Open Economy Impacts on Energy Consumption: Technology Transfer & FDI Spillovers in China's Industrial Economy*

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For Review and Comment Only

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Abstract

This paper uses firm-level data for China's industrial enterprises to test the importance of open economy effects on both overall and energy productivity. To do this, we examine both the impact of firm-level FDI and technology development expenditures on total cost and energy use as well as the horizontal, upstream, and downstream spillover effects of concentrations of FDI and technology development spending. Technology development expenditure consists of internal spending within the firm, measured somewhat more broadly than R&D, and purchases of imported technology. We find knowledge transfers through vertical linkages to have a greater influence on improving both overall and energy productivity than own-knowledge or transfers through horizontal linkages. Own-knowledge and horizontal knowledge spillovers, we find, are more important for the development of new products and for the development of products targeting the export market. As our results suggest, the past emphasis on improving China's energy productivity by increasing own-firm innovative activities and knowledge spillovers through horizontal linkages is overlooking the potentially important vertical linkages as key channels for reducing China's energy consumption.

Keywords: R&D, technological change, factor bias, China

JEL codes: O3, P2

I. Introduction

Continuous growth of overall productivity is a precondition for sustained increases in China's living standards; however, raising *energy* productivity in China is important not only for promoting living standards, but is also critical for China's energy security, world energy markets, and for environmental issues, such as climate change. As a result of China's growing integration in the world economy, the level and composition of energy consumption in China are being increasingly driven by patterns of product demand, relative factor prices, and technological opportunities that are defined by global markets.

Past studies on strategies to improve energy productivity in China have largely emphasized the role of technology—in particular, the importance of international transfers of technological knowledge to China (see, for example, Clarke et al, 2006). These studies, therefore, have highlighted the importance of own-R&D and horizontal spillovers where knowledge spillovers occur within the same industry. More recent studies, however, have identified the importance of knowledge spillovers through vertical linkages—both upstream and downstream—with many showing that vertical linkages have a greater influence on improving productivity than own-technology development or horizontal linkages (Javorcik, 2004; Jabbour and Mucchielli, 2007; Liu, 2008). Javorcik (2004), for example, finds that foreign direct investment (FDI) occurring downstream may induce productivity improvements upstream as these foreign firms demand lower-cost products from upstream suppliers. Others (e.g., Liu, 2008; Jabbour and Mucchielli, 2007) have shown that FDI occurring upstream can result in the manufacturing of products that improve efficiency in downstream firms. In this paper, we are interested in exploring the relative importance of the transfer of technological knowledge through vertical, horizontal, and own-firm channels to the improvement of firm-level overall and energy productivity.

In this paper, we utilize firm-level data to test the importance of FDI and technology development including spillovers on energy productivity. That is, unlike these previous studies, we focus on the factor bias of FDI and various channels of technology development. To do this, we include firm-level FDI and technology development expenditures in addition to FDI and technology development occurring within the firm's own industry and occurring in industries both upstream and downstream from the firm. While past studies have predominantly focused on FDI, market-mediated technology transfer from abroad, or intra-national technology development activities, we include all three in order to compare the relative impact of each. Also, while past studies have examined the impacts of these activities on economic growth or total factor productivity, we are primarily interested in understanding the implications of the open economy on energy use in China. We therefore estimate a model that captures the effects of open economy flows on both total factor productivity and factor-biased productivity, although our analytical emphasis focuses on the energy bias of FDI and channels of technology development.

According to Dahlman and Aubert (2001), in the past FDI and foreign ownership have done little to transfer knowledge. FDI has historically targeted low-technology labor-intensive industries in an attempt to exploit China's low wage rates. But increasingly in China, the impact of FDI on technology is more nuanced than suggested by Dahlman and Aubert's view. Jefferson and Zhong (2004) find that FDI substantially raises the returns to R&D in China. Hu, Jefferson, and Qian (2003) find evidence that within China, FDI serves as a distinct channel of technology transfer that substitutes for technology transfer through market-mediated channels. This is consistent with the expectation that in economic settings in which intellectual property rights are weak, FDI serves to expand the boundaries of the firm, so that proprietary technologies can be deployed to and protected by overseas subsidiaries of the parent firm.

Although FDI and in-house technology development may be important for improving the firm's production efficiency, studies have suggested that spillovers from other firms may also have an impact on firm productivity. Numerous studies have tested for the existence of knowledge spillovers. Grossman and Helpman (1991) construct a theoretical model to explain the link between international knowledge spillovers and economic growth. Coe et al. (1997) provide empirical evidence of the link between R&D activities in other countries to within-country productivity growth, operating through the trade of intermediate products and capital equipment. Branstetter (2001) compares the impact of intra-national and international knowledge spillovers on firm productivity and finds intra-national spillovers to have a greater impact than international spillovers. Lastly, in their study of China, Kuo and Yang (2008) find evidence of international technology spillovers and regional R&D spillovers affecting regional economic growth.

Spillovers may occur through horizontal or vertical channels. Horizontal spillovers imply that a firm will benefit from FDI or technology development activities conducted by firms within the same industry. As discussed in Javorcik (2004), there has been little evidence of horizontal FDI spillovers in developing countries (see, e.g., Haddad and Harrison (1993)). Javorcik argues that competitive pressures may cause firms to take measures to ensure that these types of spillovers to other firms within the same industry do not occur. Thus, spillovers may more likely occur through vertical channels—i.e., backward or forward linkages. Downstream firms receiving foreign investment may transfer knowledge to upstream firms in order to improve the quality of the product produced by these upstream firms that are supplied to the downstream firms. Alternatively, upstream firms receiving foreign investment may be producing a higher quality intermediate product used by downstream firms. Javorcik (2004) finds evidence of spillovers occurring through backward linkages in the case of manufacturing firms in Lithuania.

Several papers focus on China specifically. Lin, Liu, and Zhang (2008) and Du, Harrison, and Jefferson (2008) use similar data sets to test for both horizontal and vertical FDI spillovers to total factor productivity. While their findings exhibit important differences, for the purposes of this paper, their finding are similar in that vertical spillovers are significantly more positive and negative than horizontal spillovers. Moreover, Du et al (2008) find that horizontal spillovers are significantly negative.

The data set used in our analysis combines three data sets that are updated annually by the National Bureau of Statistics (NBS) in China. The first is an economic and financial data set, collected by the Bureau's Department of Industrial and Transportation Statistics (NBS, 2001a), that includes all of China's 22,000 large and medium-size enterprises (LMEs)[1] over the years 1995-2004. The second data set, consisting of a large set of science and technology measures, including innovation inputs and outputs, is maintained by the Bureau's Department of Population, Social, and Science and Technology Statistics (NBS, 2001b), and includes the same number of firms and years as the economic and financial data set. These two data sets are combined with an energy data set that includes 21 individual energy types and a measure of aggregate energy consumption. In this analysis we concentrate on aggregate energy. These energy data, collected annually by the NBS, include only the most energy intensive enterprises

[1] Large and medium-size enterprises are those enterprises with annual sales over 5 million Yuan.

among the population of large and medium-size enterprises over the years 1997-2004, and therefore include significantly fewer observations than the other two data sets.

We find knowledge transfers through vertical linkages to have a greater influence on improving both overall and energy productivity than own-knowledge or transfers through horizontal linkages. Own-knowledge and horizontal knowledge spillovers, we find, are more important for the development of new products and for the development of products targeting the export market. Among these vertical linkages, upstream is more important than downstream in improving both overall and energy efficiency at the firm-level. Foreign direct investment, technology imports, and internal technology development occurring upstream is resulting in a product that, when supplied to downstream firms, improves energy efficiency in these downstream firms.

As our results suggest, the past emphasis on improving China's energy productivity by increasing own-firm innovative activities and knowledge spillovers through horizontal linkages is missing a key channel of influence. Therefore, ignoring vertical linkages implies that important channels for reducing China's energy consumption are being overlooked.

The paper is organized as follows. Section II provides an overview of technology development and FDI in China, including summary statistics of these variables in our data set.

Section III presents the model we will be adopting for our estimation, Section IV discusses estimation issues we encountered and estimation strategy. Section V presents the results from our estimations, including marginal calculations. Section VI offers interpretations of the results including areas for future exploration and Section VII concludes.

