with applications, so it is not clear if a measurable effect of R&D on productivity will be found.

  Figures on R&D spending as a fraction of gross output are calculated for 1995 (PCZY, 1997). These figures include extra-enterprise research institutes serving industry, whose results are assumed to spillover to enterprises (see Zhao, 1995).

- *Export-orientation:*

  In order to produce products which can compete on world markets, domestic capability has to begin to approach international best-practice methods. Exports have been thought of as a proxy for transmission of knowledge in imperfect information markets (World Bank, 1993). In addition to transfers of new technology through imported equipment, licensing, and foreign investment, exports facilitate transfers of information from customers and increase pressure to produce commercially viable R&D. Whether the transfers of technology are more important than other aspects of export-orientation in improving TFP is still an unanswered question. The share of 1995 export value in gross output is used as an indicator of directional export-orientation (*PCZH*, 1997).

4. Interpretation and Analysis

4.1 Overall Patterns & Cautionary Notes

The overall movement of total factor productivity (TFP) found in this analysis, from 1980 to 1985, is in a similar range as several prior studies. Both the explicit and implicit deflators show moderate (annual rates of 1.3% and 2.2%, respectively) positive TFP growth over this early period. No studies are yet available to compare movements over the whole period 1980 to 1995. Using the implicit price deflator, annual TFP growth from 1980 to 1995 was found to be 5.6 percent for the industries concerned. The explicit price deflator, on the other hand, showed TFP growth to be 1.2 percent.

Low overall productivity suggested by the explicit deflator represents a relatively harsh judgement considering the rapid inflow of technology and FDI to China in the 1990s. However, the sensitivity of the *overall* TFP growth rate to slight changes in deflators and factor weights means that a general appraisal of the progress of the industrial sector as a whole cannot be rendered here. Since the goal of this study is only to examine *industry branch* differences in TFP, this does not present a serious problem. Both McGuckin &

Table 3 **Overall Performance by Industry Group**

Standardized Industry Classif.		Share of	Period 1980-95		Period 1979-94			1980-95	New
Chinese 95 SIC	English description	Industrial Output	Output Growth†	Total Factor Productivity†	Contract US$ Value $m	Contract US$ Size $k	Tech. Transf.	FDI Share	Technol. in 1985
B 06	Coal extraction	2.0%	5.0%	-0.5%	478.2	7,357	2.3%	0.0%	7.8%
B 07	Oil & gas	2.6	4.0	-8.1	557.7	5,871	2.2	0.0	15.5
B 08-10	Mining	1.4	6.0	-3.7	167.7	3,422	2.1	1.1	4.6
B 11	Timber	0.3	0.0	-2.2	5.0	2,507	0.3	0.0	3.7
C 13-16	Food, tobacco & feed processing	11.2	9.9	-0.5	659.7	2,999	1.5	7.4	14.8
C 17-19	Textiles, tailoring & leather proc.	14.2	8.9	1.7	881.6	5,839	1.8	12.3	18.4
C 20-21	Wood processing	1.1	7.5	-0.9	67.6	3,558	1.4	12.9	6.4
C 22-24	Paper, furniture & cultural prod. mfg.	3.3	9.3	0.4	664.0	5,627	4.1	12.7	15.3
C 25-30	Petroleum proc.	17.2	9.4	-0.2	12,284.8	12,236	14.8	5.6	11.0
C 31	Non-metallic mfg.	5.4	9.5	-0.9	706.1	3,478	2.0	5.8	3.5
C 32-33	Metal mfg.	9.7	8.1	-0.5	6,528.7	14,974	11.9	1.6	10.3
C 34-42	Equipment mfg.	26.7	13.2	3.2	8,802.5	3,052	9.9	10.9	9.2
D 44	Electricity & steam	4.5	9.4	-2.7	6,215.4	33,061	6.4	1.3	3.5
D 46	Running water	0.3	10.9	-1.0	15.8	1,751	0.2	0.1	5.2

Source: Output-weighted summary of Table 4. † Uses explicit price indicies.

