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S&T activities and firm performance - microeconomic evidence from manufacturing in Shanghai

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Pingfang Zhu*, Lei Li ** and Nannan Lundin ***

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Abstract

This paper examines the impact of R&D expenditure and technology import on the level and the growth of productivity, as well as on the general economic performance in manufacturing firms with various ownership structures in Shanghai, China. The empirical analyses are based on the firm-level information of a sample of manufacturing firms for the period 1998–2003.

We find clear-cut evidence indicating that firms with foreign participation have a productivity advantage over their domestic counterparts. The expenditures on technology import not only have a direct and positive effect on productivity, but also indirectly enhance the absorptive capacity of firms to facilitate in-house R&D activities. This is particularly true for firms with foreign participation, or for firms in sectors with relatively high technical standards. Furthermore, R&D expenditure and technology import may also have positive effects on profitability and export performance, depending on the ownership structure of the firm and the technical standard in the sector.

JEL classification**:** L52, O32, O38
Keywords: Science and Technology policy, Science and Technology investment, R&D

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Tiivistelmä

Tutkimme tutkimus- ja kehitysmenojen sekä teknologian tuonnin vaikutuksia tuottavuuden tasoon shanghailisissa teollisuusyrityksissä. Lisäksi tutkimme näiden tekijöiden vaikutusta yritysten taloudelliseen suorituskykyyn. Otamme analyysissä huomioon myös yritysten erilaiset omistusrakenteet. Käytämme aineistona teollisuusyritysten otosta vuosilta 1998-2003.

Tulostemme mukaan ulkomainen omistus nostaa selvästi yritysten tuottavuutta. Korkean teknologian tuotteiden tuonti nostaa tuottavuutta suoraan, mutta nostaa myös yritysten kykyä suorittaa omaa tutkimus- ja kehitystoimintaa. Tämä on erityisesti totta ulkomaalaisten omistamissa yrityksissä sekä aloilla, joilla yleinen teknologinen taso on suhteellisen korkea. Tutkimus- ja kehitystoiminta näyttää myös parantavan yritysten kannattavuutta ja vientimenestystä, mutta tämä vaikutus riippuu omistusrakenteesta ja yrityksen toimialan teknologisesta tasosta.

Asiasanat: tiede- ja teknologiapolitiikka, tiede- ja teknologiainvestoinnit, tutkimus- ja kehitystoiminta

1 Introduction

Foreign Direct Investment (FDI) has been widely regarded as one of the most important conduits for the rapid growth of the Chinese economy. In the last two decades the FDI inflows into China amounted to $306 billion, which is equivalent to 10% of direct investment worldwide and about 30% of the investment amount for all the developing countries put together (OECD, 2000). FDI in China reached $53.3 billion in the year 2003 and China has become the largest recipient of FDI among developing countries. The FDI inflows to China have continued to increase in recent years. The major contributions of FDI to the Chinese economy are the technology transfer to domestic industries and the creation of export-competitive sectors. The largest share of high-tech exports from China to the world market (up to 85% in 2003) are accounted for by FDI firms in China[1].

Besides these important contributions of FDI firms, the effort of technology upgrading made by domestic firms, in terms of in-house Research and experimental Development (R&D) investment and technology import have also increased. As reported in the latest edition of the OECD’s Science, Technology and Industry Scoreboard in 2004, China spent 15 billion yuan in R&D investment and this expenditure grew rapidly from 0.6% of GDP in 1996 to 1.3% in 2003.[2] As an international comparison, this R&D intensity, defined as R&D expenditure as a percentage of GDP, is still relatively low compared to the US (2.7%) and Japan (3.1% and the EU-25 (1.9%).[3] In terms of human capital, China also has the second highest number of researchers in the world, with 743,000. Apart from the R&D investment, the share of technology imports in total imports to China has also increased from 16.8% in 1997 to 33.7% in 2002. From the export side, the share of technology exports in total exports from China to the world market increased from 8.9% in 1997 to 20.8% in 2002.[4] The Chinese industrial sectors aim to reduce the technology gap and enhance their competitiveness in both domestic and international markets. In these contexts, one may ask if the knowledge-based and competition-driven growth as a new strategy is really going to work and if world-class enterprises and a technology-intensive economy can indeed be created? The domestic firms' ability to survive and to compete with

[1] Technology in China, The Economist, 18 December 2003.
[2] STI Scoreboard: Creation and Diffusion of Knowledge, 2003.
[3] Statistics in focus: Science and Technology, 2/2005. S. Frank, EUROSTAT.
[4] National imports and exports of high-tech products (1997-2002), Ministry of Science and Technology of the P.R.of China.

their foreign counterparts thus becomes a focus of policy discussions. Answers to these questions partly rest on the understanding of differences in technology development and economic performance among firms with various ownership structures, and the source of such differences.