II. Technology Development and FDI in China

Solow (1956) demonstrated that technological progress is critical for the sustained growth of living standards. The promotion of technology development has been an important part of the Chinese government's development strategy. While most countries' R&D intensity (defined as the ratio of gross expenditures on R&D to GDP) has been flat in recent years, China's R&D intensity has risen from 0.6% in 1996 to 1.3% in 2003. China's recently released "National Medium- and Long-Term Programme for Scientific and Technological Development (2006-2020)" sets a R&D intensity goal of 2.5% by 2020, a level similar to that of higher-income countries.[2]

Our data set (described in more detail in the Appendix) distinguishes between the following two types of technology development expenditures:[3]

[2] This is an ambitious target. Even if per capita income in China were to grow at 5% per year, per capita income will reach approximately US$11,000 by 2020 in PPP terms, roughly the per capita income level of Argentina or Poland currently.

[3] Although we use technology development expenditures to measure the level and bias of innovation effort, we use the terms "technology development" and "R&D" interchangeably.

(1) Internal technology development (*jishu kaifa jingfei zhichu*) is technology development expenditure that is conducted within the firm. The scope of this measure is broader than the standard measure of research and development expenditure. In addition to R&D spending, it includes expenditure for a wider range of process innovation activity and for improving the quality of existing products that are generally excluded from the OECD Frascoti Manual, the general arbiter of firm expenditures that qualify as R&D.

(2) Technology imports (*jishu yinjin jingfei zhichu*) i.e., purchased technology that originates from another country. These technology imports include equipment that is used to support domestic firm technology development operations (e.g. lab equipment) as well as blueprints and licenses for foreign technology.

The first column of Table 1 shows the intensity of technology development expenditures – defined as the ratio of total development expenditure to sales revenue. This table shows that three industries – timber, furniture, and paper products; chemicals; metal processing and products; and machinery, equipment, and instruments - all have technology development intensities greater than 3%. This table also shows that the intensity of technology development of state-owned enterprises (SOEs) is equal to that of non-SOEs.

For each of the two technology development expenditure categories, the last two columns in Table 1 show the distribution of technology development by internal R&D and by purchases of imported technology. The industries for which the share of imported technology is relatively large are food and beverage; timber furniture and paper products; metal processing; and petroleum processing. While the metal processing industry accounts for nearly one-third of total imported technology purchases, the industry that follows – i.e., machinery – uses proportionately more internal R&D. Together, these two industries account for more than one half of total internal technology development spending and total imported technology purchases. Combined with chemicals, these two industries stand out as those with the most overall technology development intensity. Table 1 further shows that during 1999-2004 state-owned enterprises accounted for slightly less than half of imported technology purchases, while in-house technology development is more evenly divided between the two ownership types.

Although technical progress can originate from within the country itself, developing countries rely heavily on the transfer of knowledge and technology from more developed countries. This transfer can be market-mediated (e.g., imported technology), or can occur through indirect channels such as foreign direct investment (FDI). In China, since its surge during the 1990s, FDI has been the largest source of technology transfer, providing not only more advanced technologies and knowledge, but a very important source of capital inflow from abroad.[4] Although direct investment in a firm's technological capacity is the essential initial condition, knowledge spillovers from these investments are a major reason for the Chinese government's vigorous promotion of FDI.

Generally, FDI is targeted at the consumer products sector. However, in the case of China, most FDI, approximately 70% in 2003-04, has been targeted at the manufacturing sector (Naughton, 2007). Table 2 provides a breakdown of our sample by industry. Across all industries, the machinery, equipment, and instruments sector captures 55% of China's total FDI inflows, a dominant share for a single industry. We see that the ratio of foreign capital stock to total capital stock is highest in the machinery, equipment, and instruments sector, followed by rubber and plastic products; non-metal products, food and beverage, and timber, furniture, and paper products.

The machinery, equipment, and instruments sectors are important upstream industries to the primary energy sectors (e.g., mining, petroleum, electric power)—making up approximately 12% of intermediate inputs to the primary energy sectors—and other energy-intensive industries, such as metal processing and products. Therefore, FDI and technology development in the machinery, equipment, and instruments sectors may have implications for efficiency in these

[4] Foreign direct investment in China exploded after 1992 after Deng Xiaoping's FDI-friendly policy announcements, rising from 1% of GDP in 1991 to ~6% of GDP in 1994, and falling to ~3% of GDP in 2005 (Naughton, 2007).

energy producer and energy-intensive industries. For downstream industries, intermediate products from the primary metal and metal processing and product sectors are, in turn, important inputs to the machinery, equipment, and instruments sectors—making up approximately 20% of intermediate inputs. Therefore, FDI occurring downstream in the machinery, equipment, and instruments sectors may influence efficiency upstream in the metal product industries.

III. The Model

The standard approach to measuring the neutral and factor-biased effects of FDI and technology development involves the estimation of production functions or dual cost functions. The theoretical connection between production or cost functions and factor demands makes this approach fitting for the measurement of factor bias. The choice of whether to use the production function approach or the cost function approach depends on the relevant set of exogeneity assumptions. For the production function formulation – which incorporates quantities of output and inputs – input quantities are assumed to be exogenous, whereas in the cost function input prices are assumed to be exogenous.. In highly aggregated data sets, input prices are likely to be endogenous and therefore a production function may be more appropriate. At the firm level, however, choices of factor inputs are likely to be endogenous while factor prices are more likely to be set in the market and therefore plausibly exogenous. Since our data set allows us to impute factor input prices for the individual firms,[5] we use the cost function approach. To test the assumption of price exogeneity, we also use wages and capital costs aggregated to the provincial levels to re-estimate our model.

Since the translog cost function is the most flexible of functional forms, we adopt it as follows:

$$(1)\quad \ln C = \alpha_0 + A(R,F,T) + \boldsymbol{\alpha}'_{\mathbf{Z}}\cdot\mathbf{lnZ} + \alpha_Q\cdot\ln Q + B(R,F,T,Z) + \tfrac{1}{2}\cdot\mathbf{lnZ}'\cdot\boldsymbol{\beta}_{\mathbf{ZZ}}\cdot\mathbf{lnZ} + \ln Q\cdot\boldsymbol{\beta}'_{\mathbf{QZ}}\cdot\mathbf{lnZ} + \varepsilon_Q$$

where

$$A(R,F,T) = \boldsymbol{\alpha}'_{\mathbf{R}}\cdot\mathbf{lnR} + \boldsymbol{\alpha}'_{\mathbf{F}}\cdot\mathbf{F} + \boldsymbol{\alpha}'_{\mathbf{T}}\cdot\mathbf{T}$$

$$B(R,F,T,Z) = \mathbf{lnR}'\cdot\boldsymbol{\beta}_{\mathbf{RZ}}\cdot\mathbf{lnZ} + \mathbf{F}'\cdot\boldsymbol{\beta}_{\mathbf{FZ}}\cdot\mathbf{lnZ} + \mathbf{T}'\cdot\boldsymbol{\beta}_{\mathbf{TZ}}\cdot\mathbf{lnZ}$$

$$\mathbf{lnZ}' = (\ln P_K, \ln P_L, \ln P_E, \ln P_M)$$

$$\mathbf{lnR}' = (\ln R_{int}, \ln R_{int\_3dig}, \ln R_{upstr\_int}, \ln R_{downstr\_int}, \ln R_{imp}, \ln R_{imp\_3dig}, \ln R_{upstr\_imp}, \ln R_{downstr\_imp}, \ln R_{int}*\ln R_{imp})$$

$$\mathbf{F}' = (F_{kinten}, F_{kinten\_3dig}, \ln R_{int}* F_{kinten}, \ln R_{imp}* F_{kinten}, F_{upstr\_kinten}, F_{downstr\_kinten})$$

$$\mathbf{T}' = (Year_{99}\text{-}Year_{04})$$

And furthermore:

$C \equiv$ total cost of production,

$Q \equiv$ gross value of industrial output in constant prices,

[5] The data set includes both quantities and values and therefore a price can be imputed by dividing value by quantity.