Ngugen (1992, 1993) and Jefferson (1992) found that the slight changes in measurement did not significantly affect industry-level rankings. Alternative sets of deflators, tested variances in factor weights, and alternative production functions were all used to test the sensitivity of the rankings used in this study. No major changes in the ranking of industry branch TFP were found. Thus only explicit growth and TFP is displayed in Table 3. In the regression analysis, a combined ranking of explicit and implicit TFP scores serves as the dependent variable.

Several strong patterns are found in industry performance and receipt of foreign technology. This section will first analyze investigate industry groups, then look more closely at specific industries, and finally assess the strength of relationships using regression analysis.

4.2 Industry Groups

A summary of the performance of each industry grouping is shown in Figure 3. Combinations of industry indicators into groups use weights by 1995 output. TFP and gross output growth figures use the explicit price deflators. Technology transfer flows as a fraction of fixed new investment in this Table are directly from source material, and did not have to be disaggregated.

The equipment manufacturing industries, representing 26.7% of output, are considerably more productive than the rest of industry, with a 3.2% TFP growth rate. This high productivity aided in pushing output growth to over thirteen percent per annum, also the highest of Industry. Technology transfers by these industries constituted 9.9% of fixed capital

Table 4a **Performance by Industry Branch**

Industry Category Chinese 95 SIC		Group Num.	English Name	Ouput Share 1995	Output Growth† 1980-95	Implicit TFP 1980-95	Explicit TFP 1980-95	Tech. Tran. Inv. 1979-94	Foreign Invest. 1995
-	-	-	*Overall*	100%	9.2%	5.6%	1.2%	7.0%	5.6%
B	06	#1	Coal	2.0	5.0	0.6	-0.5	2.3	0.0
B	07	#2	Oil & gas	2.6	4.0	-7.6	-8.1	2.2	0.0
B	08	#3	Ferrous	0.2	6.3	2.3	-2.2	0.5	0.2
B	09		Non-ferrous	0.6	7.4	1.5	-2.4	4.1	0.3
B	10		Non-metallic	0.6	4.7	1.8	-5.4	0.8	2.1
B	12	#4	Lumber	0.3	0.0	-1.3	-2.2	0.3	0.0
C	13	#5	Food proc.	5.5	11.4	2.5	1.6	0.2	6.8
C	14		Food mfg.	1.8	3.4	3.2	1.0	2.2	13.7
C	15		Beverages	2.1	12.0	0.7	-0.7	0.9	10.0
C	16		Tobacco	1.8	9.3	-6.3	-8.0	5.1	0.3
C	17	#6	Textiles	9.5	7.4	3.8	1.6	2.1	6.5
C	18		Garmets	2.9	11.9	7.0	2.5	0.1	25.0
C	19		Leather	1.8	12.2	5.7	0.8	1.9	23.0
C	20	#7	Wood	0.7	8.2	4.7	-1.0	1.7	11.6
C	21		Furniture	0.4	6.3	7.1	-0.7	0.7	15.3
C	22	#8	Paper	1.8	8.5	3.6	-0.2	6.8	9.2
C	23		Printing	0.8	7.1	5.6	0.1	0.5	8.9
C	24		Cultural	0.7	13.9	6.1	2.5	0.5	26.8
C	25	#9	Petroleum	3.8	3.9	-2.3	-6.5	7.2	0.3
C	26		Chemical	6.9	9.8	3.4	1.8	26.0	4.6
C	27		Medical	1.8	11.6	6.7	1.2	4.7	7.4
C	28		Fibers	1.5	15.3	4.4	0.9	11.2	3.3
C	29		Rubber	1.2	7.1	4.2	0.7	7.3	13.1
C	30		Plastics	2.1	12.9	6.1	2.0	1.5	14.8
C	31	#10	Non-metals	5.4	9.5	3.2	-0.9	2.0	5.8
C	32	#11	Ferrous mfg.	6.9	8.0	0.2	-0.6	13.7	1.1
C	33		Non-ferrous mfg.	2.8	8.3	1.8	-0.4	5.2	2.8
C	34	#12	Metals	3.1	12.4	6.1	3.0	0.7	14.5
C	35		Machines	4.4	12.0	5.9	3.1	15.9	6.5
C	36		Spec. machines	3.2	8.6	6.7	3.6	n/a	5.3
C	37		Transport equip.	6.0	13.7	6.3	3.4	14.4	7.9
C	40		Electric mach.	4.8	13.9	6.5	2.8	4.3	11.9
C	41		Comm. equip.	4.5	18.1	8.6	3.4	16.7	19.2
C	42		Instruments	0.8	7.2	6.8	1.3	7.5	15.7
D	44	#13	Electricity	4.4	9.3	-3.3	-2.7	6.6	1.3
D	45		Coal energy	0.1	12.8	-3.8	-2.2	n/a	0.7
D	46	#14	Running water	0.3	10.9	-1.6	-1.0	0.2	0.1

