Knowledge Capital, Innovation, and Growth in China

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ABSTRACT

We study the relationship between industry-level investments in intangible knowledge capital (KC) and three key economic indicators in China. We find evidence consistent with the hypothesis that investments in KC are productivity-enhancing among domestically owned and foreign invested enterprises (FIEs). Consistent with other research, we find that China's KC generates new patents, but fewer than in major industrialized economies. Finally, we find that China's comparative advantage has shifted toward those sectors where domestic firms have made larger investments in KC, but this trend appears to be independent of the KC accumulated by FIEs.

JEL Codes: O31, O33, O34, O43, P33

Key Words: Knowledge capital; technology; economic growth, intellectual property, Asia; China

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1. INTRODUCTION.

China's spectacular economic growth in the post-Mao era has been generated by a high rate of saving; dramatic improvement in the efficiency of agriculture and industry; massive reallocation of labor from farming- to the non-farm- and from rural- to the urban sectors; and adopting and adapting modern technology.[2] However, there are obvious limits to gains from resource reallocation and movement toward the world's technology frontier. Relying on these strategies alone, it is unclear whether China can safely negotiate the passage through "middle income" where many other countries become "trapped."[3]

China's future growth prospects will likely depend on (1) accumulation of physical capital and traditional human capital (an educated workforce); (2) accumulation of intangible capital; and (3) the continued institutional transformation necessary for innovation to have its full impact on productivity[4]. The analysis presented here will focus on (2), the accumulation of intangible knowledge capital (KC), as described in Corrado, Hulten, and Sichel (2005). Specifically, we focus on the accumulation of "innovative properties", which represent investments in new knowledge such as through R&D and other innovative activities. Investments in physical- and traditional human- capital are both subject to diminishing returns, and institutional transformation is probably limited to the achievement of what can be shown to be "best practice". But investment in KC is fundamental to innovation[5] that can maintain growth (or avoid decline) of total factor productivity (TFP) and avoid convergence to what may well be a "middle income trap" for China. If all investments in KC occurred within firms and generated

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[2] Representative literature documenting sources of China's post-Mao growth include Chen, Huffman, and Rozelle, 2009; Hsieh and Klenow, 2009; Jin et al., 2010; Song, et al., 2011, not to mention the excellent analyses and summaries found in Naughton (2007 and earlier work).

[3] World Bank and Development Research Center of the State Council, 2012; Cai, 2012, Zhang et al., 2013.

[4] Kuo and Yang, 2008; Fleisher, Li, and Zhao, 2010; Coase and Wang, 2012.

[5] Research and development (R&D) expenditure is linked to innovation in an immense body of literature, and it is not necessary to cite specific examples. That R&D capital is not itself subject to diminishing returns must rest on the untestable assumption that the number of potential inventions is unlimited.

no externalities, we could measure KC as an enterprise's market value less that of its physical assets. Investments in KC can occur outside the firm (through government sponsored activities, for example), and returns to investments within a firm frequently benefit other firms, and are not necessarily confined to the same industry (Sveikaulkas, 2007; Hall and Jaffe, 2012). In the analysis that follows, we use broad industry groups as the basic unit of observation in an attempt to capture some of these inter-firm spillovers and more accurately measure the economic impacts of KC.

We relate investments in KC among Chinese manufacturing industries to three measures of economic performance: (1) value of output as measured by value added (VA); (2) innovation as measured (imperfectly) by patent applications; and (3) China's comparative advantage as measured by the revealed comparative advantage (RCA) index. As previously discussed, productivity growth is essential if China is to avoid the middle income trap. Innovations, including those registered as patents, are an essential input into that productivity growth. Studying the relationship between KC and the RCA index is, in part, a recognition that China's growth has not occurred in a vacuum. If it is productive, the accumulation of KC will affect not only Chinese firms, but also firms in the rest of the world, as China's comparative advantage continues to evolve.

In the next section we overview the role of intangible knowledge capital in China's transition from a planned to a market economy. We discuss our data, present our methodology, and report our empirical results in the third section; the fourth section summarizes and concludes.

2. INTANGIBLE KNOWLEDGE CAPITAL AND INSTITUTIONAL CHANGE IN TRANSITION.

As Coase and Wang (2012) cogently note, China's true "Great Leap Forward" began in the late 1970s; grass-roots "marginal revolutions" led the way forward, harnessing China's human capital in the development of new enterprises, markets, and a product mix that began to align with the country's comparative advantages based on its human and physical resource endowments (Lin, Cai, and Li, 1996). As Yue and Hua (2002) show, China's surging exports resulted from its move toward its comparative advantage in labor-intensive production in its fastest-growing provinces. A natural outcome of this success has been the increasing scarcity of "cheap" labor and wage acceleration in coastal provinces, as discussed in recent special issues of

China Economic Journal and China Economic Review (Huang and Cai, 2010; Ge and Yang, 2012; Fleisher et al., 2011). Two results of increasing relative scarcity of labor have been: (1) industries dependent on low-cost labor have tended to relocate inland--to areas where outmigration has not yet depleted the stock of low-skilled workers (Ge and Yang, 2011); (2) firms in high(er)-wage locations have shifted toward products and methods relying more heavily on skilled workers, physical capital, and intangible knowledge capital (United States NSF, 2010).

Hulten and Hao (2012) show that investment in these types of intangible assets has been increasing in China over the past two decades. They employ a growth accounting framework to show that KC investment accounted for 7.47% of China's GDP in 2006, compared to 3.79% in 1990. This upward trend largely reflects rapid growth in investments in computerized information and innovative properties (specifically, designs and R&D). They also find that investment in KC accounted for approximately 1/6th of GDP growth for the period 2000 to 2008. While concerns over the quality of Chinese data complicate international comparisons, Hulten and Hao (2012) also compare China's share of intangibles in the total output of the market sector vs. a set of developed countries. The results indicate that China's stock of KC is low relative to developed countries. While investment in KC accounted for 7.06% of the output of China's market sector, this falls below what is observed in technologically developed countries like the U.S. (10.35%), Japan (10.19%) or the U.K. (9.67%). They also find that China also lags in terms of the share of labor productivity growth attributable to KC. Only 17% of the growth in labor productivity between 2000 and 2006 was accounted for by investment in intangibles. This is well below the levels in the U.S. (30%) and the U.K. (26%), but compares favorably with Japan (16%).

Our work differs from that of Hulten and Hao (2012) in several respects. First, they employ a growth accounting methodology, which proceeds from a strong theoretical model to impute key parameters of the production function from aggregate data. We are also interested in in identifying these parameters, but we estimate them using variation in the relevant data across China's industries. This allows us to measure the contributions of capital, labor, and KC to output without imposing such strong assumptions on the specification of the production function. Our analysis also expands beyond the analysis of growth to investigate the role of KC in the production of new innovations, as measured by patent applications. This analysis presented here follows the work reported by Hu, Jefferson, and Qian (2005) (henceforth HJQ) and Hu and

Jefferson (2009). In these studies, the authors used firm-level data from the period 1995-2001 to show that R&D investments made by domestic and foreign firms in China led to productivity growth and a greater propensity to patent. We extend their analysis by studying productivity and patent effects in China's post-WTO period (up to 2007). We also provide the first evidence of the role of KC in determining China's comparative advantage.

3. DATA, METHODOLOGY, AND EMPIRICAL RESULTS.

Our data are industry aggregates reported in China's Statistical Yearbook and Statistical Yearbook on Science and Technology. As stated above, we are most interested in the component of KC known as innovative property. We measure investments in innovative property using data on industrial expenditures on Science and Technology (S&T). China's National Bureau of Statistics broadly defines science and technology as "…activities closely related with the creation, development, dissemination and application of scientific and technical knowledge." (NBS, 2008) This definition encompasses "…research and development (R&D), the application of R&D results, and related S&T activities." (NBS, 2008) These expenditures include, among others, payments to workers engaged in S&T activities, as well as purchases of raw materials and fixed assets for S&T activities. Following the literature (Hall, 2007), we measure the KC stock as accumulated annual flows of total S&T expenditures depreciated at 15% per year[6].

3.1 Overview of KC and Physical Capital.

[Table 1 here]

Table 1 presents our data for the S&T stock and tangible physical capital stock among FIE's and domestically owned enterprises, by major industry group, for 1998 and 2007. Columns (2a), (4a), (6a), and (8a) show the ratio of the KC stock to physical capital stock for FIE's and for domestic enterprises, respectively, in 1998 and 2007. The S&T/physical capital ratio varies considerably across industries and is higher for enterprises without foreign

[6] The initial stock is set as annual flow in 1998 multiplied by 5. While the 15% depreciation rate is common in literature following the seminal papers of Griliches (1980 and earlier), it is not a measure that is robust to alternative and reasonable methods of estimating it (Hall, 2007), and estimation results based on the assumed 15% depreciation rate should be evaluated accordingly.

involvement than for foreign-invested enterprises (FIE's). In most cases, the S&T/physical capital ratio rose between 1997 and 2007. This is presented graphically in figure 1.