P_K ≡ price of fixed assets , which is calculated as (value added - wage bill - welfare payments)/(net value fixed assets),

P_L ≡ price of labor, which is calculated as (wage bill + welfare payments)/employment),

P_E ≡ price of aggregate energy, which is calculated as (energy expenditures)/(quantity of energy purchased in standard coal equivalent (SCE)),

P_M ≡ price of materials, calculated as the weighted average of industry prices using input-output shares,

R_X ≡ stock of technology development expenditures (X = internal (int), imported (imp)),

R_{X_3dig} ≡ stock of internal technology development expenditures in firm's 3-digit SIC industry (X=internal (int), imported (imp));

R_{upstr_X} ≡ weighted average stock of internal technology development expenditures in firm's 2-digit SIC upstream industries (weighted using input-output shares) (X=internal (int), imported (imp));

$R_{downstr\_X}$ ≡ weighted average stock of internal technology development expenditures in firm's 2-digit SIC downstream industries (weighted using input-output shares) (X=internal (int), imported (imp));

F_{kinten} ≡ foreign capital stock intensity, calculated as (foreign capital stock)/(total capital stock);

F_{kinten_3dig} ≡ foreign capital stock intensity of firm's 3-digit SIC industry;

F_{upstr_kinten} ≡ weighted average foreign capital stock intensity of firm's 2-digit SIC upstream industries;

$F_{downstr\_kinten}$ ≡ weighted average foreign capital stock intensity of firm's 2-digit SIC downstream industries;

Finally, Year99 - Year04 are time dummies for the period 1999-2004, for which 1999 is the reference year. The function A(R,F,T) in equation (1) represents the neutral productivity effects of deliberate technology development (R), foreign direct investment (F), and time (T), while the function B(R,T,Z) represents the factor-biased productivity effects of R, F, and T. Rather than use contemporaneous R&D expenditures, in order to incorporate a more plausible time structure between R&D inputs and outputs and to limit endogeneity, we construct R&D stock variables using the perpetual inventory method. Details of the construction of these R&D stock variables and the other variables listed above are provided in Appendix A.

Using Shephard's Lemma, we derive the cost share equation associated with each factor input by taking the derivative of the cost function with respect to the relevant input price; i.e.,

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{P_i X_i}{C} \quad i = \text{K, L, E, M}$$

Specifically, taking the derivative of equation (1) with respect to each input price, we obtain the following cost share equations:

(2) $VL / VC = \alpha_L + \beta_{LL}\ln P_L + \beta_{LK}\ln P_K + \beta_{LE}\ln P_E + \beta_{LM}\ln P_M + \beta_{QL}\ln Q + \mathbf{\ln R'\cdot\beta_{RL}} + \mathbf{F'\cdot\beta_{FL}} + \mathbf{T'\cdot\beta_{TL}} + \varepsilon_L$

(3) $VE / VC = \alpha_E + \beta_{EE}\ln P_E + \beta_{EK}\ln P_K + \beta_{EL}\ln P_L + \beta_{EM}\ln P_M + \beta_{QE}\ln Q + \mathbf{\ln R'\cdot\beta_{RE}} + \mathbf{F'\cdot\beta_{FE}} + \mathbf{T'\cdot\beta_{TE}} + \varepsilon_E$

(4) $VM / VC = \alpha_M + \beta_{KM}\ln P_K + \beta_{LM}\ln P_L + \beta_{EM}\ln P_E + \beta_{MM}\ln P_M + \beta_{QM}\ln Q + \mathbf{\ln R'\cdot\beta_{RM}} + \mathbf{F'\cdot\beta_{FM}} + \mathbf{T'\cdot\beta_{TM}} + \varepsilon_M$

where

$VL \equiv$ value of labor expenditures (equal to wage bill + welfare payments)

$VE \equiv$ value of energy expenditures

$VK \equiv$ value of capital (equal to value added – VL)

$VM \equiv$ value of material expenditures (value of intermediate inputs - VE)

$VC \equiv$ value of total cost.

Dropping the capital share equation and estimating this system of four equations,[6] we can analyze the neutral and factor biased effects of deliberate technical change, FDI, and the passage of time. As shown in the above four-equation system, we assume that technology development

[6]Since the cost shares must sum to one, we drop one of the cost share equations – the cost share equation for capital. Coefficient estimates and standard errors will be invariant to the choice of which cost share equation is dropped (see Berndt,1991).

and foreign direct investment affect a firm's production function through the factor-neutral and factor-biased productivity terms. Autonomous factor-neutral and factor-biased technological change, i.e., technological change occurring through processes other than deliberate purchases of R&D and imported technology, are captured by the coefficients associated with the year dummies, $Year_{99}$- $Year_{04}$. Factor-neutral effects—i.e., in which the effects of technology development and foreign direct investment are proportional across all inputs—are captured by the terms $\boldsymbol{\alpha'_R \cdot \ln R}$ and $\boldsymbol{\alpha'_F \cdot \ln F}$. The factor-biased effects, which causes movement along the isoquant, are captured by $\boldsymbol{\ln R' \cdot \beta_{RZ} \cdot \ln Z}$ and $\boldsymbol{F' \cdot \beta_{FZ} \cdot \ln Z}$.

IV. Estimation Issues and Strategy

Because equations (1) – (4) represent a system of equations in which shocks to the factor shares are likely to be correlated across the error structure of the model, the system is estimated as a seemingly-unrelated regression (SUR). To ensure that the coefficients exhibit the usual properties of symmetry and homogeneous of degree one in prices, we impose the following constraints:

$\beta_{a,b} = \beta_{b,a}$

$\boldsymbol{i' \cdot \alpha_Z = 1}$

$\boldsymbol{\beta_{ZZ} \cdot i = 0}$

$\boldsymbol{\beta_{RZ} \cdot i = 0}$

$\boldsymbol{\beta_{RTZ} \cdot i = 0}$

$\boldsymbol{\beta_{TZ} \cdot i = 0}$

$\boldsymbol{\beta_{QZ} \cdot i = 0}$

where i is a vector of ones. Our test of the constant-returns-to-scale (CRS) condition rejects CRS. Therefore, our results in Section V do not incorporate the restriction of CRS. We find, however, that imposing CRS does not affect the qualitative nature of our findings. We also test for concavity in prices and find that while global concavity does not hold, local concavity does; i.e., the function is concave when evaluated at the relative prices observed in the sample period.

We expect the cost function error term to include permanent (i.e., non-time varying) unobserved productivity differences across firms, transitory (i.e., time varying) unobserved productivity differences, and measurement error. In the case of permanent unobserved productivity differences, issues of simultaneity exist, since these unobserved permanent productivity differences are known to the firm when variable and fixed input choices are made. For example, unobserved variation in managerial quality is likely to be associated with cost. If high quality managers achieve low cost production, which is reflected in the firm's error structure, and high quality managers are simultaneously able to use effectively R&D or FDI resources, then the unobserved heterogeneous managerial quality will lead to a spurious association between low cost and the use of R&D and FDI inputs. Furthermore, if high quality managerial services are associated with high labor quality (reflected in the price of labor), then we would expect the set of coefficients on labor and its interactive terms to suffer from downward bias, i.e. labor would appear to create more cost-saving efficiencies than it actually does. To remedy the fixed effects problem, we use a fixed effects estimation procedure. We do this by incorporating into our estimation procedure a dummy for each of the N firms that appears in the panel data set. Provided that our firm effects are indeed fixed, the estimates will be unbiased and consistent.

We anticipate that measurement error is a problem in our data set. For example, our measures of R&D expenditure and imported technology purchases, even if accurately reported, are but approximations of the true quality of R&D effort and the true quality of imported technology purchases. In particular, the errors-in-variables problem will result in underestimates of the β coefficients. We do not have a remedy for this measurement problem, however, any downward bias in our estimates should only serve to strengthen our results in Section V.