Based on detailed firm-level information on a sample of manufacturing firms in Shanghai, this paper aims first at examining the effects of R&D expenditure and technology import on productivity. Secondly, we investigate how the above science and technology (S&T) activities also affect firms' general economic performance, in terms of the profitability and export of new products.

Investigating such experiences of manufacturing in Shanghai is interesting for at least the following reasons. First, there is a large body of literature that has examined the implication of ownership for firm performance, e.g. in terms of productivity. In general, previous evidence supports the claim that firms with different ownership do perform differently, but through which channel the ownership is at work is less clear-cut. Second, as emphasised by Markusen and Venable (1999), the knowledge-based and firm-specific assets play a key role in the performance advantages of multinational firms and R&D is one of the most important determinants of such advantages. However, the relationship between R&D and productivity is very seldom investigated in firms with different types of ownership in developing countries. Furthermore, the capacity for conducting innovation in developing countries is generally very limited; innovation activities usually start with imitation and the technology imported from abroad is one of the most important sources of technology upgrading. This is particularly true for domestic firms. On the other hand, the lack of protection of intellectual property rights in the local market also makes foreign firms reluctant to conduct R&D investment in developing countries. The required technology is often imported in the form of intra-firm trade. In other words, the import of technology is also an important, if not more important source of performance improvement in both the short- and the long-run. Third, the productivity spill-over effect from FDI firms to domestic firms is well documented from previous studies, on both industrialised and developing countries. Given that there might be spill-over effects, the ability of domestic firms to innovate is at least equally important in the face of intensified competition at home and in enlarged international markets. Nevertheless, the above aspects have not received sufficient attention in previous studies on economic growth in China, possibly due to data constraints.

From a policy point of view, the above issues are of particular interest to policy makers in China, where both the ongoing restructuring of state-owned sectors and the promotion of innovation activity are important items on the development agenda. This study thus contributes to the existing empirical work in various aspects. First, the empirical studies on China using micro data are very limited. We apply a unique dataset containing both firm-level financial and innovation activity information in Shanghai, which is the most FDI- and high-tech intensive and fastest growing region in China. Second, we attempt to directly assess the impact of knowledge- and technology-related factors on productivity in both domestic and joint venture firms. Finally, instead of productivity alone, we also look at other important performance indicators, such as profitability and export of new products in order to give a more thorough assessment of the effect of S&T activity.

To preview our results, we find that firms with foreign participation do have productivity advantages compared to domestic firms in terms of total factor productivity. Firms' expenditures on technology import have not only a direct and positive effect on productivity, but also indirectly enhance the absorptive capacity of firms to facilitate their in-house R&D activities. This is particularly true for firms with foreign participation, or for firms in sectors with relatively high technical standards. The strongest effect of R&D expenditure is found in firms with higher absorptive capacity and/or in sectors with relatively high technical standards. Furthermore, both R&D expenditure and technology import may also have positive effects on profitability and export performance. These effects also differ depending on the ownership structure of the firm and the technical standard in the sector.

The remainder of the paper is organised as follows. The previous evidence is reviewed in Section 2. Section 3 provides some background information on the development of ownership structures and S&T activities in the manufacturing sector in Shanghai. Section 4 presents the dataset and some related methodological issues are discussed. The econometrical modelling and results are presented in Section 5. We conclude the discussion in Section 6.

2 Previous studies

The link between FDI and economic growth and the link between R&D and economic growth have been extensively investigated in previous studies, particularly at the macro-economic level. In more recent literature, empirical evidence obtained by applying micro-economic data at the firm and establishment levels is also presented. Generally speaking, the conclusion drawn from previous studies regarding how FDI and R&D may contribute to economic development and growth can be summarised in the following factors:

- Cutting-edge technology of foreign firms, which is acquired through imitation and/or innovation by domestic firms.
- Export orientation of both domestic and foreign firms.
- Clustering of foreign investors in the domestic market.
- Interaction between foreign and domestic firms in the forms of technology spill-over and competition.