[Figure 1 here]

3.1.1 Industry dispersion of the KC/physical capital ratio over time

The growth of the real S&T and physical capital stocks between 1998 and 2007 for each industry group is depicted in figure 2. Both the aggregate levels of S&T and physical capital increased substantially over the 1998-2007 period, at about the same rates, so that the ratio of KC to physical capital is only slightly higher in 2007 than in 1998 for both domestic and foreign-invested enterprises in the aggregate. However, the aggregates conceal substantial dispersion across industries, even if we overlook Petroleum and Other Fuels, where FIE's were encouraged to invest heavily in order to help China develop its domestic energy resources. For example, for electrical machinery and equipment, the ratio of the stock of physical capital in 2007 to that in 1998 is 2.7 for FIE's and 2.3 for domestic enterprises, while the corresponding ratios for S&T stock is approximately 3.4 for each ownership category. In contrast, for the electronic machinery and equipment industry, the FIE physical capital stock grew by over five-fold between 1998 and 2007, somewhat less than the 6-fold increase for domestically owned enterprises. But the S&T stock grew by much more, both proportionately and in absolute magnitude, for FIEs than for domestically owned enterprises.

[Figure 2 here]

3.1.2 Change Over Time in the Share of FIEs in Production and KC Stock

Figures 3a and 3b compare change over time in the share of FIEs in total industry production and change over time in the share of FIEs in total industry S&T stock. We are interested to see whether the influx of foreign direct investment into China has brought with it new emphasis on investing in KC. The vertical axis measures the share of FIEs in total industry S&T stock in the year 2001 divided by the share in 1998; the horizontal axis measures the share of FIEs in total industry production in the year 2001 divided by the share in 1998. Figure 3b shows the same variables, but the ratios are for the year 2007 divided by the year 2001. The figures therefore represent China's pre- and post-WTO trading regimes, respectively. Figure 3a .1 includes the outlying Petroleum and Fuels industry (mentioned above), while figure 3a.2 shows the scatter with Petroleum and Fuels excluded. Comparing figures 3a.2 and 3b we see wider dispersion in the growth of the FIE share in total S&T stock across major industry groups (the y-axis dispersion of the plotted points) in the period following China's accession to the WTO. In the pre-WTO period, the scatter of FIE share in total S&T change clusters around unity (excluding Petroleum and Fuels), while in the post-WTO period, the share of FIE's in total S&T change varies between approximately 0.9 to almost 2.3 (for Textiles and Clothing). We take this change as evidence that foreign investors began to concentrate more on a specific sub-set of industries in China following WTO accession.

[Figure 3a here]

[Figure 3b here]

3.1.3 FIE versus Domestic Enterprise KC Growth

Figures 4a and 4b compare the growth of industry S&T stock among FIE's with that of domestic enterprises. The standard deviation of the 2001/1997 ratio is 0.25 among FIEs (excluding Petroleum and Fuels) compared to 0.22 among domestic enterprises. Dispersion of the 2007/2001 ratio is greater than the 2001/1997 ratio for both ownership categories—0.59 for FIEs and 0.42 for domestic enterprises, rising by a ratio of about 2.3 for FIE's compared to about 1.9 for domestic enterprises. Moreover, the correlation between the cross-industry growth rates of FIEs and domestic enterprises is negative in the post 2001 period compared to the positive correlation over the pre-WTO period (negligible if Petroleum and Fuels were included). The negative correlation between FIE and domestic enterprise S&T stock growth after 2001 suggests that some kind of sorting was taking place.

[Figure 4a here]

[Figure 4b here]

4. METHODOLOGY AND EMPIRICAL RESULTS.

Our aim is to identify KC's impact on indicators of innovation, productivity, and comparative advantage in China. These indicators are productivity as reflected in a value-added production function, patent applications[7], and the RCA index.

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[7] We note that patent applications are an imperfect measure of successful innovation, especially when lax and variable enforcement of IPR legislation can increase the likelihood that inventions are copied illegally. A substantial body of research finds that patent protection has not seemed essential to the introduction of a significant number of innovations, and that the impact of patent

4.1 Productivity

Our approach to estimating the impact of KC in China on productivity is to estimate the production function:

$$Y_{(i,t)} = A_{(i,t)} L_{(i,t)}^{\alpha} K_{(i,t)}^{\beta} S\&T_{(i,t-1)}^{\theta} e^{u_{(i,t)}} \quad (1)$$

where $Y_{(i,t)}$ represents industry value added, $L_{(i,t)}$ is the industry labor force, $K_{(i,t)}$ is the industry physical capital stock, measured as the net value of fixed assets, $S\&T_{i,t-1}$ is the stock of accumulated investments in S&T, and the subscripts i and t denote industry and year, respectively. Note that we employ lagged values of the S&T stock on the right-hand side in order to address potential concerns over endogeneity with TFP in year *t*. As previously discussed, the S&T stock is calculated as the depreciated sum of expenditures on science and technology (S&T) by China's large and medium enterprises (LME), as recorded in China's Statistical Yearbooks. In year *t*, the S&T stock of a given industry is calculated as:

$$S\&T_{(i,t)} = S\&TExpenditures_{(i,t)} + 0.85 * S\&T_{(i,t-1)} \quad (2)$$

The S&T stock for 1999[8], the first year in our estimation sample, was calculated as five times the total S&T expenditures in that year. We also estimate an additional specification that separates out the labor, fixed asset, and 'other' components of the S&T stock as described in greater detail in the discussion of our empirical results and in notes to table 2.

We assume the error term can be rewritten as:

$$u_{i,t} = \gamma_i \delta_t \varepsilon_{i,t}$$

where the γ_i capture unobserved industry characteristics and δ_t captures unobserved characteristics of a given year, constant across all industries. The term $\varepsilon_{i,t}$ is an iid error term. Empirically, we estimate the production function in its log transformation:

$$y_{(i,t)} = a_{(i,t)} + \alpha l_{(i,t)} + \beta k_{(i,t)} + \theta s\&t_{(i,t-1)} + \gamma_i + \delta_t + \varepsilon_{i,t} \quad (3)$$

Note that we use the lagged value of the S&T stock to estimate (3). This is to address possible concerns about endogeneity, to the extent that the S&T stock might be correlated with industry

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protection on innovation and the number of patents varies widely across industries (Mansfield, Schwartz, and Wagner, 198a; Levin, Klevorick, and Nelson, 1988; Arundel, 2001; Moser, 2005.)

[8] Our estimation sample is restricted to the years 1999-2007 because the earlier statistical yearbooks did not separately report components of total S&T expenditures included in our regression models.

unobservables in the current year. We also suspect there might be a lag between the accumulation of KC and its effect on productivity. The results are reported in Table 2.

[Table 2 here]

We also estimate the production function using the estimation routine described in Levinsohn and Petrin (2003), hereafter L-P. This approach allows us to address concerns about endogeneity while still exploiting cross-sectional variation to estimate the model parameters. We use an industry-level measure of energy consumption, expressed in 10,000 tons of standard coal equivalent, to proxy for unobservable productivity shocks. These results are reported in Table 3.[9]

[Table 3 here]

In columns (2) – (6), labor and capital stocks are net of those inputs reported as used for S&T activities. Capital Stock is the net value of fixed assets for the industry reported by the NBS minus our constructed measure of S&T Capital Stock. Labor is the total employment in the industry minus the number of workers employed for S&T activities (S&T Labor). Column 2 of Table 2 shows the estimated elasticity of value added with respect to total S&T stock. The coefficient implies that a one percent increase in the S&T stock is associated with a 0.26% increase in industry value-added. In column (3), the S&T stock is net of expenditures on S&T labor and S&T capital[10], and the (lagged) S&T capital stock and S&T labor are included as separate regressors. The relationship between S&T and value added is less clear in this specification. The estimated coefficient on S&T capital stock is positive while that on S&T labor is negative, though both are only marginally significant. The estimated coefficient on adjusted S&T expenditures is insignificant. In column (4), we report results of a specification in which expenditures on S&T labor are capitalized in the same manner as expenditures on S&T described previously. Substituting the capitalized expenditures on S&T labor in column (4) yields estimates similar to those in column (3), although capitalized S&T labor is now statistically insignificant, and the coefficient on the adjusted S&T stock has decreased in magnitude and

[9] We also estimated the production function in per worker form. The results were nearly identical to those presented in Table 2, so they are not presented here.

[10] The NBS data do not provide a clear explanation of what is included in these "net" S&T expenditures. It includes purchases of raw materials for S&T activities as well as any other expenditure not recorded as a payment for labor or the purchase of fixed assets.

significance. Finally, columns (5) and (6) report estimation results separately for domestically owned firms and FIEs. The results for domestic firms in column (5) are similar to the aggregate results reported in column (2), except that the estimated coefficient on the capital is smaller in magnitude. The results for FIEs in column (6) yield no evidence of a significant correlation between S&T stock and value added.

In order to address concerns over endogeneity bias in the estimation of production function parameters, we estimate each specification in Table 2 using the Levinsohn Petrin (L-P) estimator and report these results in Table 3. Because total energy use is not recorded for the LME sample, we take data on energy use from industry aggregates for firms "above designated size" (ADS), as identified by the NBS. The S&T stock employed in this specification is still calculated using expenditures on S&T by firms in the LME sample.[11] The variable industry-specific energy usage allows us to drop the industry dummies to control for industry-specific productivity shocks. Thus the L-P estimator allows us to exploit cross-sectional variation in the data not available in the FE procedure to estimate the model parameters. These results are presented in Table 3. Once again, the labor and capital stock variables used in columns (2) – (6) are adjusted to avoid double-counting the inputs used for S&T activities. Comparing column (1) between Table 1 and Table 2, we see that the estimated coefficient on labor is slightly larger while the estimated coefficient on the capital stock is unchanged, but less precisely estimated. Comparing column (1) and (2) in Table 3, the estimated coefficients on labor and capital are reduced in magnitude and level of statistical significance. This may be due to the introduction of measurement error in the process of adjusting the labor and capital stock variables to avoid double-counting with the inclusion of the S&T stock in the same regression. Although the labor and capital stocks are calculated using data from the ADS sample, they are adjusted using data from the LME sample. The coefficient on total S&T stock is positive and significant at the 5% level, and it implies that a one percent increase in S&T stock is associated with a 0.32% increase in value added, similar to what we found in the two-way fixed effect estimator. It is encouraging to note that with all three inputs included, the input elasticities sum to 1.11, and the sum is not significantly different from 1.0 (p=0.82), consistent with constant returns to scale at the industry level, which we find plausible.