Given the history of price controls in China, we should be concerned about whether prices are market determined and exogenous as assumed by our choice of functional form. While some firms continue to receive a portion of their inputs, notably energy, at controlled prices below market prices, product prices are generally no longer subject to price controls. While price controls are not ubiquitous as they once were, it may still be the case that distortions recommend a shadow cost function approach. To test this, we estimate a shadow cost function following Atkinson and Halvorsen (1984) and test whether the factors of proportionality of the shadow prices are equal (p. 652).[7] If the factors are equal, the implication is that relative prices are the same between the actual cost function and the shadow cost function, leading to similar value shares, so that the actual cost function reduces to the shadow cost equivalent. In our estimation and subsequent tests of the factors of proportionality, we cannot reject the hypothesis that the factors are the same and therefore cannot reject the hypothesis that there is no significant difference between the actual and shadow cost functions.

Another issue that arises in our analysis is sample selection bias. Within the population of China's industrial enterprises, our sample includes only large- and medium-size industrial enterprises, whose energy consumption exceeds 10,000 tons standard coal equivalent (SCE). The exclusion of firms below this threshold limits our ability to generalize the results of this paper to smaller industrial firms and those that are less energy consuming. As discussed in Appendix A, the importance of measuring the energy bias of FDI and technology development in China requires us to work with the smaller, less representative sample. Since the energy sample criterion is based on levels and not intensity of energy consumed, the sample includes both energy intensive firms (firms with a higher energy/sales ratio) and firms that may be less energy

[7] See Parker (1995) for an earlier application of the shadow cost function to Chinese firm-level data.

intensive, but are large enough to consume more than 10,000 tons SCE of energy. As shown in Table A.1 in Appendix A, although the sample represents only one percent of total industrial enterprises, it captures 20 percent of total industrial assets, 15 percent of total industrial employment and 40 percent of total industrial energy consumption. Our findings, therefore, are limited to this sub-sample of China's total industry.

An additional limitation on the data results from our use of a balanced set of data, which omits firms with missing technology development data, economic data, or energy data in any of the six years. Firms may not report in all six years for any of several reasons. First, in each year a significant number of firms drop out of the data set. Specifically, firms that have undergone a change in their formal ownership designation, been merged or acquired, or have changed industry or location are often assigned new enterprise identification numbers, so that these firms cannot be tracked. Furthermore, from time to time firms consume levels of energy that fall below the required 10,000 SCE threshold and hence are omitted from the survey. In order to focus as much as possible on a stable set of firms and to limit the influence of exit and entry on stock measures of the technology variables, we require that the included firms survive the full six-year period. As described in Appendix A, we use the 1999 expenditures on technology development to create an estimate of the initial stock of technology development expenditure in 1999, using the perpetual inventory approach, and then use subsequent measures of annual technology development expenditure as flows to adjust the initial stock estimate. Thus, firms that enter after 1999 or enter, then exit, in less than five years yield estimates of their technology development stocks that do not capture technology development expenditure flows while they were not in the sample, and are likely to exhibit substantial measurement error in relation to the firms with longer durations.[8] These considerations – the use of five-years of data to construct the appropriate technology development stocks and an additional one year for the fixed effects approach – lead us to conduct our analysis using a balanced data set.

Sample selection bias can arise if firms are "exiting" the data set due to closure, where exit is correlated with unobserved poor productivity performance. In this case, the usual remedy is to apply the Heckman two-stage procedure in which a regression using information from the exiting firms is used to correct for bias implicit in the population of surviving firms (Heckman, 1979). While we anticipate that the phenomenon of exit and entry may result in some change in technology orientation, our analysis shows that within our data set firms that exit or enter the data set do not as a group exhibit lower levels of productivity than the surviving firms.[9] While the phenomenon of exit and entry may not significantly affect estimates of neutral productivity

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[8] An additional argument for using balanced sample is related to our need to include firm fixed effects in our estimation. Because we use a fixed-effects estimator that consumes a year's observation for each firm, we effectively require five years of observations for each firm.

[9] Results are available from the authors upon request.

change, the exclusion of exiting and entering firms may affect the factor-saving bias of technological change. However, correcting for bias in the estimates of factor-saving technological change resulting from the excluded firms is beyond the scope of this paper. Hence, we limit our claim of the relevance of our results to our sample of surviving large and medium-size enterprises.

V. Results

Tables 3a-3c summarize the regression results. While the model is estimated using a SUR estimator for Equations 1-4, portions of the results from the SUR estimation are reported in each of three tables. Table 3a first reports the coefficients and p-values of the regression estimates for internal technology development, all in log form. These are: the stock of firm-level internal technology development expenditures; the stock of internal technology development expenditures in the firm's 3-digit SIC industry; the stock of technology development expenditures in the the firm's 2-digit SIC upstream industries; the stock of technology development expenditures in firm's 2-digit SIC downstream industries; and the interaction terms of these four variables with the four factor prices (capital, labor, energy, and materials). Similar to the presentation of the results for internal technology development in Table 3a, two other tables show results for the variables related to the stock of imported technology (Table 3b) and foreign capital intensity (Table 3c). Table 3b also reports the results for variables related to the interaction of internal technology development and imported technology.

Impact on overall cost: Tables 3a and 3b show the range of estimates for cost elasticities for internal and imported technology development. We see that, in most cases, the overall or neutral impact of technology development on cost is highly significant, although the estimates for internal technology development are more consistently robust than those for imported technology. Among the four potential channels of the neutral impact of technology purchases on cost, one key result is that the largest cost-reducing effects originate with the upstream stocks of internal and imported technology expenditure while the largest cost-increasing effects originate with the stocks of downstream technology spending. Apart from the impacts of these vertical spillovers, no other technology development expenditures - neither those occurring within the firm nor the horizontal spillovers within 3-digit industries - exhibit significant cost effects.

Table 3c shows that for foreign capital, none of the neutral impacts on cost are statistically significant. Moreover, none of the neutral effects of the within firm variables – either FDI or technology development – is significant nor any of the horizontal 3-digit spillovers. We conclude from these results, that the principal neutral or overall cost impacts associated with technology and foreign capital are vertical spillovers of technology, both upstream and downstream. Why the upstream spillovers from technology spending should exert large and negative neutral impacts on production cost while downstream technology spending exerts large and positive impacts is a puzzle that we explore in Section VI where we interpret the results reported in this section. In the next subsection, we examine the factor bias of technology and foreign capital, particularly that of energy.

Energy-saving biases. Estimates of the factor-bias elasticities, while generally smaller than the impact of the neutral cost elasticities, typically exhibit higher statistical significance. Among the technology stocks, the largest negative impacts on energy's factor share are downstream internal technology (Table 3a) and the imported technology stock of upstream industries (Table 3b), with energy-bias coefficients of -0.0423 and -0.0990, respectively. The own-firm's stock of internal technology also exhibits negative effects on the energy share. Table 3b shows that the largest positive impact on energy's share originates with the downstream stock of imported technology. Other sources of positive impact on energy's factor share include the upstream stock of internal technology, and the aggregate stocks of both the internal and imported technology expenditures in the 3-digit industry.

Finally, Table 3c shows that while foreign capital exhibits no significant neutral impacts on cost, it does exhibit significant energy-saving biases. The largest of these energy-saving biases is the negative effect of upsteam foreign capital; conversely, the FDI accumulated in downstream industries exhibits the largest energy-using bias. Unlike the general absence of horizontal impacts from technology spending on either overall cost or energy bias, foreign capital does show horizontal impacts on energy bias, with own foreign capital intensity exhibiting an energy-saving bias as does the within-firm interaction between foreign capital intensity and internal technology stock. The accumulation of FDI at the 3-digit level exerts an energy-using impact on firms within those industries.

Total impacts on the quantity and value of energy consumption: Based on the results in Tables 3a-c, Table 5 compute the marginal effects on the value shares of energy and the quantity of energy consumed. Table 4 shows the total marginal effects, consisting of the sum of the factor-biased effects and the neutral effect, of each of the channels through which internal and imported technology and foreign capital have an effect on the cost of production. The aggregate impact of these inputs is -71.347 million yuan. The fact that seven of the 15 channels result in cost increases indicates that these are not all cost-reducing effects. We address this implication in the following section, which interprets the results.