The key questions in these studies are, on the one hand, whether or not foreign firms are indeed better than domestic firms and, on the other hand, whether domestic firms improve their competitiveness when foreign firms enter or increase their presence in the domestic market. In other words, if there are spill-over effects.[5] From the viewpoint of developing countries, the performance gap between domestic and foreign firms is not sufficient, but is nonetheless an absolutely necessary condition for the catch-up process. The ownership effect can be both direct and indirect. The direct effect can take place if foreign firms have access to superior assets, including knowledge-based assets. The indirect effects are associated with a higher level of capital intensity and a more skilled labour force. It is

[5] In the large body of theoretical and empirical literature, the spill-over effect can take various forms. It can be summarised as demonstration-, job turnover- competition- and backward- or forward-linkage effects. See, e.g., Blomström and Kokko (1998) and Görg and Strobl (2001) for more detailed discussions. The spill-over effect has been modeled by using the share of FDI production or share of FDI employees in industrial sectors as proxies. However, it is not a direct measure of the sources and mechanisms of the technical upgrading process. In other words, the specific sources of the technological advantages of FDI and the positive effects of FDI cannot be quantified. To overcome the drawback in the conventional spill-over literature and to identify explicit channels and mechanisms of the technical upgrading process, some recent empirical studies, e.g. Andretsch and Feldman, (1996), Branstter (2001), use patent and innovation data to investigate the knowledge spillover. Peri and Urban (2004) use the productivity gap between domestic and foreign firms, combined with the geographic dimension of spillovers to investigate the catching-up of domestic firms.

important from a policy point of view since the host countries, particularly developing countries, can benefit from the potential for spill-over effects on domestic firms.

However, the productivity gap needs also to be interpreted with caution. As pointed out in Girma and Görg (2003), in the case of acquisition, the link between ownership and productivity can even emerge due to the scale effect. When foreign owners possess better marketing skills, access to foreign markets etc., these factors allow multinational firms to produce and sell a larger quantity of their output. This would enable them to increase their productivity even without changing the actual production technology. Alternatively, it can simply be a structural effect: the multinational firms are clustered in industries with above average productivity (Wang et al. 2002).

The productivity gap between domestically and foreign-owned firms has been investigated, applying data from both industrialised and developing economies. Davis and Lyons (1991), Griffith and Simpson (2002), Wang et al. (2002) are examples for the UK, while Doms and Jensen (1998) provide similar results for the U.S. Blömström and Kokko (1998) give a detailed survey on the empirical evidence obtained from Latin American countries. Blomström and Sjöholm (1999) examine the productivity gap between different types of ownership in Indonesian establishments. For transition economies in Europe, Hunya (2000), Resmini (2000) and Konings (2001) and Yudaeva et al. (2003) have provided firm-level evidence of the effect of FDI in Bulgaria, Romania, Poland, the Czech Republic, Hungary and Russia.

For developing countries, the technology upgrading and catch-up processes start with imitating technology created in industrialised economies. The imitation process can take place in different forms. Technology purchase and technology transfer by multinationals or joint ventures are the most common channels. However, in the long run the ability to innovate, in the form of domestic firms' own R&D effort is also essential. Drawing on experiences of Taiwan in the transition from imitation to innovation, Cohen and Levintal (1989) argue that R&D, particularly in developing countries, not only involves innovation but also learning. A by-product is therefore to improve domestic firms' absorptive capacity, which in turn boosts the efficiency of technology transfer and development. From previous experiences of other newly industrialised countries and developing countries in Asia, the relative importance of various forms of innovation and their dynamics differ, associated with country-specific characteristics and institutional background. As summarized in Jefferson and Zhong (2003), FDI has played an important role in technology development for the Philippines and Thailand, whereas South Korea has tended to limit FDI and relied on foreign technology import and indigenous R&D investment. There are also a few studies on Indian firms, e.g., by Deolalikar and Evernson (1989), Basant and Fikkert (1996) and Katrak (1997), supporting the argument that technology transfer and indigenous R&D investment have a complementary relationship, and jointly have an effect on firm-level productivity. Moreover, other studies point out that, technology transfer is more intensive in FDI subsidiaries than in domestic Indian firms.[6]