[11] S&T data are not available for the ADS sample.

In Table 3, the estimated coefficient on adjusted S&T stock is larger in column (3) than in column (2), but imprecisely estimated. The estimates for S&T capital and labor are also statistically insignificant. When S&T labor is capitalized (column (4)), the estimated coefficient of adjusted S&T stock declines in magnitude and significance, while that of S&T capital and capitalized labor remain insignificant. Finally, in columns (5) and (6), we estimate separate regressions for domestically-owned firms and FIEs. The results indicate a positive relationship between S&T and value added for both firm types, though the marginal affect appears to be larger for domestic firms.

It is interesting to compare our production function estimation results with those of HJQ. Their study is based on the micro data for LMEs that underlie our industry aggregates; their data cover the period 1995 through 1999, while ours encompass the period 1998 through 2007. HJQ's estimates are based on a very large sample of over 10,000 enterprises, while ours are based on similar data aggregated into industry level variables[12]. As do HJQ, we use time- and industry fixed effect estimation to estimate the effect of S&T on production. HJQ also introduce a dummy variable for enterprise ownership (foreign or domestic). HJQ include an R&D stock variables constructed similarly to our measurement of S&T, but they also include measures of purchased technology (license fees to use patented technology and so on), which they also measure as a stock subject to depreciation. Their production elasticities for physical capital and labor are 0.46 and 0.54, respectively, in OLS estimation that also includes terms for purchased technology and in-firm KC. These elasticities are quite close to those we report in Table 2 and 3, though our estimated labor elasticity is generally lower. HJQ also report OLS estimates for domestic and foreign-invested enterprises separately. They find a higher production elasticity for labor among domestic firms (0.35) compared to FIES (0.10), as well as a higher production elasticity for capital among FIEs (0.70) compared to domestic firms (0.51). Our results in Table 2 reflect the higher production elasticity of capital for FIEs ($p = 0.00$), but we are unable to reject the equivalence of our estimated labor elasticities for FIEs and domestic firms ($p = 0.48$).

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[12] We use the broadest possible cross-section of industries in each regression model. Changes in the number of industries or years covered reflects the unavailability of data from the Statistical Yearbooks.

In their production function estimates, HJQ report positive, significant estimated elasticities for R&D stock (not differentiated by ownership), a positive, significant elasticity for technology stock purchased from foreign enterprises and a negative, significant elasticity for technology stock purchased from domestic enterprises. Although, methodological differences make it difficult to directly compare our point estimates to theirs, we note that their estimated elasticity of value-added with respect to R&D stock ranges between 0.007 and 0.029 in pooled samples, while our estimated elasticity for S&T stock is 0.26 using the two-way fixed effects estimator and 0.32 using the L-P estimator. This could imply that production in China has become more S&T-intensive since the period studied by HJQ, or it may indicate the presence of substantial intra-industry spillovers from investment in S&T, which were not studied in HJQ.

4.2 Patent applications

Our approach to patent applications follows that of Hu and Jefferson (2009) in that we estimate parameters of a "patent production function" in which an input is the S&T stock. It has been shown that patent applications are well described with a Poisson process, which describes the number of occurrences of an event in a given time interval (Hausman et al. 1984). For patent panel data measured, there is a further issue concerning over-dispersion, whereby the conditional variance exceeds the conditional mean (Hausman et al. 1984; Cincer 1997). Thus, we use a negative binomial model to estimate the following patent production function with year- and industry fixed effects:

$$Applications_{(i,t)} = f\left(S\&T_{(i,t-1)}, L_{(i,t-1)}\right) \tag{4}$$

where S&T is as defined previously, and l (industry labor force) is included to capture scale effects that may be important in explaining the propensity to patent in an industry (Hu and Jefferson, 2009).

Estimation results for the patent application model are presented in Table 4. Once again, our data are industry aggregates of the firm-level data for Large and Medium Enterprises (LME's) and cover the period 2001 through 2007, compared to the period 1995 through 2001 in Hu and Jefferson (2009).

[Table 4 here]

We emphasize the results for invention patent applications by domestically-owned enterprises, which we define as "domestic invention patents". Our regressors are similar to those of Hu and Jefferson (2009), except that we do not include a quadratic term for S&T expenditures. As in the case of the value added production function, we report estimation results for specifications that include the adjusted S&T stock, S&T labor, S&T capital stock, and capitalized S&T labor expenditures, as well as specifications including the unadjusted S&T stock. Despite the differences in time period covered and in specification, our estimation results tell a story similar to that of Hu and Jefferson (2009). Column (1) shows that total S&T stocks are positively associated with the rate at which domestic firms in an industry file for patents. Specifically, a 1% increase in S&T stock is associated with a 0.07% increase in the number of patent applications filed, evaluated at the sample mean. Hu and Jefferson (2009) report the same patent elasticity evaluated at their sample median, but find a substantially larger patent elasticity (0.3) evaluated at their sample mean. The coefficient of labor (adjusted to remove S&T personnel) does not indicate a significant scale, or industry size, effect on patent applications. In column (2), we see that decomposing the S&T stock using the same procedure reported for the production function results in a substantial decline in estimation precision. In column (3), we substitute capitalized S&T labor expenditures for S&T employment, and the results are similar to those in column (2). Finally, columns (4) and (5) show the results for patent applications by domestic firms and FIEs, respectively. We include both domestic and FIE S&T stock in each regression, to test for possible spillover or demonstration effects. In column (5), we see evidence of positive scale effects and an estimated patent elasticity of 0.09 for domestic firms. We find no evidence that S&T activities among FIEs affect the patenting behavior of domestic firms. In column (6), we find no evidence that patenting by FIEs is related to S&T stock in China.

4.3 Comparative Advantage

Finally, we examine the relationship between S&T stock and China's revealed comparative advantage (RCA) (Balassa, 1965). RCA is a measure of the share of a Chinese industry's exports in the nation's total exports relative to the corresponding measure for total world exports. The RCA index for industry *i* in country *c* vs the rest of the world *w* is:

$$RCA_i = \frac{X_{i,C}/X_C}{X_{i,W}/X_W} \tag{5}$$

An RCA index greater than one implies that the industry's share of total exports from *C* to the rest of the world exceeds the industry's share in total world exports. This "reveals" the country's comparative advantage in good *i.* Figures 5a and 5b illustrate the relationship between the change in S&T stock and the change in the RCA index, by industry, over our sample period for domestic and foreign-invested enterprises, respectively. The figures illustrate a striking contrast between S&T investments by domestic and FIE enterprises. For textiles and clothing, for example, the S&T stock of domestically owned enterprises increased by much less than the industry average, between 2001 and 2007, while FIEs increased their S&T stocks over four-fold. At the same time, China's RCA in textiles and clothing plummeted by almost one-half. In contrast, China's RCA index nearly doubled in the electrical machinery and the electronic and communication equipment industries, while its S&T stock in those industries more than doubled in the 2001-2007 period. A simple trend line suggests that China was increasing its relative share of world exports in those industries that saw large accumulations of KC by domestic firms. FIE investments in S&T were (weakly) associated with industries that put a stronger focus on the domestic (Chinese) market.

[Figure 5a here]

[Figure 5b here]

To more formally explore the relationship between S&T and an industry's RCA index, we estimate the following model:

$$RCA_{(i,t)} = f\left(LaborIntensity, CapitalIntensity, S\&T_{(i,t-1)}\right) \quad (6)$$

where S&T is defined as above. We also include two variables to capture the physical factor intensity of each industry (Lee, 1986). These are *Labor Intensity*, which is the ratio of industrial employment to value-added, and *Capital Intensity*, the ratio of industrial net value of fixed assets to value-added. The period covered is 2001 to 2007. The estimation results will allow us to identify the characteristics of those industries in which China has a revealed comparative advantage. These results are presented in Table 5. Across every specification, the estimated coefficient on *Labor Intensity* is positive and significant at the 5% level, while the coefficient on *Capital Intensity* is negative but statistically insignificant. These results support the commonly-held belief that China enjoys a comparative advantage in relatively labor intensive sectors. The results in column (1) show that a 1% increase in industrial S&T stock is associated with an approximately 0.1% increase in the industry's RCA index. In column (2), we report estimation results for adjusted S&T, S&T labor, and S&T capital as defined previously. In this specification, we estimate a significant, positive relationship between RCA and adjusted S&T stock, but the estimated coefficients on the S&T Capital Stock and Labor are insignificant. In column (3), we replace S&T Labor with capitalized S&T labor expenditures. The results are similar to those in column (2). In the estimates reported in column (4), the total S&T stock is divided into its domestic and FIE components. We find that a 1% increase in S&T stock among domestic firms is associated with a 0.1% increase in the RCA index, while there appears to be no relationship between RCA and FIE S&T stock. These estimated coefficients are qualitatively consistent with the patterns observed in Figures 5a and 5b, although they fall short of encompassing the outliers. China's comparative advantage has apparently shifted toward those industries that have accumulated greater stocks of knowledge capital. However, this result seems to reflect the KC accumulated by domestic firms, and not FIEs. This is consistent with the idea that FIEs have focused their innovative activities on adapting to the Chinese market, rather than competing in world markets.