The results shown in Table 4 largely mirror the estimated elasticities reported in Tables 3a-c. The largest cost-reducing FDI channel is downstream collections of FDI, for which the magnitude of the cost-reducing effect is substantially greater than the impact of any of the other FDI channels. The second largest FDI impact operates through upstream foreign capital intensity; its magnitude is somewhat more than half the size of downstream foreign capital intensity. Within the set of technology inputs, upstream imported technology and upstream internal technology create substantial cost savings. By contrast, downstream internal technology development spending substantially raises costs, while downstream imports of technology exert a trivial impact on total cost. Among the horizontal impacts, own-firm foreign capital intensity and the capital intensity of the firm's own 3-digit industry raise total cost, while the own 3-digit industry's aggregation of internal technology stock reduces cost. The magnitudes of the other channels are all comparatively small. As we found with the output elasticities reported in Tables 3a-c, the dominant impacts and spillovers operate through vertical linkages. The largest four of these operate through vertical channels.

Table 5 reports the effects of the 15 channels of technology and foreign investment impact on energy consumption. Nine of 15 of these channels result in energy-saving impacts; six are energy-using. Across these 15 channels, the cumulative factor bias is an energy savings of 229,739 tons of standard coal equivalent (SCE). The key result from Table 5 is that the upstream channels exhibit large energy-saving effects. Downstream FDI also exhibit a significant energy-saving effect, although downstream internal and imported technology stocks exhibit energy-using effects.

Table 4 breaks out the marginal effects on cost by factor-biased (including energy-biased) and neutral effects. We see that the factor-biased effects are driving the total cost reduction. Two of the factor-biasing impacts stand out. These are factor-saving bias of downstream foreign investment, which imparts a total cost saving of 738.324 million yuan. Upstream foreign investment generates a factor-using impact of 535.020 million yuan. Thus, the vertical foreign capital intensities dominate the factor bias as they do total cost. The other vertical channels that exhibit substantial impacts on factor bias are the factor-saving bias of downstream imported technology and the factor-using biases of both upstream internal and imported technology. Once again, the horizontal impacts of the factor-biased channels are relatively small with own-firm foreign capital intensity exhibiting a cost saving of 35.830 million yuan and FDI within the own 3-digit industries exhibiting an factor-using cost bias of 43.806 million yuan.

In conclusion, two patterns stand out that beg for interpretation. The first is that most of the channels through which the inputs of technology, both internal and imported, affect both overall cost and energy bias are through vertical channels. The second pattern is that the effects of upstream spillovers of foreign capital on cost are shown to be positive; the effects of downstream spillovers on cost are negative. For energy consumption, however, both upstream and downstream FDI are cost-reducing. For technology development, upstream internal and imported technology expenditures both exhibit robust total cost-reducing spillovers, and have energy-saving effects. In the next section we offer an economic interpretation of these patterns documented in Tables 3-5.

VI. Interpretation

The results in the previous section provide strong evidence that concentrations of technology and FDI that generate vertical spillovers are much more important for affecting total production cost and firm-level energy intensity and consumption than are firm-level technology development and FDI operating within the firm. This result is consistent with studies, such as Javorcik (2004), and with more recent work in China, including Lin et al (2008) and Du et al (2008), that find little evidence of horizontal spillovers but strong vertical spillovers. More specifically, our results show that among the vertical linkages, in virtually all cases upstream and downstream linkages operate with different signs. FDI tends to raise total costs while downstream FDI reduces total cost. Conversely, for technology, upstream internal and imported technology linkages reduce total cost and both are robustly energy-saving. By comparison, downstream internal technology conveys substantial cost increases with positive energy bias, while cost increases associated with downstream imported technology are small, even as downstream imported technology is substantially energy-using. What economic forces account for this mixed pattern of impacts and spillover?

One explanation of why FDI and technology spending may operate differently through different channels is that some channels, particularly those associated with higher cost, may be associated with new product development; other channels associated with lower costs may be focused on efficiency, say through process innovation. We may also find systematic associations between a firm or industry's export orientation and the concentration of FDI or technology within the firm or its industrial environment. To see to what extent the cost-saving impacts align with new product development and exports, we use a probit analysis to determine the extent to which the 15 technology and foreign capital factors are associated with new product development and export activity. The results are reported in Tables 6 and 7.

In this section, we particularly focus on economic interpretations of the cost and energy-bias impacts of certain vertical channels of spillover, for which our estimates show largest impacts. These are upstream and downstream FDI and the upstream and the downstream stocks of internal and imported technology development expenditure. The unifying feature of these spillovers on which we particularly focus is the symmetric nature of these spillovers in which the effects of upstream and downstream spillovers on cost are large, the largest we estimate, and of opposite signs, positive for upsteam FDI and negative for downstream FDI. At the same time the two forms of upstream technology spillover – internal and imported – are of the same negative sign, while the counterpart downstream spillovers exhibit positive spillovers on total cost. In all cases but upstream FDI, the direction of energy bias is the same as that of the total cost impact. We first focus on the upstream spillovers.

Upstream FDI, while strongly associated with increasing total costs and robust energy-using effects on its downstream firms, is shown in Tables 6 and 7 not to be highly correlated with new product development or exports. We base this conclusion on the last columns of each table, since these include both ownership and industry effects and thus best approximate the econometric strategy of the fixed effects estimator that was used to estimate the cost system from which the estimates in Tables3a-c are based and the figures in Table 4 and 5 were calculated. If not exhibiting a distinct orientation toward new product development and export markets, the high-priced upstream industries must be offering higher quality variants of established products on the market. Thus the robust growth of domestically-owned Chinese industry, combined with the rapid technological and upgrading of Chinese-owned firms, may be creating a substantial market for quality improvements of existing products, as well as the new products, which the upsteam industries supply in proportions that approximate all of China's LMEs.

Concurrently, upstream internal and imported technology are both cost reducing and energy saving. Upstream producers may be using internal and imported technology to offset the relatively high cost of high quality products and new products brought forth by the foreign sector. We find, in particular, that the upstream foreign-invested firms rely more heavily on internal technology spending than on imported technology. We anticipate that the reason for this is that foreign-invested firms transfer overseas technology from their parent organizations within the boundaries of the firm, thus limiting the need for market-mediated purchases of imported technology. One consequence of these internal technology transfers, however, is that the foreign-invested firms rely more heavily on internal technology spending to adapt and apply their overseas technologies to local Chinese markets. We now turn our attention to the downstream spillovers.

Not only do upstream foreign-invested firms utilize internal technology spending seemingly to reduce the cost of their comparatively more costly products, the downstream firms too appear to utilize their internal technology to mitigate the cost of higher-cost products purchased from upstream suppliers. This observation is based on the fact, as shown in Table 3a, that firms concentrate their internal technology spending on material and energy-saving investments.

Downstream foreign capital intensity, which strongly reduces costs and exhibits robust energy-saving effects, according to Tables 6 and 7, is neither associated with new product development or exporting. This finding is consistent with others, including Javorcik (2004), who find that downstream FDI induce productivity gains and lower costs upstream. An alternative interpretation is that downstream FDI congregates in sectors that can take advantage of low-cost, energy-efficient upstream suppliers. Table 6 show that downstream foreign firms are not particularly oriented toward new products; by substantially selling into domestic markets, they are likely to look toward their upstream firms to supply low-cost inputs.

One set of results shown in Table 6 that had not been anticipated is the orientation of own-firm and 3-digit spillovers originating with FDI and technology spending to be strongly oriented toward new product development. While the magnitudes of the within-firm effects and the horizontal impacts on cost and factor bias shown in Table 4 are generally less than their counterpart vertical spillover effects, the effects of within-firm FDI and technology development and the horizontal spillover effects on new product development, as shown in Table 6, are generally positive.

That new product development would be more focused within firms and that firms should rely more on the market to acquire lower-priced inputs is consistent with contract theory, particularly in an environment in which legal enforcement might be weak. In this situation, firms would be expected to develop quality improvements and new products internally so as to avoid hold-up problems in which they depend on upstream firms for their supply. That the horizontal 3-digit spillovers are cost increasing and associated with higher incidences of own-firm new product innovation may not so much reflect the within-industry sales of new products as they do technology spillovers through imitation, labor mobility and other avenues of product and quality upgrading over which individual firms can exercise greater control.