The empirical evidence on China, particularly at the firm level, is very scarce. To the best of our knowledge, there are merely three studies related to our analyses to various extents. Hu and Jefferson (2002) look at the electronic and textile industries for the period 1995-1999. They find that in the short run, FDI may reduce the productivity and market share of domestic firms; however, the disadvantage of domestic firms disappears in the longer run. A possible explanation is that domestic firms that survive in the face of intensified competition from FDI firms seem to be able to capture some of the technology and know-how that are introduced from abroad. In another cross-sectional study by Hu (2001), the author examines 813 high-tech firms in Beijing in 1995 and finds a significantly positive link between R&D and productivity. The R&D investments of private firms yield higher output elasticity. The most detailed and extensive study so far was conducted by Jefferson et al. (2003). Using firm-level data for Chinese manufacturing during the period 1995-1999, the authors find that technology transfer, as measured by firms' expenditure on technology purchased from foreign and domestic providers, affects productivity only through its interaction with in-house R&D. In other words, technology transfer only becomes productive when the firm itself is also engaged in R&D activity.

To summarise, there is a large body of literature that has demonstrated differences between firms with various ownership structures and provided evidence of the spill-over effect, in both industrialised and developing economies. However, there are still some missing pieces, namely the source of such differences and the concrete mechanism of the spill-over. To apply data on science and technology activities to such studies may shed some new light on these questions.

[6] See, e.g., Ramachandran (1993) and Vishwasrao and Bosshardt (2001).

3 Background information on S&T activities and ownership structure in Shanghai

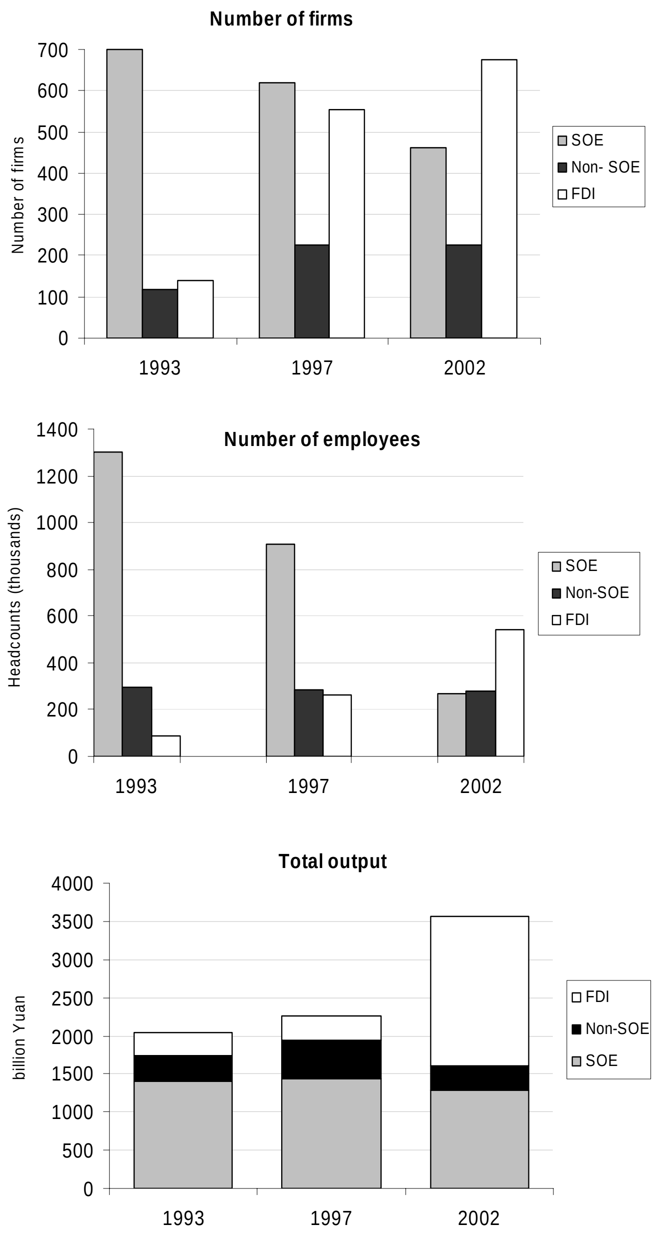
In this section we give a general description of developments in the manufacturing sector in Shanghai using aggregate information on various aspects. We look at manufacturing as a whole as well as break it down into subgroups with different types of ownership.