[Table 5 here]

5. SUMMARY AND CONCLUSIONS.

Our results are based on data of large and medium enterprises aggregated by industry, covering the period from 1998 through 2007. They are broadly consistent with results reported by Hu, Jefferson, and Qian (2005) and by Hu and Jefferson (2009) whose work relies on micro data of large and medium enterprises through 2001, prior to China's entry into WTO. Using industry aggregates allows us to capture important intra- and inter-industry spillovers, which were not identified in this previous work. Our results support the hypothesis that domestic KC, measured as the depreciated stock of expenditures on science and technology, has led to increases in productivity following China's WTO accession. Using the L-P estimator, we find some evidence that FIE investments in KC increased productivity in the period following China's accession to the WTO and adoption of the TRIPS protocol, though this effect does not appear to be as large as that for domestic firms. Domestic investments in KC also lead to increases in patented technology among domestic firms, while the "demonstration effect" of foreign KC noted by Hu and Jefferson (2009) is not evident in our estimation results. We find it noteworthy that China's revealed comparative advantage has shifted toward those sectors in which domestic firms have accumulated large stocks of KC. This suggests a change in China's comparative advantage in favor of technology-intensive industry. Exploring the implications of these trends for China and the rest of the world should provide direction for interesting further research.

As Hamilton and Liu (2013) suggest, intangible wealth is an important and elusive component of the total capital of the world's higher-income countries. The growth of the KC stock of both domestically-owned and foreign-invested enterprises in China has increased sharply since China joined in TRIPS protection of intellectual capital and entered WTO. The positive returns we find to investments in KC suggest that, to maintain its economic growth, China should reinforce its development of an institutional and legal framework that assures adequate protection for innovators and encourages the spread of domestically produced new technology.

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Tables and Figures

Table 1
Comparison of Physical and Knowledge Capital Stocks

	Foreign Invested Enterprises						Domestic Enterprises				
	Capital	S&T	Capital	S&T	Capital Stock	S&T Stock	Capital	S&T	Capital	S&T	S&T Stock
	Stock	Stock	Stock	Stock	Growth	Growth	Stock	Stock	Stock	Stock	Growth
Industries	1998	1998	2007	2007	2007/1998	2007/1998	1998	1998	2007	2007	2007/1998
Food and Tobacco	456.35	8.44	870.05	43.01	1.91	5.10	1094.62	68.86	1707.03	186.21	2.70
Textiles, Clothing, Etc.	410.71	11.79	984.67	42.25	2.40	3.58	806.02	110.09	1689.34	160.23	1.46
Timber, Wood, Furniture.	193.95	5.52	740.88	33.26	3.82	6.03	229.77	33.78	1095.69	58.6	1.73
Printing and Recorded Media	90.53	2.63	213.61	9.96	2.36	3.79	109.02	7.61	244.15	15.23	2.00
Petroleum and other Fuels	36.4	0.28	256.97	5.9	7.06	21.07	856.76	43.19	1447.18	75.91	1.76
Chemical Raw Materials and Products	242.52	15.62	1,117.19	49.13	4.61	3.15	1290.98	178.73	2511.83	378.01	2.11
Pharmaceuticals	69.51	9.64	213.1	42.65	3.07	4.42	199.39	37.72	544.41	126.11	3.34
Chemical Fibers, Rubber, Plastic	384.14	21.7	816.78	57.7	2.13	2.66	663.43	63.24	1125.21	139.89	2.21
Mineral, Ferrous, Nonferrous Materials	604.63	44.13	1,740.02	98.16	2.88	2.22	2927.43	269.44	7470.11	870.64	3.23
General Purpose Machinery	490.52	97.3	1,953.01	348.29	3.98	3.58	1712.97	545.73	3452.66	1022.84	1.87
Electrical Machinery, Equipment	217.22	33.56	594.99	118.22	2.74	3.52	404.72	109	916.71	379.5	3.48
Electronic Machinery, Equipment	431.55	86.92	2,338.46	511.87	5.42	5.89	424.99	128.56	2533.71	455.79	3.55

[a]Capital Stock and S&T Stock (100,000,000 yuan at 1990 prices)

Table 2
Production Function Estimates: Two-Way Fixed Effects

	(1) Log VA	(2) Log VA	(3) Log VA	(4) Log VA	(5) Log Domestic VA	(6) Log FIE VA
Log Labor	0.21***	0.23**	0.29***	0.25**	0.32***	0.31***
	(0.07)	(0.02)	(0.01)	(0.01)	(0.00)	(0.00)
Log Capital Stock	0.60***	0.50***	0.52***	0.53***	0.32**	0.76***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Log S&T Stock (t-1)		0.26**			0.34**	0.02
		(0.04)			(0.02)	(0.28)
Log Adj. S&T Stock (t-1)			0.12	0.06		
			(0.31)	(0.64)		
Log S&T Capital Stock (t-1)			0.21*	0.23*		
			(0.07)	(0.06)		
Log S&T Labor (t-1)			-0.14*			
			(0.07)			
Log S&T Wage Stock (t-1)				-0.05		
				(0.64)		
Observations	213	213	213	213	213	213
R-squared	0.88	0.90	0.90	0.90	0.89	0.91
Industry FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES

[a]Data for the models in columns (1)-(6) are industry aggregates for the Large and Medium Enterprise (LME) sample reported by China's National Bureau of Statistics for the years 1999-2007.
[b]The number of industries included in the sample is 36.
[c]Data on S&T expenditures are taken from recorded total expenditures on Science and Technology by LME firms in China's Statistical Yearbook.
[d]Values in parentheses are p-values calculated using robust standard errors.
[e]Significance levels ***, **, and * are p<0.01, 0.05, and 0.1, respectively.
[f]Value Added is the value added by firms in the LME sample in 1999 prices
[g]Labor is the total workforce employed by firms in the LME sample.
[h]Capital Stock is the net value of fixed assets for firms in the LME sample in 1999 prices.
[i]Labor and Capital Stocks in columns 2-6 are adjusted to remove any labor or capital used for S&T activities.
[j]S&T Stock in 1999 is calculated as five times the expenditures on S&T in that year. S&T Stock in subsequent years is calculated by adding deflated S&T expenditures in year *t* to the stock in year *t-1*, discounted at 15%.
[k]Adjusted S&T Stock is calculated by subtracting wages paid to S&T workers and purchases of fixed assets for S&T from total S&T expenditures. These adjusted S&T expenditures are then accumulated as with S&T stock.
[l]S&T Capital Stock in 1999 is calculated as five times the expenditures on fixed assets for S&T in that year. S&T Capital Stock in subsequent years is calculated by adding deflated expenditures on fixed assets for S&T in year *t* to the stock in year *t-1*, discounted at 15%.

Table 3
Levinsohn – Petrin Production Function Estimates

	(1) Log VA	(2) Log VA	(3) Log VA	(4) Log VA	(5) Log Domestic VA	(6) Log FIE VA
Log Labor	0.34**	0.28	0.29*	0.26	0.22	0.30***
	(0.03)	(0.11)	(0.07)	(0.11)	(0.32)	(0.00)
Log Capital Stock	0.61	0.51	0.54	0.53	0.63*	0.57***
	(0.15)	(0.21)	(0.26)	(0.20)	(0.05)	(0.00)
Log S&T Stock (t-1)		0.32**			0.23*	0.13***
		(0.03)			(0.07)	(0.00)
Log Adj. S&T Stock (t-1)			0.41	0.26		
			(0.12)	(0.47)		
Log S&T Capital Stock (t-1)			-0.03	-0.01		
			(0.91)	(0.98)		
Log S&T Labor (t-1)			-0.13			
			(0.45)			
Log S&T Wage Stock (t-1)				0.04		
				(0.90)		
Observations	170	170	170	170	170	170

[a]Data for the models in columns (1)-(6) are industry aggregates for the Above Designated Size (ADS) sample reported by China's National Bureau of Statistics for the years 1999-2007.
[b]The number of industries included in the sample is 36.
[c]Data on S&T expenditures are taken from recorded total expenditures on Science and Technology by LME firms in China's Statistical Yearbook.
[d]Values in parentheses are p-values calculated using robust standard errors.
[e]Significance levels ***, **, and * are $p<0.01$, 0.05, and 0.1, respectively.
[f]Value Added is the value added by firms in the LME sample in 1999 prices
[g]Labor is the total workforce employed by firms in the LME sample.
[h]Capital Stock is the net value of fixed assets for firms in the LME sample in 1999 prices.
[i]Labor and Capital Stocks in columns 2-6 are adjusted to remove any labor or capital used for S&T activities.
[j]S&T Stock in 1999 is calculated as five times the expenditures on S&T in that year. S&T Stock in subsequent years is calculated by adding deflated S&T expenditures in year *t* to the stock in year *t-1*, discounted at 15%.
[k]Adjusted S&T Stock is calculated by subtracting wages paid to S&T workers and purchases of fixed assets for S&T from total S&T expenditures. These adjusted S&T expenditures are then accumulated as with S&T stock.
[l]S&T Capital Stock in 1999 is calculated as five times the expenditures on fixed assets for S&T in that year. S&T Capital Stock in subsequent years is calculated by adding deflated expenditures on fixed assets for S&T in year *t* to the stock in year *t-1*, discounted at 15%.