† Uses explicit price indicies.

Table 4b **Performance by Industry Branch (con't)** ‡

Industry Chinese 95 SIC		New Technol. 1985	Average Contract Size ($T)	Cap. / Labor 1995	State shr. V.A. 1995	Engin-eers 1995	Inv. in Updating 1980-95	Assim. Expend. 1993	R&D spent 1995	Export shr. G.O. 1995
-	-	7.8%	6,990	100	53.8%	6.9%	37.4%	3.9%	0.58%	14.2%
B	06	7.8	7,360	70	81.7	3.7	41.1	0.0	0.20	3.6
B	07	15.5	5,870	310	94.6	11.8	31.4	2.4	1.10	7.6
B	08	4.9	690	62	49.4	5.6	68.5	0.0	0.10	0.6
B	09	4.6	6,780	75	60.7	6.1	51.6	0.5	0.27	2.0
B	10	4.6	1,460	47	39.2	5.0	28.4	1.6	0.32	4.0
B	12	3.7	2,510	42	97.3	6.5	14.1	0.9	0.21	0.8
C	13	19.8	1,640	94	46.4	6.8	49.0	1.2	0.10	7.4
C	14	5.2	1,960	88	35.4	6.0	12.4	6.6	0.13	10.8
C	15	10.7	1,960	108	57.9	7.7	48.2	15.7	0.50	2.5
C	16	13.8	6,720	271	98.1	7.1	94.6	1.8	0.15	3.3
C	17	12.7	7,190	61	36.4	4.2	44.0	1.2	0.33	21.6
C	18	27.0	720	32	6.3	3.7	7.4	0.6	0.05	44.9
C	19	35.3	2,660	37	7.6	3.7	15.0	0.8	0.09	43.2
C	20	4.3	4,400	45	18.3	4.9	26.5	0.7	0.08	11.8
C	21	10.3	1,660	42	8.0	6.5	13.8	1.4	0.10	14.5
C	22	4.2	7,190	74	38.0	5.4	46.3	2.1	0.39	5.5
C	23	21.9	1,390	64	45.6	5.4	34.6	0.4	0.12	3.5
C	24	37.6	730	37	12.1	4.2	17.4	2.4	0.17	49.1
C	25	8.4	19,100	322	89.7	12.4	33.6	7.2	0.42	3.1
C	26	4.0	15,800	118	56.4	8.5	54.2	2.1	0.80	7.5
C	27	8.3	4,230	87	46.5	12.0	62.0	13.5	0.79	11.4
C	28	23.9	11,590	300	28.8	8.2	36.4	16.9	0.60	6.6
C	29	5.5	5,020	57	39.2	5.2	61.9	9.5	0.71	15.1
C	30	35.2	2,000	80	10.6	5.8	17.4	6.0	0.35	14.6
C	31	3.5	3,480	65	34.9	5.8	37.2	1.7	0.45	5.1
C	32	10.1	21,150	186	77.1	6.3	54.1	2.5	0.47	8.0
C	33	10.7	3,820	155	63.4	7.6	44.2	6.9	0.43	6.6
C	34	4.2	2,480	55	15.5	6.5	21.4	1.3	0.40	16.2
C	35	3.5	2,170	58	40.8	8.4	60.6	4.2	1.14	8.3
C	36	2.8	n/a	65	49.5	8.8	51.9	8.8	1.43	5.6
C	37	4.5	9,210	81	52.2	9.8	44.2	4.5	1.17	5.3
C	40	8.3	1,870	72	22.8	8.4	32.0	5.1	0.86	11.6
C	41	29.8	10,010	104	24.6	13.1	43.7	3.5	0.99	32.8
C	42	11.7	910	61	36.1	11.3	29.0	12.8	1.53	24.0
D	44	3.5	33,060	661	80.5	12.3	13.0	3.9	0.26	1.4
D	45	3.4	n/a	303	42.3	9.5	44.8	1.9	0.43	1.0
D	46	5.2	1,750	308	88.9	9.0	20.1	0.3	0.23	8.5