Summarizing, upstream FDI intensity implies more purchases of higher prices inputs; controlling for FDI intensity, firms will demand that these higher priced inputs be standardized and produced more efficiently. Upstream firms apply both internal and imported technology to achieve such cost reductions. In the meantime the firms that depend on these upstream suppliers use internal technology spending to invest in material and energy-saving innovations in order to limit their dependence on expensive upstream suppliers. At the same time, they utilize their within-firm resources to develop their own in-house new product innovations in order to avoid hold-up associated with high-end, high-price suppliers. Finally, downstream concentrations of foreign invested firms demand less expensive goods from upstream firms; they may also move into industries in which upstream firms are successful in producing lower-cost supplies.

VII. Conclusions

As China is one of the world's largest consumers of energy, it is important to understand the factors that influence China's domestic energy use. Capital and technology transfers from more advanced economies, particularly those that themselves are dependent on imports of foreign energy, should improve energy efficiency in China. Since China's accession to the WTO in 2001, China is now more open to foreign influence.

In this paper, we examine the effects that FDI, internal technology development, and imported technology have had on China's energy intensity and use and overall productivity, using a set of Chinese industrial firm level data for the years 1999-2004. We are not only interested in the influence of FDI and technology development measured at the firm level, we are also interested in estimating the influence of spillovers, both vertical and horizontal. We therefore include in our analysis within-industry FDI and technology development in addition to agglomerations of FDI and technology development in industries upstream and downstream from the firm.

We find vertical spillovers to be the most important influences on both firm-level overall and energy productivity. In particular, FDI and internal and imported technology purchases occurring upstream from the firm have substantially lowered firm-level energy consumption. These results suggest that concentrations of foreign capital and technology upstream from the firm may be inducing energy efficiencies in downstream firms. At the same time, firms that engage in internal technology development downstream may be demanding from upstream firms products that require less energy to produce. We also find that, while vertical spillovers are targeting efficiency improvements, within-firm and within-industry FDI and technology development are targeting new product development and the development of products for the export market.

Table 1
Shares of Technology Development Expenditures
By Industry and Ownership Type, 1999-2004
(in percent)

	Cumulative Technology Development Expenditures		
	Relative to sales revenue	Of which	
		Internal*	Imported*
Mining	2.3	86 (9)	14 (4)
Food and beverage	1.3	63 (3)	37 (5)
Textiles, apparel and leather products	2.9	67 (5)	33 (7)
Timber, furniture, and paper products	3.9	58 (3)	42 (5)
Petroleum processing and coking	0.8	63 (2)	37 (4)
Chemicals	3.5	73 (16)	27 (16)
Rubber and plastic products	2.7	78 (2)	22 (2)
Non-metal products	1.7	80 (2)	20 (1)
Metal processing and products	3.2	66 (23)	34 (33)
Machinery, equipment and instruments	3.0	81 (31)	19 (21)
Electric power	0.6	83 (3)	17 (2)
Other industry	0.6	98 (1)	2 (<1)
Total industry	2.4	74 (100)	26 (100)
State-owned enterprises	2.3	75 (49)	25 (46)
Non-state-owned enterprises	2.5	72 (51)	28 (54)

*Figures not in parentheses are average firm shares (rows sum to 100%); figures in parentheses are shares within the total sample (columns sum to 100%).

Table 2

Foreign Capital Shares by Industry, 1999-2004

(in percent)

	Relative to total capital	Share of total foreign capital*
Mining	0.02	0.05
Food and beverage	15.4	7.9
Textiles, apparel and leather products	5.7	2.2
Timber, furniture, and paper products	13.0	3.4
Petroleum processing and coking	3.5	2.4
Chemicals	3.9	6.2
Rubber and plastic products	21.3	4.3
Non-metal products	17.4	9.9
Metal processing and products	1.9	4.7
Machinery, equipment and instruments	25.0	55.2
Electric power	1.9	3.3
Other industry	0.0	0.0
Total industry	7.4	100

*Figures are shares within the total sample (column sums to 100%).

Table 3a

Effects of Internal Technology Development on Cost

(from the same regression as results reported in Tables 3b and 3c)

Independent variables in logs	Coefficient	P-value
internal technology stock	-0.0006	0.935
price of capital*internal technology stock	0.0020	0.000
price of labor*internal technology stock	0.0017	0.000
price of energy*internal technology stock	-0.0023	0.000
price of materials*internal technology stock	-0.0015	0.004
internal technology stock at 3-digit industry	-0.0174	0.477
price of capital*internal technology stock at 3-digit industry	0.0003	0.827
price of labor*internal technology stock at 3-digit industry	-0.0012	0.130
price of energy*internal technology stock at 3-digit industry	0.0101	0.000
price of materials*internal technology stock at 3-digit industry	-0.0092	0.000
internal technology stock of upstream industries	-0.3382	0.017
price of capital*internal technology stock of upstream industries	-0.1083	0.000
price of labor*internal technology stock of upstream industries	-0.1098	0.000
price of energy*internal technology stock of upstream industries	0.0665	0.000
price of materials*internal technology stock of upstream industries	0.1515	0.000
internal technology stock of downstream industries	0.3999	0.009
price of capital*internal technology stock of downstream industries	0.0341	0.005
price of labor*internal technology stock of downstream industries	0.1253	0.000
price of energy*internal technology stock of downstream industries	-0.0423	0.004
price of materials*internal technology stock of downstream industries	-0.1171	0.000

Table 3b

Effects of Imported Technology on Cost

(from the same regression as results reported in Tables 3a and 3c)

Independent variables in logs	**Coefficient**	**P-value**
imported technology stock	0.0271	0.082
price of capital*imported technology stock	-0.0004	0.723
price of labor*imported technology stock	-0.0001	0.891
price of energy*imported technology stock	-0.0011	0.421
price of materials*imported technology stock	0.0016	0.237
imported technology stock at 3-digit industry	0.0146	0.105
price of capital*imported technology stock at 3-digit industry	-0.0019	0.008
price of labor*imported technology stock at 3-digit industry	-0.0019	0.000
price of energy*imported technology stock at 3-digit industry	0.0027	0.002
price of materials*imported technology stock at 3-digit industry	0.0010	0.222
imported technology stock of upstream industries	-0.6472	0.000
price of capital*imported technology stock of upstream industries	-0.0183	0.000
price of labor*imported technology stock of upstream industries	0.0540	0.000
price of energy*imported technology stock of upstream industries	-0.0990	0.000
price of materials*imported technology stock of upstream industries	0.0633	0.000
imported technology stock of downstream industries	0.4767	0.000
price of capital*imported technology stock of downstream industries	0.0219	0.007
price of labor*imported technology stock of downstream industries	-0.0990	0.000
price of energy*imported technology stock of downstream industries	0.1318	0.000
price of materials*imported technology stock of downstream industries	-.00547	0.000
imported technology stock*internal technology stock	-0.00128	0.378
price of capital*imported technology stock*internal technology stock	0.00009	0.402
price of labor*imported technology stock*internal technology stock	0.00008	0.247
price of energy*imported technology stock *internal technology stock	0.00007	0.619
price of materials*imported technology stock*internal technology stock	-0.00024	0.073

Table 3c--Effects of Foreign Capital on Cost

(from the same regression as results reported in Tables 3a and 3b)

Independent variables in logs (except for foreign capital intensity)	Coefficient	P-value
Foreign capital intensity	0.2388	0.172
price of capital*foreign capital intensity	0.0662	0.000
price of labor*foreign capital intensity	-0.0135	0.058
price of energy*foreign capital intensity	-0.0383	0.006
price of materials*foreign capital intensity	-0.0144	0.293
Foreign capital intensity at 3-digit industry	0.0852	0.742
price of capital*foreign capital intensity at 3-digit industry	-0.0771	0.000
price of labor*foreign capital intensity at 3-digit industry	-0.0236	0.010
price of energy*foreign capital intensity at 3-digit industry	0.0345	0.056
price of materials*foreign capital intensity at 3-digit industry	0.0662	0.000
Foreign capital intensity*internal technology stock	-0.0271	0.197
price of capital*foreign capital intensity*internal technology stock	-0.0016	0.362
price of labor*foreign capital intensity*internal technology stock	-0.0004	0.691
price of energy*foreign capital intensity*internal technology stock	-0.0049	0.023
price of materials*foreign capital intensity*internal technology stock	0.0069	0.001
Foreign capital intensity*imported technology stock	0.0039	0.868
price of capital*foreign capital intensity*imported technology stock	0.0046	0.025
price of labor*foreign capital intensity *imported technology stock	0.0009	0.510
price of energy*foreign capital intensity *imported technology stock	-0.0009	0.730
price of materials*foreign capital intensity *imported technology stock	-0.0046	0.066
Foreign capital intensity of upstream industries	-1.0788	0.664
price of capital*foreign capital intensity of upstream industries	0.8685	0.000
price of labor*foreign capital intensity of upstream industries	0.9957	0.000
price of energy*foreign capital intensity of upstream industries	-1.9006	0.000
price of materials*foreign capital intensity of upstream industries	0.0364	0.777
Foreign capital intensity of downstream industries	1.2827	0.471
price of capital*foreign capital intensity of downstream industries	-0.1326	0.100
price of labor*foreign capital intensity of downstream industries	-1.1151	0.000
price of energy*foreign capital intensity of downstream industries	1.1695	0.000
price of materials*foreign capital intensity of downstream industries	0.0782	0.424