Table 4
Invention Patents

	(1) Invention Patents	(2) Invention Patents	(3) Invention Patents	(4) Domestic Invention Patents	(5) FIE Invention Patents
Labor	0.11	0.03	0.10	0.29*	0.11
	(0.13)	(0.73)	(0.61)	(0.07)	(0.69)
S&T Stock (t-1)	0.07*				
	(0.11)				
Adj. S&T Stock (t-1)		0.16	0.19		
		(0.26)	(0.22)		
S&T Capital Stock (t-1)		-0.15	-0.17		
		(0.41)	(0.61)		
S&T Labor (t-1)		0.08			
		(0.37)			
S&T Wage Stock (t-1)			-0.01		
			(0.98)		
Dom. S&T Stock (t-1)				0.09**	0.09
				(0.03)	(0.77)
FIE S&T Stock (t-1)				-0.02	0.15
				(0.63)	(0.63)
Observations	200	200	200	200	200
Industry FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

[a]Data for the models in columns (1)-(4) are industry aggregates for the LME sample reported by China's National Bureau of Statistics for the years 2001-2007.
[b]The number of industries included in the sample is 29.
[c]Data on S&T expenditures taken from recorded total expenditures on Science and Technology by Large and Medium Enterprises in China's Statistical Yearbook.
[d]S&T stock in 1999 was calculated as five times the flow in that year. S&T stock in subsequent years is calculated by adding the flow in year *t* to the stock in year *t-1*, discounted at 15%.
[e]Values in parentheses are p-values calculated using standard errors estimated with a jackknife procedure
[f]Significance levels ***, **, and * are p<0.01, 0.05, and 0.1, respectively.
[g]Coefficients in columns (1) - (5) are elasticities evaluated at the sample means.
[h]Elasticities could not be calculated for the specification in column (6), so these coefficients represent the effect of a change in the log of the regressor on the log of the expected count of patents.
[i]Labor is the total workforce minus workers used for S&T activities.
[j]Adjusted S&T Stock is the total S&T Stock minus payments to S&T Labor and the value of fixed assets used for S&T.
[k]S&T Capital Stock in 1999 is calculated as five times the expenditures on fixed assets for S&T in that year. S&T Capital Stock in subsequent years is calculated by adding deflated expenditures on fixed assets for S&T in year *t* to the stock in year *t-1*, discounted at 15%.
[l]S&T Wage Stock in 1999 is calculated as five times the wages paid to S&T personnel in that year. S&T Wage Stock in subsequent years is calculated by adding deflated wages paid to S&T personnel in year *t* to the stock in year *t-1*, discounted at 15%.
[m]S&T Labor is the total workforce used for S&T activities by firms in the LME sample.

Table 5
RCA Model Results

VARIABLES	(1) RCA	(2) RCA	(3) RCA	(4) RCA
Labor Intensity	0.87**	0.86**	0.85**	0.88**
	(0.03)	(0.03)	(0.03)	(0.03)
Capital Intensity	-0.32	-0.31	-0.33	-0.30
	(0.19)	(0.17)	(0.17)	(0.21)
S&T Stock (t-1)	0.09***			
	(0.00)			
Adj. S&T Stock (t-1)		0.24*	0.19*	
		(0.08)	(0.08)	
S&T Capital Stock (t-1)		-0.17	-0.15	
		(0.29)	(0.34)	
S&T Labor (t-1)		-0.06		
		(0.70)		
S&T Wage Stock (t-1)			0.02	
			(0.69)	
Dom. S&T Stock (t-1)				0.10*
				(0.06)
FIE S&T Stock (t-1)				0.01
				(0.74)
Observations	156	156	156	156
R-squared	0.21	0.16	0.19	0.20
Industry FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

[a]Data for the models in columns (1)-(4) are industry aggregates for the LME sample for the years 2001-2007.
[b]The number of industries included in the sample is 26.
[c]Coefficients reported above are elasticities evaluated at sample means.
[d]Values in parentheses are p-values calculated using robust standard errors.
[e]Significance levels ***, **, and * are p<0.01, 0.05, and 0.1, respectively.
[f]Labor Intensity is the ratio of total non-S&T employment to value added, in 1999 prices.
[g]Capital Intensity is the ratio of the net value of fixed assets not used for S&T to value added, in 1999 prices.
[h]Data on S&T expenditures taken from recorded total expenditures on Science and Technology by Large and Medium Enterprises in China's Statistical Yearbook.
[j]S&T Stock in 1999 is calculated as five times the expenditures on S&T in that year. S&T Stock in subsequent years is calculated by adding deflated S&T expenditures in year *t* to the stock in year *t-1*, discounted at 15%.
[k]Adjusted S&T Stock is calculated by subtracting wages paid to S&T workers and purchases of fixed assets for S&T from total S&T expenditures. These adjusted S&T expenditures are then accumulated as with S&T stock.
[l]S&T Capital Stock in 1999 is calculated as five times the expenditures on fixed assets for S&T in that year. S&T Capital Stock in subsequent years is calculated by adding expenditures on fixed assets for S&T in year *t* to the stock in year *t-1*, discounted at 15%.
[m]S&T Labor is the total labor used in the industry for S&T activities.
[n]S&T Wage Stock in is 1999 calculated as five times the wages paid to S&T personnel in that year. S&T Wage Stock in subsequent years is calculated by adding wages paid to S&T personnel in year *t* to the stock in year *t-1*, discounted at 15%.
[o]Dom. S&T Stock and FIE S&T Stock refer to the S&T stock accumulated by domestic and foreign firms in the industry, respectively.

Figures

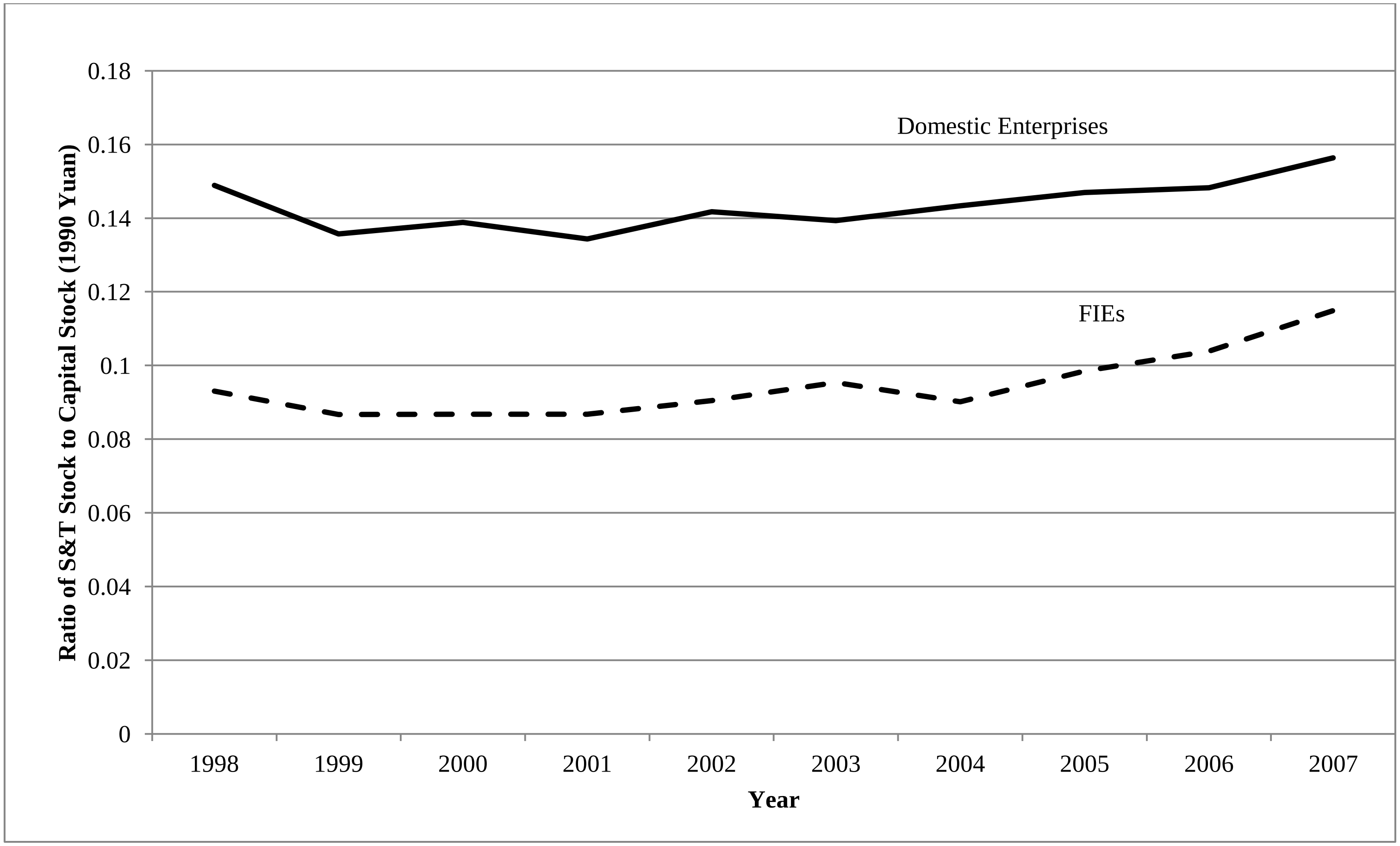


Figure 1. Ratio of S&T Stock to Physical Capital Stock. Domestic firms show a consistently higher ratio of intangible to physical capital stock compared to foreign-invested firms. This ratio has risen since the early 2000s for both firm types.