‡ Intermediate 10,000-cell datasetavailable upon request.

investment, third highest of the industry groups. A healthy 10.9% flow of FDI also appears to contribute to TFP.

Surprisingly, the metal and petroleum processing, with even higher levels of technology transfers (11.9% and 14.8%), performed sub-par in terms of TFP growth. These industries represent a substantial share of output—petroleum with 17.2% and metals with 9.7%—and both grew at close to ten percent per year. The most apparent differences in these industry groups and the equipment sector is the size of contract values. Equipment manufacturing focused on much smaller transfers with an average size of only US$3.05 million dollars, while both metal and petroleum processing transfers averaged US$12.3 million.

The single industry with a higher average contract value is electricity and steam power, with an average transfer size of US$33 million. The power sector imported a sizeable amount of foreign technology, 6.4% of fixed capital investment, on top of an antiquitated base (in 1985 only 3.5% of technology was of 1980s vintage). Regrettably, the TFP record here is poor, third lowest of the industry groups. A substantial amount of presumably domestic capital investment was required to support its 9.9% output growth.

Only the extractive and mining industries showed a worse TFP growth rate than energy, with oil & gas extraction the worst at -8.1%. This sector absorbed very little technology independently, only 2.2% of investment, and virtually no FDI. Moderate growth of 4.0% had to be supported by large infusions of domestic capital investment.

Textiles & leather manufacturing, representing 14.2% of 1995 industrial output, received little new technology (1.8% of investment), but considerable FDI (12.3%). This industry group performed second-best, with TFP improvement of over one percent per year. Larger scale and a more modern base (18.4% 1980s vintage) distinguished this sector from wood processing, which received slightly more FDI, but performed disappointingly.

4.3 By Industry Branch

More detailed performance indicators by industry branch are shown in Table 4. In addition to implicit TFP, included are all of the potential control variables discussed in section 3.5.4. As in the aggregate, implicit TFP is more impressive, even though the ranking of industry branches is more-or-less consistent.

All of the equipment industries are similarly impressive in terms of their TFP growth, with the communications equipment industry—which includes microcomputers and other electronics—having the highest growth rate. This industry acquired a commanding lead in equipment by 1985, with thirty percent 1980s vintage equipment, but its large share of both technology transfers (16.7%) and foreign direct investment (19.2%) were probably even more important. R&D for these industries, over one percent on average, is impressive. Furthermore, specific firms in this sector, such as Motorola and Legend, have been lauded for innovative zeal (*Asiaweek*, 6/13/97).

Despite considerable technology transfers to ferrous manufacturing (13.7% of investment), this industry's TFP record is nearly negligible, using both explicit and implicit deflators. The large size of technology transfers, at over US$21 million, may be symptomatic of an undue emphasis on acquiring foreign embodied equipment to the exclusion of production techniques and know-how. Ferrous manufacturing is dominated by state-owned enterprises, and is relatively capital intensive in China.