3.1 Output, employment and ownership structure in Shanghai

After a decade of industrial restructuring by, on the one hand, privatising stated-owned enterprises (SOE) and, on the other hand, attracting foreign investment, the ownership structure has changed remarkably in manufacturing sectors in Shanghai. Consequently, the distribution of output and employment among firms with different types of ownership has also changed. This development is evident in Figure 1.

The most remarkable changes that have taken place in manufacturing are decreases in both the number of SOEs and their employees. In contrast to these decreases, domestic non-SOEs and firms with foreign participation have been becoming increasingly important and contributing to job creation and production expansion in manufacturing. This development is more evident since 1997. Despite increases in the number of firms and in production that are associated with privatisation and foreign participation, total employment in manufacturing has decreased. It can be explained by the fact that while a large number of workers have been displaced because of the large-scale closure of SOEs, intra- and intersectoral relocations of the labour force in manufacturing are limited. Furthermore, the domestic non-SOEs and firms with foreign participation are more capital-intensive instead of labour-intensive. It therefore limits the possibility of job creation as well.

Figure 1. Employment and output and ownership structure



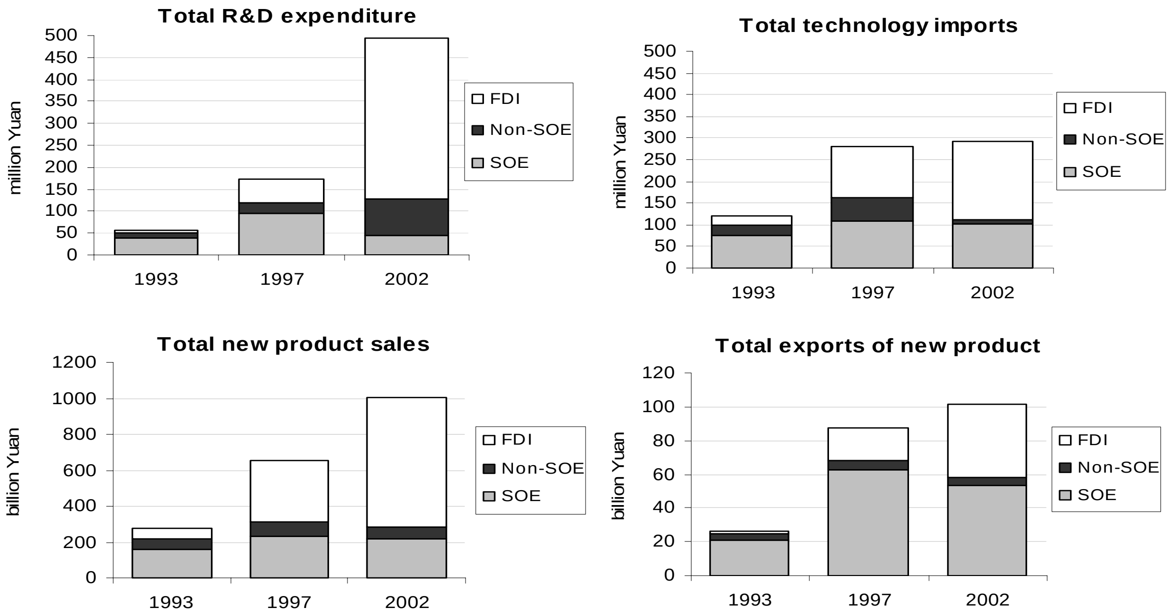
3.2 Science and technology activities

In addition to the remarkable influence of privatisation and foreign participation, another notable development, which received high policy priority is the promotion of new and high-technology industries such as the automobile, telecommunication, power station equipment, steel, electronics, bio-medicine and new material industries. In carrying out an active FDI policy, the government in Shanghai has been encouraging multinational firms to set up R&D centres by providing preferential policies to strengthen their R&D and innovation efforts. In addition, joint ventures are encouraged to participate in the transformation of SOEs, particularly allowing foreign investment participation in the asset reorganisation and technical renovation of the SOEs.[7]

As shown in Figure 2, R&D expenditure has increased remarkably, particularly since 1997 and the largest share of this increase is from firms with foreign participation. The contribution from SOEs is still moderate and R&D expenditures of SOEs have actually decreased since 1997. In addition to R&D expenditure, the import of technology is another important source of technology upgrading. Firms with foreign participation have the largest share in technology imports and the volume of imports has been increasing steadily. The technology imports by SOEs have remained stable. However, compared to domestic non-SOEs, the technology imports of SOEs are more substantial.