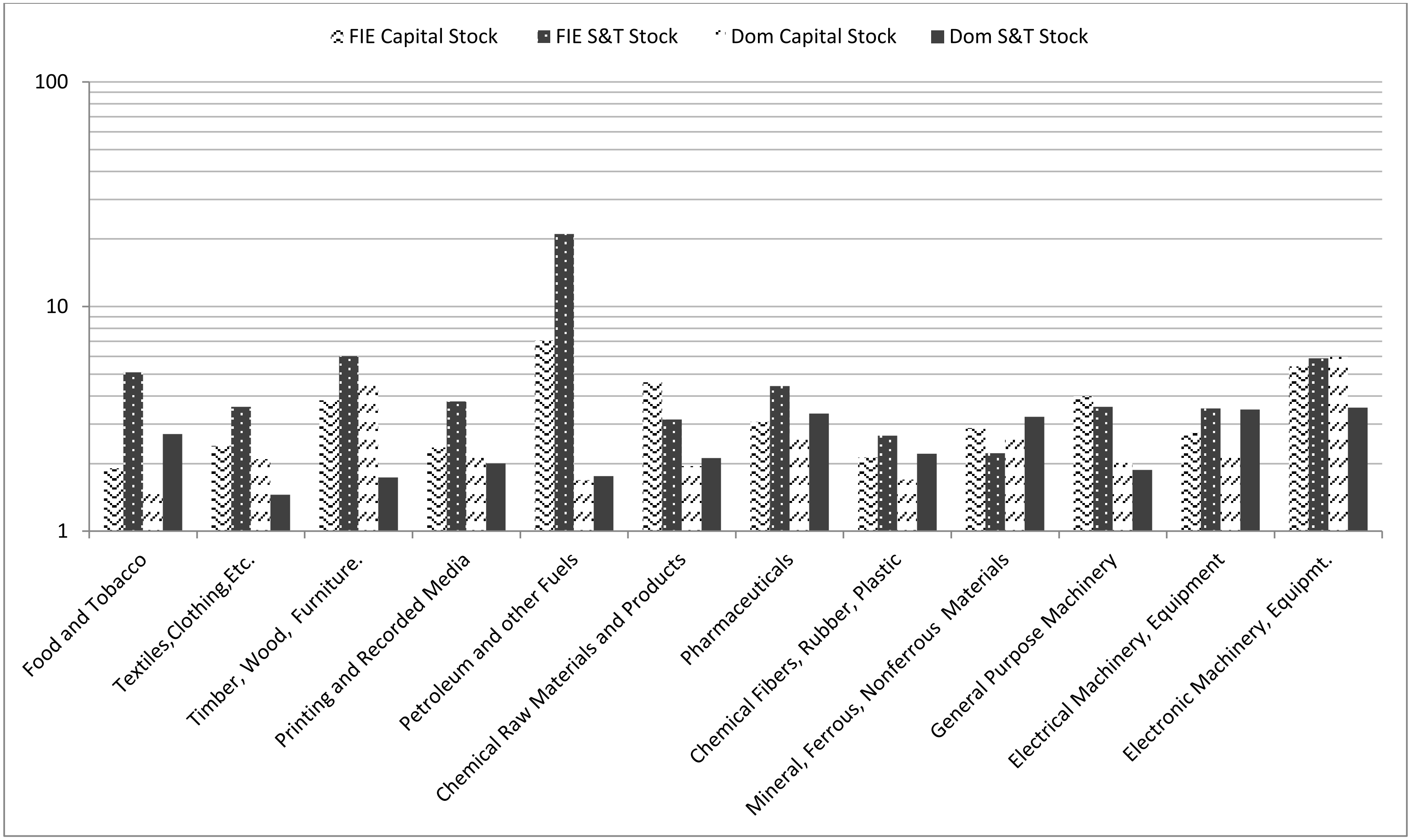
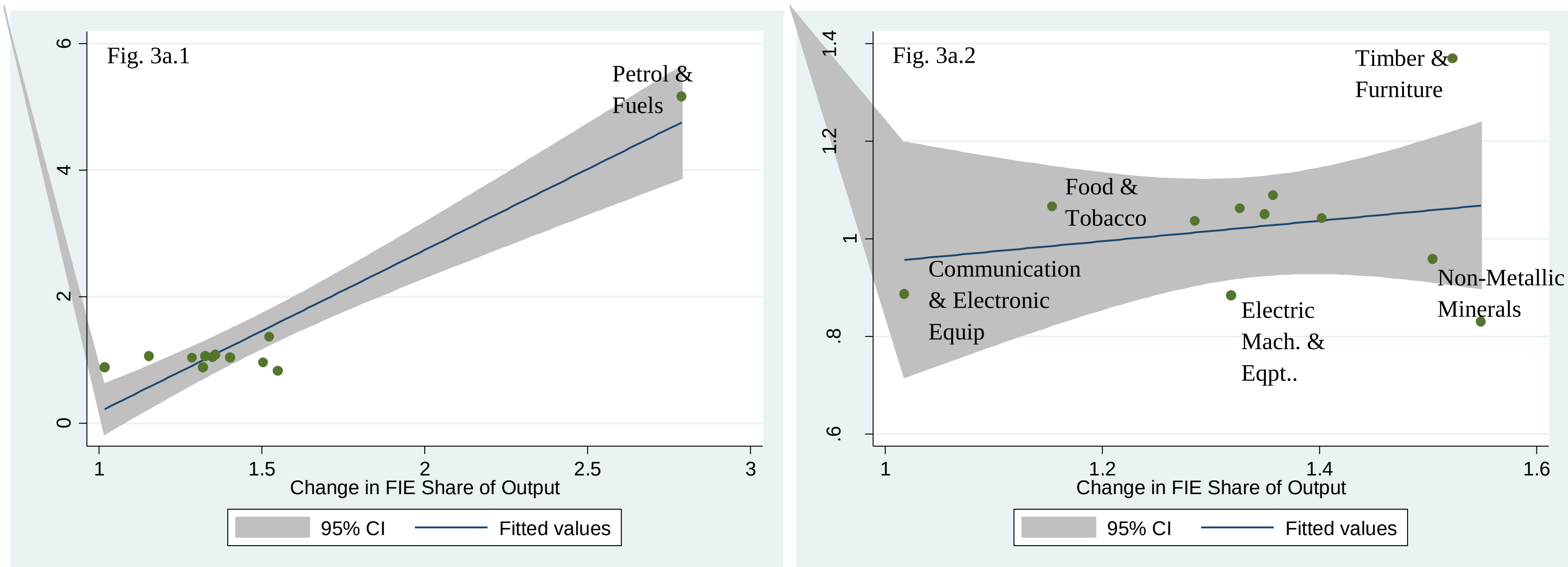


Figure 2. Ratios 2007/1998 of Physical Capital and S&T Stocks by Industry. Values on the y-axis are expressed in log scale.



Figures 3a.1 & 3a.2. FIE Share in S&T Stock 2001/1998 vs. FIE Share in Total Production 2001/1998. Figure 3a.1 includes Petroleum and Fuels; Figure 3a.2 does not. Prior to 2001, the share of FIE S&T in the total industrial stock appears unrelated to the share of FIEs in industrial output.