Petroleum refining, an even more capital intensive industry than ferrous manufacturing, has an even poorer record of TFP growth: quite negative. While a moderate amount of technology was transferred to this industry, its domination by state-owned enterprises and lack of any foreign investment may have compounded its problems. Price increases leading to negative output growth and overly large project sizes (implying low know-how transfers) only compounded this industry's problems.

The chemical and chemical fibers industries have received proportionally more than twice as much technology transfer value than refining, and have apparently applied this technology more effectively, yielding moderate implicit TFP growth. The chemical fiber industry is the best performing of all of the capital-intensive industries.

Electricity, the most capital intensive industry in this study, performed fairly poorly, likely due to its relatively moderate utilization of technology transfers and lack of substantial foreign direct investment. State-ownership dominated the sector (80.5% of value added), presumably offering little innovative zeal. Average contract size was quite large, at over US$33 million, complicating management.

Oil & gas extraction suffered from similar problems as electricity, namely no FDI and low proportions of transferred technology. Research & development spending in this industry is twice average (1.10%), but does not appear to have paid off. State domination of 94.6 percent in value added means that market forces are not being well utilized.

The moderate TFP growth of the textile, tailoring, and leather industries can be attributed to FDI inflows, which are probably bringing in considerable soft technology. For garmets and leather, FDI represents over 20% of its fixed investment.

4.4 Regression Analysis

To better understand and evaluate the overall strength of the relationship between technology flows and TFP, ordinary least-squared regression is applied to the industry-level data set. Although the sample size is small at 35 eligible observations, there *are* enough to examine patterns statistically. Because of the aggregated nature of the variables, potential exists for substantial multicollinearity between independent variables, so diagnostic checks are performed.

The dependent variable used in the regression analysis is an ordinal variable based on a ranking of the additive combination of explicit and implicit ranked TFP scores. By using an ordinal measure of TFP, the effect of measurement error is minimized. This method is consistent with the contention that the ordering of TFP performance is more reliable than the actual growth rate given weaknesses in factor and elasticity measurement.

4.4.1 Diagnostic Checks

An examination of the multicollinearity between independent variables found that several of the variables were highly correlated. Fortunately, the two critical variables of technology transfer contracts and FDI have a very weak *negative* correlation.

The highest correlation of .87 exists between FDI and exports, which is expected as a result of their conceptual similarity, as discussed in section 3.5.4. Because of the close relationship between these variables, models are estimated alternately with each variable in turn. FDI is also highly correlated (negative coefficient of -.80) with the state-owned share of value added; while a correlation between these variables is not surprising, they *are* conceptually independent and will be included together in regression equations to the extent that multicollinearity effects are not observed. The only other pair of variables to have a correlation with an absolute value greater or equal to .75 were the capital-to-labor ratio and the average size of technology transfers. Since both of these variables represent a closely related concept of labor/capital intensity, they are both cautiously included in alternative models.

4.4.2 Technology and TFP

As a first cut at the hypothesized relationship between TFP and technology transfers, in addition to the basic model, each potential control variable is tested separately with the basic variables of technology transfer contracts and foreign direct investment. The models are shown in Table 5. In virtually every model tested, the link between TFP and technology transfers & foreign direct investment is uniformly strong, confirming the most basic hypothesis of this study. Significance levels are particularly high for FDI and moderately high for technology transfer. The adjusted R-squared statistic shows more than 60 percent of the variance in TFP orderings is explained by just these two variables.

FDI appears to have a larger impact on TFP than transfer contracts based on the regression coefficients, even though in only a couple of industries do foreign firms contribute anywhere close to half of value added, implying that spillovers are considerable. Since the other variables are not divided by accumulated investment, the coefficients for these other variables are not directly comparable; only the R-squared statistic can shed light on their relative explanatory importance.