Table 4

Marginal Effects on Total Cost*

(1000 Yuan)

	Total	**Factor-biased effects**	**Neutral effects**
Foreign capital intensity	24648	-35830	60478
Foreign capital intensity within own 3-digit industry	65385	43806	21579
Internal technology stock*Foreign capital intensity	-2437	4430	-6866
Imported technology stock*Foreign capital intensity	-2425	-3408	983
Upstream foreign capital intensity	261760	535020	-273259
Downstream foreign capital intensity	-413418	-738324	342906
Internal technology stock	-318	-167	-150
Internal technology stock within own 3-digit industry	-11130	-6721	-4409
Upstream internal technology stock	-43810	41858	-85668
Downstream internal technology stock	111380	10083	101297
Imported technology stock	7921	1055	8685
Imported technology stock within own 3-digit industry	3426	-281	3707
Upstream imported technology stock	-79778	84162	-163940
Downstream imported technology stock	7886	-112856	120742
Internal technology stock*imported technology stock	-437	-113	-3241
Total	-71,347	-177,286	122,844

* Values represent the change in total cost from a unit change in the variable. Since the technology stocks are in logs, these values represent the change in total cost from a percent change in the technology stocks. In the case of foreign capital intensity, these values represent the change in total cost from a unit change in the intensity. Therefore, a one percentage point (or 1/100th) change in the foreign capital intensity implies a (value/100) change in total cost.

Table 5
Marginal Effects on Quantity of Energy Consumed*
(Tons of Standard Coal Equivalent (SCE))

	Total	Energy-biased effects	Neutral and other factor-biased effects
Foreign capital intensity	12159	-12921	25079
Foreign capital intensity within own 3-digit industry	78167	11638	66529
Internal technology stock*Foreign capital intensity	-4127	-1648	-2479
Imported technology stock*Foreign capital intensity	-2763	-295	-2467
Upstream foreign capital intensity	-374099	-640435	266336
Downstream foreign capital intensity	-26549	394096	-420644
Internal technology stock	-1094	-771	-323
Internal technology stock within own 3-digit industry	-7919	3406	-11325
Upstream internal technology stock	-22156	22420	-44576
Downstream internal technology stock	99075	-14252	113327
Imported technology stock	7678	-381	8059
Imported technology stock within own 3-digit industry	4402	916	3486
Upstream imported technology stock	-114535	-33363	-81172
Downstream imported technology stock	52445	44421	8024
Internal technology stock*imported technology stock	-423	22	-445

* Values represent the change in total energy consumed from a unit change in the variable. Since the technology stocks are in logs, these values represent the change in total energy consumed from a percent change in the technology stocks. In the case of foreign capital intensity, these values represent the change in total energy consumed from a unit change in the intensity. Therefore, a one percentage point (or 1/100th) change in the foreign capital intensity implies a (value/100) change in total energy consumed.

Table 6
Determinants of New Product Development—Probit Analysis
(P-values in parentheses)

Foreign capital intensity	-0.3319 (0.006)	-0.3634 (0.003)	-0.2994 (0.118)	-0.3847 (0.049)
Foreign capital intensity within own 3-digit industry	0.5999 (0.001)	0.5463 (0.003)	0.6597 (0.000)	0.3757 (0.059)
(Internal technology stock intensity/sales revenue)*Foreign capital intensity	4.0817 (0.015)	4.6910 (0.006)	4.8664 (0.005)	5.1541 (0.003)
(Imported technology stock/sales revenue)*Foreign capital intensity	1.6391 (0.108)	1.5517 (0.131)	1.6443 (0.114)	1.4120 (0.163)
Upstream foreign capital intensity	7.5867 (0.000)	5.0798 (0.005)	4.4699 (0.014)	-4.2588 (0.203)
Downstream foreign capital intensity	-0.3647 (0.739)	0.9590 (0.393)	1.4762 (0.191)	2.8170 (0.282)
Internal technology stock/sales revenue	0.6011 (0.000)	0.5590 (0.000)	0.5076 (0.000)	0.5273 (0.000)
Internal technology stock within own 3-digit industry/3 digit sales revenue	4.7483 (0.000)	4.3640 (0.000)	4.1917 (0.000)	4.5852 (0.000)
Upstream internal technology stock/upstream sales revenue	-3.5915 (0.226)	2.8745 (0.333)	2.8806 (0.333)	-3.6095 (0.637)
Downstream internal technology stock/downstream sales revenue	15.596 (0.000)	24.626 (0.000)	24.465 (0.000)	2.5533 (0.665)
Imported technology stock/sales revenue	0.4974 (0.000)	0.4742 (0.000)	0.4309 (0.002)	0.4202 (0.002)
Imported technology stock within own 3-digit industry/3 digit sales revenue	1.8186 (0.000)	2.3071 (0.000)	2.6167 (0.000)	1.7746 (0.000)
Upstream imported technology stock/upstream sales revenue	23.378 (0.000)	18.989 (0.000)	19.148 (0.000)	-4.4947 (0.124)
Downstream imported technology stock/downstream sales revenue	-9.8674 (0.000)	-15.182 (0.000)	-14.891 (0.000)	0.3252 (0.918)
(Internal technology stock/sales revenue)*(imported technology stock/sales revenue)	-1.9754 (0.010)	-2.073 (0.008)	-2.1116 (0.008)	-1.7612 (0.017)
Included dummies	None	Year	Year, Ownership	Year, Ownership, Industry

Table 7

Determinants of Export Activity—Probit Analysis

(P-values in parentheses)

Foreign capital intensity	1.2296 (0.000)	1.2305 (0.000)	1.0166 (0.000)	1.0026 (0.000)
Foreign capital intensity within own 3-digit industry	-0.1751 (0.296)	-0.2410 (0.154)	-0.4515 (0.009)	-1.0037 (0.000)
(Internal technology stock intensity/sales revenue)*Foreign capital intensity	0.6792 (0.658)	1.1870 (0.446)	1.0028 (0.525)	1.7937 (0.272)
(Imported technology stock/sales revenue)*Foreign capital intensity	0.0734 (0.932)	-0.0492 (0.955)	-0.1548 (0.857)	-0.2044 (0.812)
Upstream foreign capital intensity	2.3558 (0.088)	-0.5016 (0.743)	0.1532 (0.921)	-18.354 (0.000)
Downstream foreign capital intensity	-1.8457 (0.045)	-0.6083 (0.520)	-0.9868 (0.301)	12.952 (0.000)
Internal technology stock/sales revenue	1.1993 (0.000)	1.1479 (0.000)	1.1817 (0.000)	1.1891 (0.000)
Internal technology stock within own 3-digit industry/3 digit sales revenue	4.5949 (0.000)	4.2784 (0.000)	4.1197 (0.000)	4.2866 (0.000)
Upstream internal technology stock/upstream sales revenue	7.8545 (0.000)	13.563 (0.000)	12.160 (0.000)	-6.4925 (0.259)
Downstream internal technology stock/downstream sales revenue	9.0984 (0.000)	18.101 (0.000)	18.832 (0.000)	-6.1770 (0.192)
Imported technology stock/sales revenue	0.3368 (0.005)	0.2981 (0.012)	0.3041 (0.011)	0.2875 (0.020)
Imported technology stock within own 3-digit industry/3 digit sales revenue	1.1251 (0.007)	1.5766 (0.000)	1.4395 (0.001)	-0.2551 (0.599)
Upstream imported technology stock/upstream sales revenue	28.983 (0.000)	24.410 (0.000)	24.691 (0.000)	0.3050 (0.901)
Downstream imported technology stock/downstream sales revenue	-12.925 (0.000)	-20.438 (0.000)	-20.903 (0.000)	2.6559 (0.289)
(Internal technology stock/sales revenue)*(imported technology stock/sales revenue)	-3.2731 (0.000)	-3.2026 (0.000)	-3.221 (0.000)	-3.1473 (0.000)
Included dummies	None	Year	Year, Ownership	Year, Industry, Ownership