The very general measures of the return on innovation investment in terms of R&D expenditure and technology import are sales and exports of new products, which are to various extents related to these innovation activities. The impression we get from Figure 2 is that innovation activities have resulted in increases in both domestic sales and exports of new products. Examining the total sale of new products, we observe that firms with foreign participation have much superior performance than their local competitors. However, the distribution of exports of new products by ownership shows that the performance advantage of firms with foreign participation is not as evident as in the domestic market. It may reveal the quality aspect of new product exports. The exports of new products of SOEs are more labour-intensive, with lower value-added compared to exports by FDI firms. Also, in order to improve their efficiency in production and the technology standards of their products, the SOEs may largely rely on technology imports. On the other hand, beyond the superior performance in the domestic market, firms with foreign participation increasingly orientate towards the international market by exporting products with higher technology content and better quality.

Figure 2. Science and technology: Input and output



To summarise this section, there are observable differences in the performance and investment behaviour of firms with various types of ownership, which are the result of structural changes and new policy orientations in manufacturing. Based on these observations at the aggregate level, we continue our analyses by applying more detailed firm-level information to have a closer look at the underlying mechanisms and dynamics.

4 Data and methodological issues

The data used in this study are from two different sources. The first one is balance sheets of manufacturing enterprises obtained from the Shanghai Statistical Bureau. The other source is innovation-related statistics from the Science and Technology Information Centre in Shanghai. Comparing variables included in the balance sheets, the data structure in our dataset is very similar to financial accounts of enterprises applied in previous empirical

[7] See " China in the global economy: foreign direct investment in China", (OECD, 2002) for detailed descriptions.

studies on other European countries. The industrial classification for firms is according to ISIC, rev. 3. This dataset is obtained through two steps. First, we compile a representative sample of manufacturing firms. In the second step, in order to obtain information on innovation activities, we merge the production and economic performance data with the science and technology indicators from the second data sources. Merging these two datasets and using firms' identification codes, we obtain both the standard financial statistics and innovation activity information, which can be divided into three categories: 1) Firm-level economic variables, such as employment, wage bills, sales, value-added, fixed assets and intermediate material costs; 2) Innovation activity variables, such as R&D expenditure, S&T employment and technology imports; and 3) Ownership structure, divided into SOEs, domestic non-SOEs and firms with foreign participation, defined as joint ventures in our study.[8] The nominal variables in the dataset are deflated by using the producer- investment- and consumer-price indexes for Shanghai. The dataset used in the empirical analysis contains 189 manufacturing firms in Shanghai for the period 1998–2003. The sample coverage is 10%–15% of total manufacturing employment in Shanghai, depending on the year of calculation.

4.1 The advantages and disadvantages of the dataset

The most advantageous feature of this dataset is the detailed information it provides at the firm level, combined with information on innovation in the most FDI- and R&D-intensive region in China. However, the methodological issues related to the sample selection and the measurement of the knowledge stock need to be addressed before moving on to the empirical analysis.

Due to the merging with the S&T information, joint ventures are overrepresented (60% in the sample compared to 46% in the population) while SOEs are underrepresented (25% in the sample compared to 38% in the population) for the investigated period. One plausible reason is that joint ventures are in general more commonly engaged in innovation activities. In other words, firms included in this dataset bias towards firms with foreign participation and/or firms with relatively high technology standards in the manufacturing sector in Shanghai. Table 1a, Table 2a and Data Appendix 3 present more detailed infor-

[8] See Data Appendix 2 for more detailed information on ownership variables.

mation on the ownership- and sector distribution of the firms. The SOEs in the dataset to a large extent engage in science and technology activities. Assuming relatively well-performing SOEs have the resources and capacity to conduct S&T activities, differences in performance between joint ventures and SOEs may be underestimated in this dataset compared to the population.

The ownership classification of firms relies on the ownership indicator, which has been constant over the investigated period. We cannot observe how and when the ownership shift took place. The problem of the endogenous acquisition of firms therefore cannot be probably controlled for. It might be the case that foreign firms picked up domestic firms with superior performance as partners in order to establish joint ventures. If this is the case, the ownership effect is thus blurred by this selection bias. On the other hand, when the acquisition is under extensive regulation by the local government, it can also be the case that domestic partners, who do not necessarily have superior characteristics, are pointed out by the local authorities.