4.4.3 Additional Variables

Only about half of the tested control variables appear to have a significant impact on TFP performance. Size of transfer contracts, capital-to-labor ratio, state share of value added, and research & development intensity were all found to have important complementary roles, while export orientation was found have a more substitutive role with respect to FDI. Starting technology level, presence of engineers, technical updates, and assimilation spending were not found to have statistically significant relationships with TFP. Only the interaction of technology transfer contracts with the capital-labor ratio, state ownership, and R&D was found to be significant. Effects of technology transfers through FDI appear to be relatively independent of these confounding factors.

The lack of support for the starting technology level is somewhat surprising, but perhaps this is a result of the larger scale of technology transfers (especially FDI) in the 1990s, making the venue of equipment in the early 1980s less important. The negative sign of the coefficient for this variable suggests the backward sectors have the most potential for catch-up.

Table 5 **Regression Results with TFP Rank as Dependent Variable (N=35)**

Additional Variable Name	Constant	Technology Transfer Contracts	Foreign Direct Investment	Additonal Variable	Adjusted R^2
	Regression Coefficients and Standard Errors				
Base model: only technology transfers	6.98*** (1.89)	60.0*** (18.0)	107*** (14.2)	n/a	.644
New imported technology vintage, 1985	7.49** (2.07)	59.1*** (18.2)	114.3*** (18.0)	-8.61 (13.5)	.637
Average technology transfer contract size	9.63*** (2.02)	86.2*** (19.4)	93.3*** (14.1)	$-4.70x10^{-4}$** ($-1.80x10^{-4}$)	.700
Relative capital-to-labor ratio index	11.0*** (2.33)	64.9*** (16.7)	89.7*** (14.7)	-.0230** (.00882)	.700
Capital-labor ratio interacted with transf. contracts	8.29*** (1.87)	97.3*** (23.4)	96.1*** (14.2)	-.306** (.133)	.686
State-owned share of value added, 1995	21.6*** (4.46)	60.8*** (15.5)	46.0* (21.2)	-20.5*** (5.81)	.738
State-owned share of value added without (w/o) FDI	30.4*** (2.01)	59.0*** (16.3)	n/a	-30.8*** (3.52)	.707
State-owned share w/o technology transfers	32.6*** (2.51)	n/a		-29.1*** (4.67)	.512
State-owned share interacted with transf. contracts	8.89*** (1.86)	167*** (42.2)	86.2*** (15.0)	-221*** (79.8)	.705
Proportion of engineers to productive workers, 1995	7.12* (3.70)	60.4*** (20.3)	107*** (14.8)	-2.13 (45.8)	.632
Technical updating to fixed investment	5.91** (3.30)	57.1*** (19.7)	110*** (15.8)	2.67 (6.72)	.634
Assimilation spending to transfer costs, 1993	6.84*** (2.04)	59.2*** (18.7)	107*** (14.4)	4.99 (24.5)	.633
Research & Development (R&D) share, 1995	5.52*** (2.00)	36.2 (22.0)	105*** (13.8)	616* (346)	.670
R&D interacted with technology transfer contracts	9.63*** (1.86)	-74.5 (44.8)	93.0*** (13.2)	14700*** (4570)	.724
Export value in gross output, 1995	6.96*** (1.89)	60.8*** (18.0)	132*** (28.8)	-17.1 (17.4)	.643
Exports in gross output, without FDI	9.92*** (2.27)	52.7*** (22.9)	n/a	52.3*** (10.9)	.420
Exports in gross output, w/o technology transfers	13.2*** (2.04)	n/a		49.7*** (12.2)	.304

Note: number of asterisks imply level of statistical signficance: *** .01, ** .05, * .10

The presence of engineers, which aught to affect absorption capacity, has a similar lack of statistical support and reversed sign, perhaps a result of the relatively uniform distribution of engineers. With the lowest presence of engineers at 3.7 percent, a minimum set of skilled workers are available in each industry.

Technical updates and assimilation spending have signs which are consistent with expectations, but their low level of statistical significance suggests they not affecting productivity. Support for the effect of R&D suggests that the updating and assimilation expenditures are either misdirected, in the case of updates, or insufficient, in the case of assimilation spending.