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Appendix A: The Data

The empirical tests of the hypotheses developed in this paper are based on a data set that includes approximately 1,500 large and medium-size Chinese industrial enterprises and spans the years 1999-2004. The data set combines three separate data sets that are updated annually by the National Bureau of Statistics (NBS) in China. The first is a set of economic and financial data, collected by the Bureau's Department of Industrial and Transportation Statistics, that includes all of China's approximately 22,000 large and medium-size enterprises (LMEs) over the years 1999-2004. The second data set consisting of the same firm population and including a large number of R&D measures – both innovation inputs and outputs – is maintained and updated annually by the Bureau's Department of Social and Science and Technology Statistics. These two data sets are combined with an energy data set, also maintained by the Department of Industrial and Transportation Statistics, that includes measures of approximately 20 individual energy types and aggregate measures of both the value and physical quantity of energy consumption. We derive price data from these value and quantity measures. Because this energy data set includes only the most energy intensive enterprises among the population of large and medium-size enterprises over the years 1999-2004, our combined data set includes significantly fewer observations than the two data sets from which the individual firms are drawn.

Although by combining the first two data sets with the energy data set we lose a significant number of observations, the combined data set expands our set of factor inputs from capital and labor to a full blown KLEM data set. To test the robustness of the factor bias of various technology sources and FDI, we welcome the addition of five pair-wise factor relationships in addition to the conventional capital-labor substitution possibilities. The inclusion of energy in our data set will allow us to investigate how energy fits into the pattern of factor bias in China's technology development and FDI.

Table A.1 compares levels of sales, employment, fixed assets and energy consumption in our sample (i.e., the "KLEM sample") with both total industry and with the full population of 22,000 large and medium-size enterprises. As shown, although our sample represents but one percent of the number of China's industrial enterprises with annual sales in excess of five million yuan (approximately $600,000), within this group, it captures 13 percent of industrial sales, 15 percent of industrial employment, 20 percent of industrial assets, and 40 percent of industrial energy consumption.

The NBS data set classifies enterprises into 37 industrial categories. For the purposes of this analysis, we group the 37 industrial classifications into 12 industry categories. This industry distribution is shown in Table A.2. Not surprisingly, relative to the distribution of total industry and LMEs, the energy sample includes high proportions of enterprises in the more energy-intensive industries, including the chemical and electric power industries.

Table A.1
Shares of LMEs and energy sample in aggregate industry, 1999
(% of total industry)

Measure	All industry[1]	Of which: L&M Enterprises[2]	Of which: KLEM sample
Sales (100 million yuan)	69,851 (100%)	41,166 (59%)	9,062 (13%)
Employment (10,000 persons)	4,428 (100%)	3,061 (69%)	679 (15%)
Assets[2] (100 million yuan)	71,847 (100%)	53,070 (74%)	14,428 (20%)
Energy consumption (10,000 tons of standard coal (SCE))	130,119 (100%)	90,797 (70%)	36,285 (40%)
No. of enterprises	162,033 (100%)	22,000 (14%)	1,518 (1%)

[1] Industrial state owned and non-state owned enterprises with annual sales over 5 million Yuan. Source: China Statistical Yearbook, 2000 [NBS, 2000]. [2] Original value fixed assets

The NBS data set also classifies enterprises into seven ownership classifications, consisting of state-owned enterprises and the six other non-state classifications shown in Table A.3. In 1999, our sample is largely concentrated in the state-owned sector, i.e. 62 percent of total sales in our sample originated with SOEs. This SOE ownership bias in our sample is not surprising, since a large portion of China's energy intensive firms that occupy the capital-intensive sectors are state-owned.

Table A.2

Industry distribution, 1999 (%)

Industry classification (2-digit SIC)	Total industry[1]	LMEs	KLEM sample only
Mining (06-10,12)	7,257 [4%]	829 [4%]	113 [7%]
Food and Beverage (13-16)	20,125 [12%]	2,593 [11%]	123 [8%]
Textile, apparel, and leather products (17-19)	20,784 [13%]	2,637 [12%]	93 [6%]
Timber, furniture, and paper products (20-24)	12,374 [8%]	1,332 [6%]	69 [5%]
Petroleum processing and coking (25)	988 [1%]	120 [1%]	39 [3%]
Chemicals (26-28)	15,412 [10%]	2,760 [12%]	297 [20%]
Rubber and plastic products (29-30)	7,852 [5%]	893 [4%]	28 [2%]
Non-metal products (31)	14,366 [9%]	1,699 [8%]	242 [16%]
Metal processing and products (32-34)	13,644 [8%]	1,429 [6%]	70 [5%]
Machinery, equipment, and instruments (35-37,39-42)	29,955 [18%]	6,287 [28%]	162 [11%]
Electric power (44)	4,941 [3%]	1,039 [5%]	213 [14%]
Other industry (43,45,46)	14,335 [9%]	971 [4%]	60 [4%]
Total	162,033 [100%]	22,589 [100%]	1,518 [100%]

[1] Includes all state and non-state enterprises with annual sales above 5 million yuan. Source: NBS (2000).

Table A.3

Ownership distribution, 1999 (%)

Ownership type	Total industry[1]	LMEs	KLEM sample only
State-owned	61,301 [38%]	10,451 [46%]	1,045 [69%]
Collective-owned	42,585 [26%]	3,381 [15%]	64 [4%]
Hong-Kong, Macao, Taiwan	15,783 [10%]	1,567 [7%]	64 [4%]
Foreign	11,054 [7%]	1,966 [9%]	70 [5%]
Shareholding	4,480 [3%]	4120 [18%]	263 [17%]
Private	26,830 [17%]	316 [1%]	2 [0%]
Other domestic		792 [4%]	10 [1%]
Total	162,033 [100%]	22,111 [100%]	1,518 [100%]

[1] Includes all state and non-state enterprises with annual sales above 5 million yuan.

For estimation purposes, we use the perpetual inventory method to construct stocks of technology development expenditure for each firm in our data set. The stocks are constructed as the accumulation of reported technology development expenditures minus depreciation; i.e.

$$K_{R,i,t} = (1-\delta)K_{R,i,t-1} + I_{R,i,t-1}$$

where

$K_{R,i,t}$ ≡ stock of R&D of firm i at time t;

$I_{R,i,t-1}$ ≡ flow of R&D expenditures of firm I at time t-1; and

δ ≡ depreciation rate (assumed to be 15%).

The NBS data set supplies technology development expenditures for the years 1999-2001. We estimate the initial R&D stock in 1999 as,

$$K_{R,i,1999} = I_{R,i,1999} / (\delta+\gamma)$$

where γ is the growth rate of I_R estimated as the average annual growth rate of the 2-digit industry of firm i.

Table A.4 provides input price indices and input value shares for the years 1999 and 2004, averaged over the firms in our sample**.** Overall, we find that input prices increased over the sample period across the board. The value shares of labor and energy fell slightly while materials increased and capital was unchanged. These data indicate that, relative to the other inputs, firms are, on average, economizing on energy.

Table A.4
Sample Statistics—Mean values

		1999	**2004**
Input price indices (relative to the year 1999)	Capital	1.00	1.41
	Labor	1.00	1.69
	Energy	1.00	1.06
	Materials	1.00	1.05
Input value shares	Capital	0.18	0.18
	Labor	0.08	0.07
	Energy	0.19	0.17
	Materials	0.55	0.58