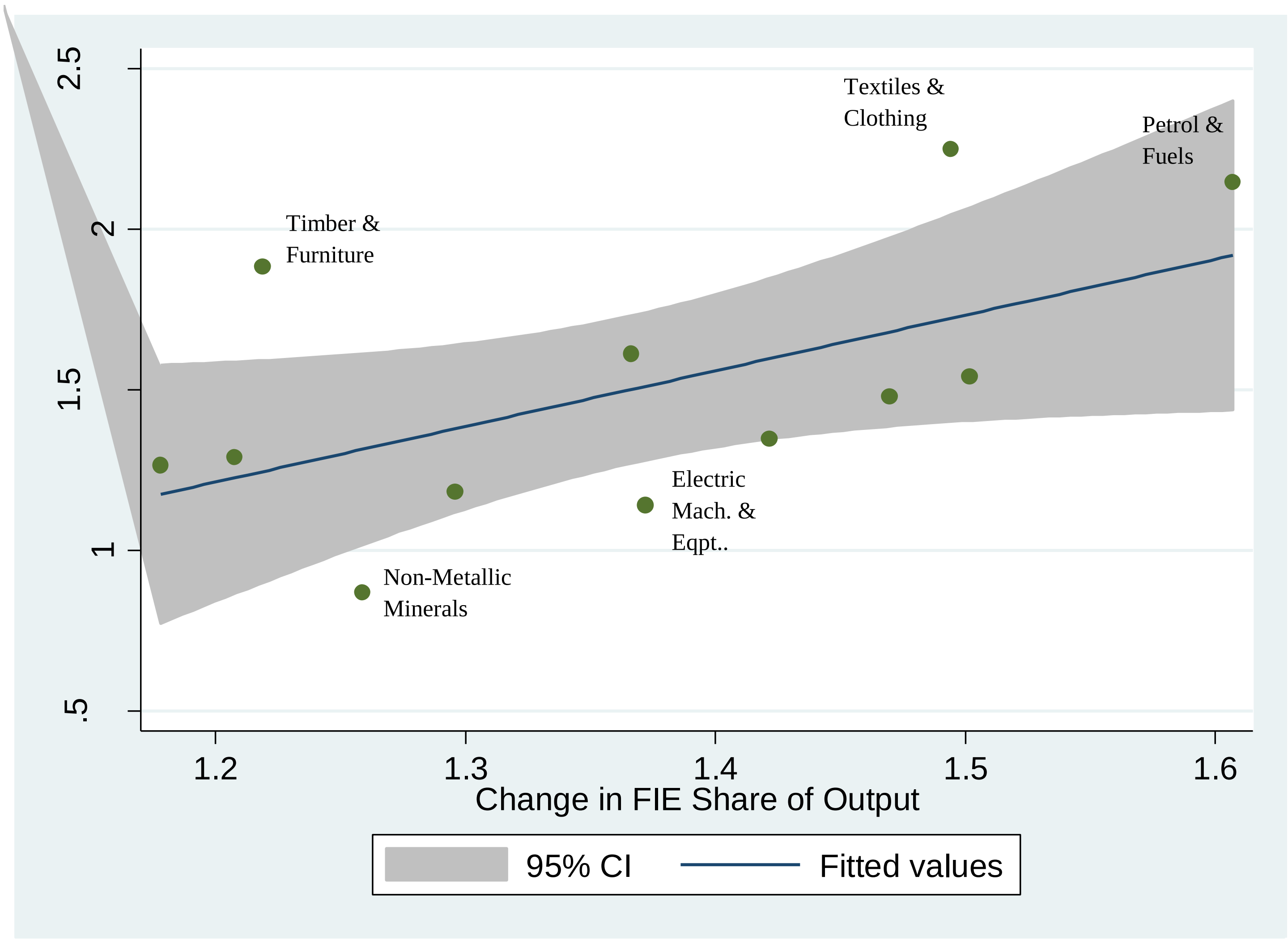


Figure 3b. FIE Share in S&T Stock 2007/2001 vs. FIE Share in Total Production 2007/2001. Post-2001, increases in the share of FIE S&T in total industry stock are positively related to increases in the share of FIEs in total output.

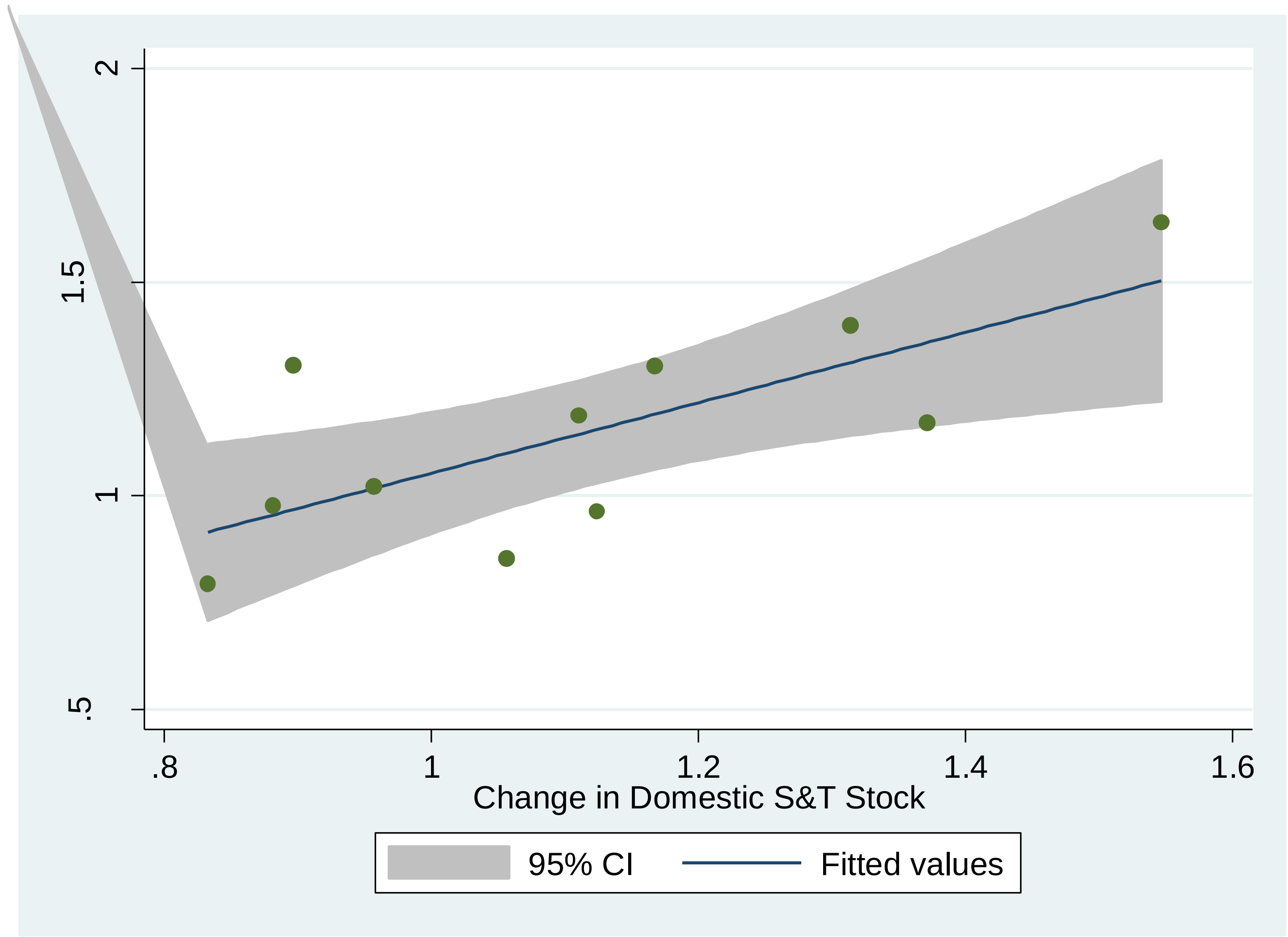


Figure 4a. S&T Stock Growth 2001/1997 Excluding Petroleum and Energy (FIEs' 6.0;Domestic 1.1). Prior to 2001, Domestic investments in S&T are positively related to FIE investments in S&T.

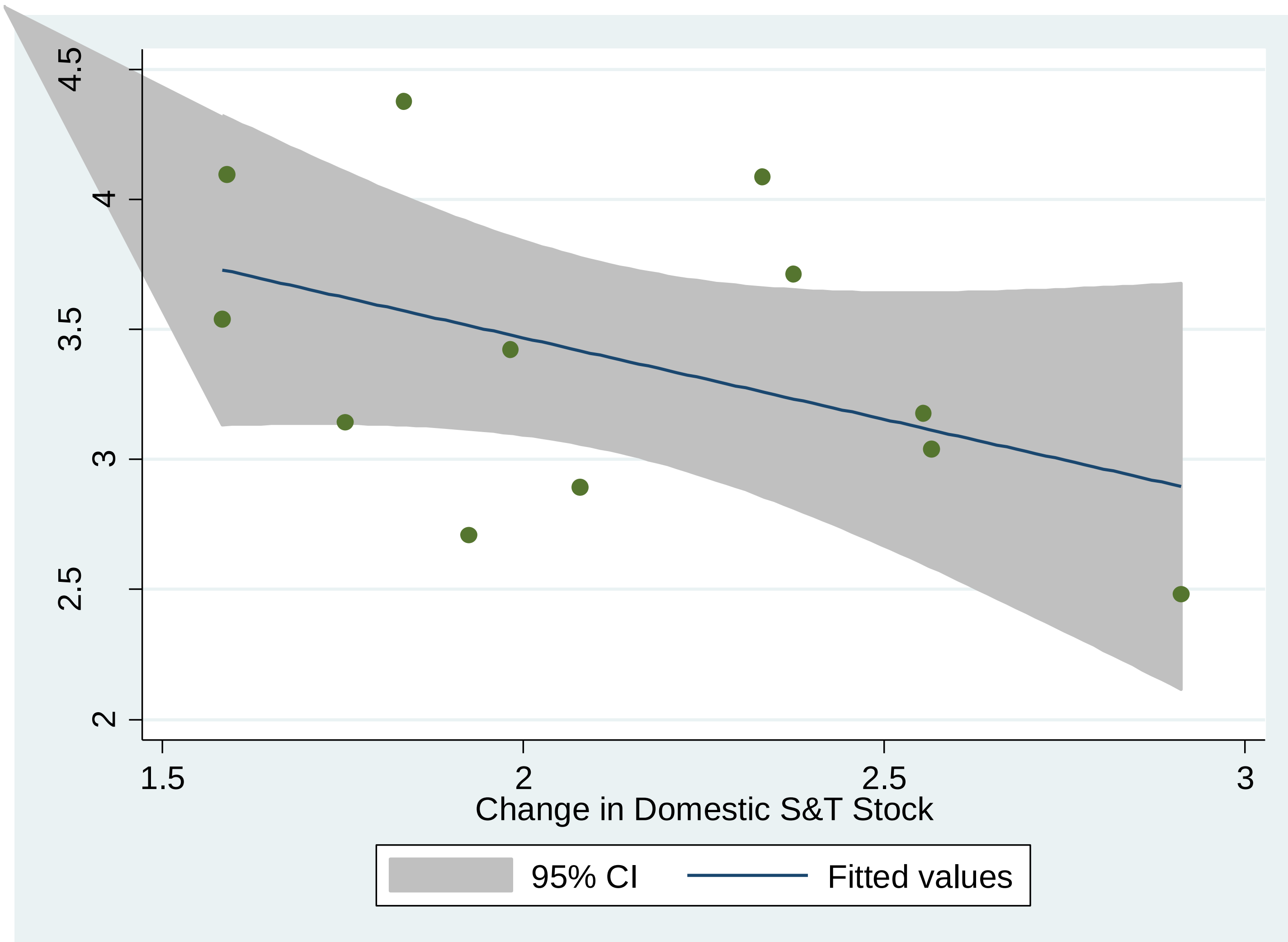


Figure 4b. S&T Stock Growth 2007/2001. Post-2001, domestic investments in S&T are negatively related to FIE investments in S&T.