Average contract size and the capital-to-labor ratio interaction with transfer contracts garner strong statistical support, suggesting that *appropriate* technology is vital. The negative coefficient on contract size implies that incremental technology such as licensing is more effective at improving TFP growth than large transfers like complete sets of equipment. The similar sign on the interaction term suggests that relatively labor-intensive industries are best able to assimilate new technology. Interestingly, when the capital-to-labor ratio was interacted with both transfer contracts and FDI in one model (not shown in Table 6), only FDI yielded a positive albeit not quite significant coefficient, implying that foreign investment is a better option than independent technology transfer in capital intensive industries.

Additonal support for a direct effect of the capital-to-labor ratio on TFP suggests that capital-intensive industries utilize inputs inefficiently irregardless of technology transfers. This finding is consistent with the presumption that China's comparative advantage is still in labor-intensive industries. Since contract size is closely correlated with the capital intensity of an industry, the more labor intensive industries are the primary recipients of the smaller technology transfers.

The state share of value added proves to be the strongest control variable, with a high level of statistical significance and the highest R-squared in Table 5. The inclusion of this variable acts as a test of the importance of enterprise ownership relative to technology transfer. To directly compare the role of ownership with technology, models with ownership & transfer contracts and ownership by itself are also estimated. The adjusted R-squared of the model with ownership by itself is lower than that of the base technology transfer model, although the model with ownership & transfer contracts together is higher than the base model. Due to substantial multicollinearity, the comparisons may be biased. Nevertheless, similarly large R-squared statistics imply technology transfers have a similar level of importance compared with ownership in explaining variable TFP performance.

Evidence of an interaction between ownership and technology transfer contracts indicates that state-dominated industries have more difficulty adopting new technology. Moreover, after this interaction is taken into account, technology transfer contracts become considerably more beneficial for productivity than FDI, meaning that spillovers of technology from typically SOE recipient enterprises to non-state enterprises are substantial.

Both a direct and an interactive role of research and development in gross output is found to explain TFP growth. The coefficient on R&D is quite large, and while it is not measured in comparable terms with the technology variables (gross output as opposed to fixed investment), its value implies that the return rate may be very high. More interestingly, when the interaction of R&D and transfer contracts is included in the model, direct R&D becomes insignificant. In fact, a model with only the interactive variable has a higher adjusted R-squared than the original model. Moreover, with this augmented model, the sign of transfer contracts becomes negative, implying that technology which is not bundled with R&D digestion efforts is unlikely to be beneficial in terms of TFP growth. This result confirms arguments that R&D in a developing country like China must be closely tied in with technology importation efforts.

The last control variable to be tested is export-orientation, which is found to lack an role independent of FDI. Because exports can be thought of as a proxy for activities including various types of technology transfers with an emphasis on foreign-invested firms (thus the high export-FDI correlation), an additional model is tested without FDI. The result of this analysis suggests that exports are a weaker indicator of measures necessary for TFP

Table 6 **Combined Regression Results of Significant Control Variables**

Regression Coefficients and Standard Errors

Combined Model	Constant	Technology Transfer Contracts	Foreign Direct Investment	Relative Capital-labor Ratio	State Share of Value-added	Research & Development	Exports in Gross Output	Adjusted R^2
A	20.7*** (4.05)	37.9** (17.9)	40.9** (17.3)	-.0125 (.00802)	-18.3*** (5.67)	661** (280)	n/a	.785
B	24.3*** (2.93)	57.1*** (19.7)	n/a	-.0132 (.00818)	-22.8*** (4.54)	708** (284)	15.9* (8.74)	.777
C	23.0*** (3.15)	n/a		-.0168* (.00849)	-20.5*** (4.82)	1170*** (228)	18.0* (9.39)	.745

Note: number of asterisks imply level of statistical signficance: *** .01, ** .05, * .10

improvement than either FDI or technology transfer contracts, based on relatively low adjusted R-squared values. Perhaps analyses of export-led growth should focus more narrowly on the technology transfer dimension.

4.4.4 Combined Equations

By testing each variable separately, multicollinearity problems were minimized, but a more complete picture of the overall situation may have been sacrificed. In order to assess the strength of the technology transfer–TFP relationship more closely, variables which were significant in Table 5 were combined into single regression equations, as appropriate. The results are shown in Table 6.

Statistically similar pairs of variables were reduced the conceptually superior alternative. Both average contract size and relative capital intensity are represented by capital intensity in these results, as contract size does not cover the foreign-invested sector. The non-interactive versions of the capital intensity, state ownership, and R&D variables are used instead of their interactions with technology transfer contracts.

For the capital intensity and state ownership variables, the non-interactive versions have more explanitory power based on the R-squared statistic. In the case of R&D, the additional inclusion of the interactive version was not found to contribute any explanatory power to the models, and the interactive version was considered inappropriate in the equation by itself[6]. Exports are treated separately just as they were in the previous section.

Model A appears to be an excellent representation of the determinants of China's TFP by industry. With an R-squared of .785 and highly significant coefficients (except for the capital-to-labor ratio, which is close to significant), the model's explanatory power appears to be very impressive. The sign of each term is consistent with expectations, and the size of each coefficient is on the same order of magnitude as in Table 5.

Models B & C, which include exports in place of FDI and technology transfers, have

[6]The alternative sets of variables were tested in analogous models and did not yield qualitatively different results. Specifically, the R&D interactive variable appeared to have similar characteristics as R&D by itself when *substituted* in the models.

slightly lower R-squared statistics, but are otherwise quite similar. In this integrated framework, the marginally more impressive Model A suggests that technology transfers in general and FDI in particular are better benchmarks for determining the requirements of continued TFP growth.

6. DISCUSSION OF RESULTS

Through this interpretive and systematic review of the quantitative measures, considerable evidence supporting the linkage between technology transfers and total factor productivity growth has been found. However, diffuculties in measuring TFP mean that this studies' conclusions need to be interpreted with some caution and further investigated with more firm-level studies.

Whether in the form of technology transfer contracts or foreign direct investment, *appropriate* transfers of foreign technology to China appear to be able to improve China's TFP growth. Prudence should be used in capital-intensive industries as a result of the uneven ability of industries to improve TFP, consistent with Conrad's (1992) warnings. Transfers should be directed towards industries which can digest the technology and utilize its technical content effectively. Capital intensive industries, especially those dominated by state-owned enterprises, seem to be the worst candidates for Chinese enterprises to attempt to independently acquire and digest foreign technology. Foreign direct investment may be a better option, to the extent that these heavy industries can be competitive in China's labor-rich economy (Naughton, 1996: 381).

While general R&D does appear to improve TFP, those efforts which are closely integrated with technology tranfers can maximize these productivity gains by assimilating the embodied knowledge. Assimilation and updating expenditures need to follow the lead of productive R&D in their focus, whereupon they might be more effective. Indications that the return rate to transfer-integrated innovation investment is very high at the industry level suggests that unexploited productivity gains exist which have sizable spillovers effects.

Transfers of know-how and more incremental, digestible technologies have been the most effective. This implies that technological leap-frogging is not realistic, and sustained receipt of appropriate foreign technology is a more viable strategy, as Chen (1997) has argued. The impact of foreign direct investment is considerable for entire industries, even if it does not always bring in the highest level of technology.

China's blossoming machinery and electronic equipment industries show that innovative zeal and at least moderate openness to foreign direct investment can yield considerable productivity gains even in these even-balanced labor–capital intensity industries. The enlightened policies of this sector will likely be able to sustain its long-term growth. Further examinations of the technology learning process now seem appropriate, ideally from the prospective of specific types of transfers at the firm level.

The paucity of previous quantitative examinations of these issues in China and elsewhere in the developing world suggests that more research needs to be done. Perhaps there has been an undue focus on ownership to the exclusion of technology transfer in explaining TFP growth. Only by understanding the whole picture of change can we understand how a country like China can move toward more uniformly intensive growth.

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