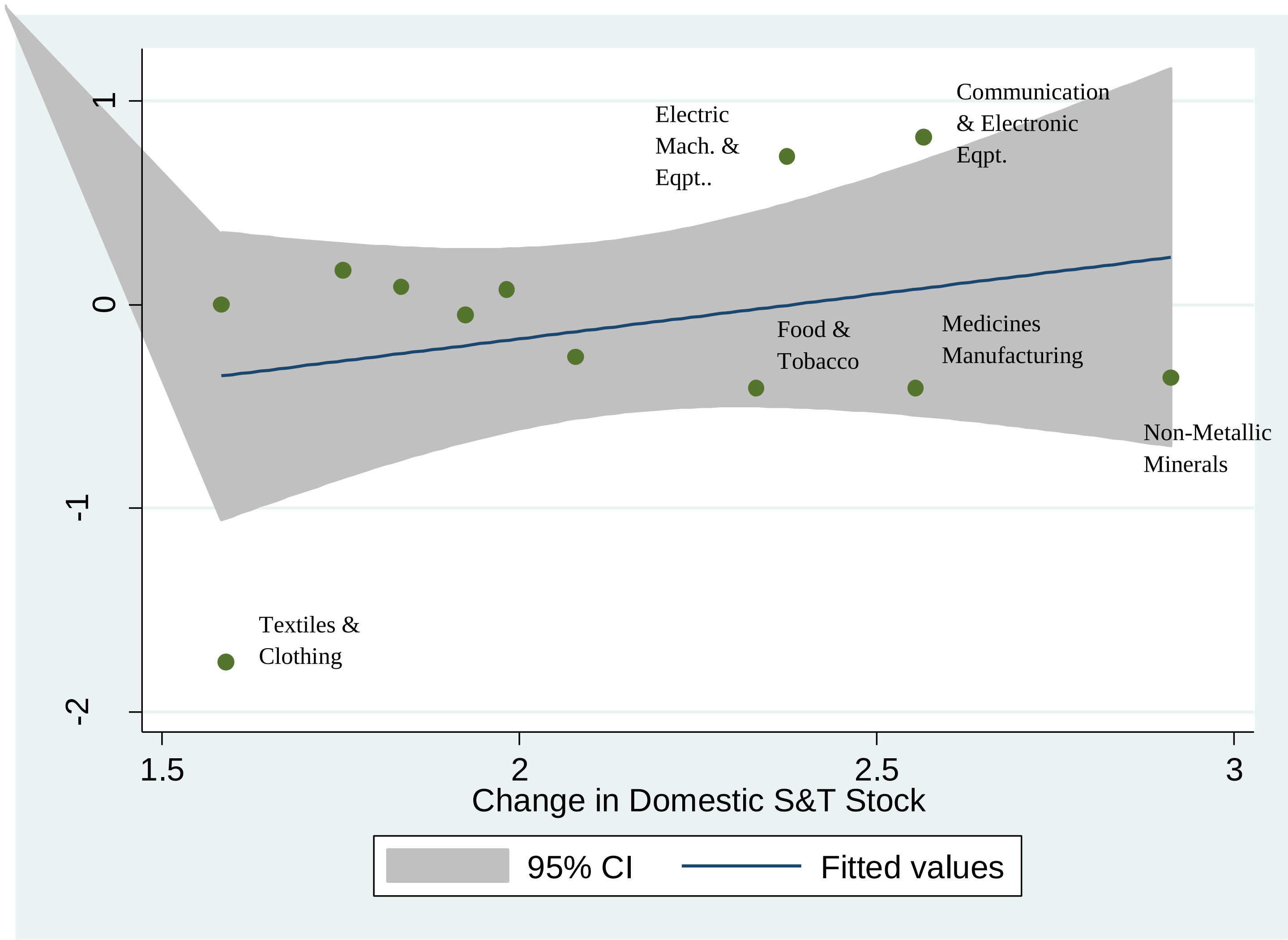


Figure 5a. Domestic S&T Change 2007/2001 & RCA Change 2007-2001. Increases in the S&T stock of domestic firms are associated with increases in the industrial RCA index.

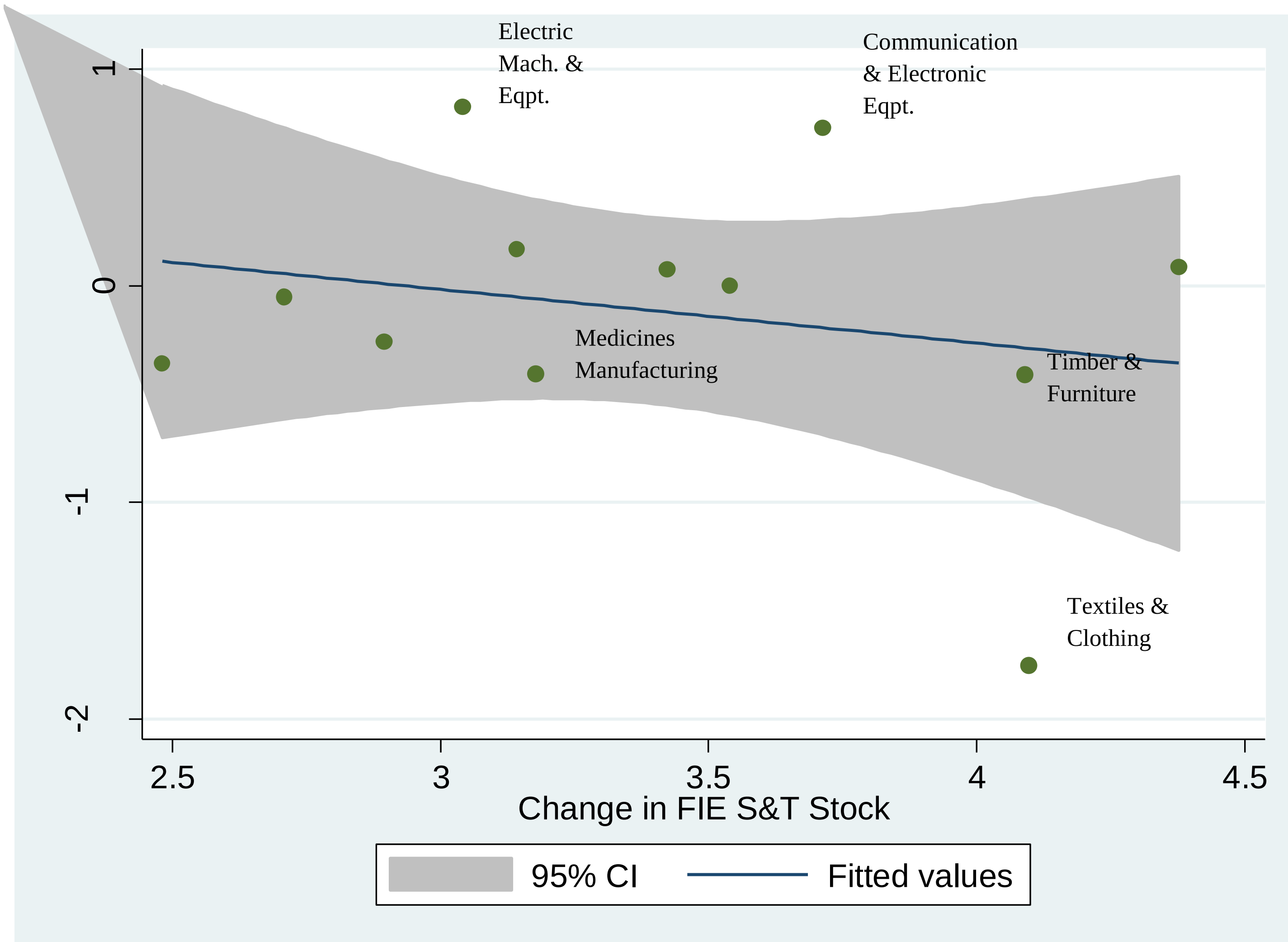


Figure 5b. FIE S&T Change 2007/2001 and RCA Change 2007-2001. Increases in the S&T stock of foreign invested firms are associated with decreases in the industrial RCA index.