It is nevertheless difficult to quantitatively assess the impact of such selection issues on our empirical results. A preferred methodology to deal with the selection problem, which is frequently applied in recent empirical work, is matching combined with difference-in-difference estimation. However, such methodology requires a large sample size to identify the matchable pairs, which is not applicable to this study with its rather small sample size. Since the focus of this paper is the science and technology activities of firms, the inference and conclusion from the empirical analysis thus are not generalisable to manufacturing as a whole, rather to the subpopulation with a relatively high technology intensity.

4.2 The measurement and lag structure of R&D

According to the commonly used international classification from the OECD, R&D is defined as follows.

R&D: comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society and the use of this stock of knowledge to devise new applications. The term R&D covers three activities: basic research, applied research and experimental development (Frascati Manual, 2002, OECD).

In practice, the measure of the knowledge stock often causes methodological concerns. In this study, both R&D expenditure and technology import are regarded as important sources of technology upgrading and transfer. Preferably, R&D stock should be used as a measure of the knowledge stock that contributes to productivity. Nevertheless, most previous empirical studies have used R&D expenditure instead of R&D capital stock due to the difficulty in obtaining such a measure. The largest drawback with such a substitute is that it may neglect the reduction in the effective appropriation of knowledge and therefore may also overestimate the net rate of return on R&D.[9]

Furthermore, the lag structure of R&D expenditure is often an open empirical issue. Assuming a contemporaneous relationship between R&D expenditure and productivity appears to be inappropriate. In our empirical analysis, we try to deal with this problem by estimating all the specifications with various lag structures. However, Mairesse and Sassenou (1991) in their survey argue that R&D expenditure by firm can be stable over time. Most of the variation is instead in the cross-section. It implies that applying lags to R&D expenditure may have little impact on the results.[10]

Having acknowledged the above drawbacks in the dataset, there are still very interesting dynamics that can be investigated in order to shed some light on the impact of innovation on firm-level performance. However, it is important to keep these methodological issues in mind as potential caveats when the results are interpreted.

5 Empirical analyses and results

The empirical analyses are carried out in two steps. First, we investigate how S&T activities affect productivity at the firm level. Second, we make assessments of the effect of S&T activities on the overall firm-level performance in terms of productivity, profitability and export performance.

The sample is also split into sub-samples in two dimensions, namely domestic versus joint venture firms and high-tech versus low-tech sectors. Due to the small number of

[9] See e.g. Wakelin (2001) for a more detailed discussion on the substitution of R&D expenditure for R&D stock.

[10] See Wang and Tsai (2004) for a detailed survey of results from various lag structures and R&D measures in manufacturing sectors in Taiwan, Japan, the U.S. and some other European countries. In a study on manufacturing in Taiwan, the authors applied the average lag approach by using the lag structure of two years.

firms with private ownership, we merge SOEs and private firms into the domestic sub-group. Preferably, the dimensions of ownership and technology may be combined to assess the differential effects of various ownership-associated technical standards. Unfortunately the small sample size does not allow such combinations.

5.1 S&T activities and productivity

To assess the impact of S&T activities on firm-level productivity, the following empirical model, in the framework of an augmented Cobb-Douglas production function is estimated:

$$\begin{aligned} \text{I}nX_{it} &= \alpha + \beta_R R\&D_{i,t-n} + \beta_{im} \text{Im}\ port_{i,t-n} + \beta_{Rim} R\&D_{i,t-n} \times \text{Im}\ port_{i,t-n} + \lambda Firm_{it} + \\ &+ \sum \beta_w Ownership_i + \sum_{t=1} \beta_t Year_t + \sum \beta_{ind} Industry_{jt} + \varepsilon_{it} \end{aligned} \tag{1}$$

where i is index for firms, j is index for industries and t is index for years. The variables included in the specification are defined as follows:

X_{it}: An indicator for total factor productivity (TFP).

$R\&D_{i,t-n}$: Lagged R&D expenditure in logarithm, where n is the number of lags.

$\text{Im}\ port_{i,t-n}$: Lagged technology import in logarithm.

$Firm_{it}$: A vector of firm characteristics such as skill intensity and average wage.

$Ownership_i$: Ownership dummy variable indicating SOE, non-SOE or joint venture.

$Year_t$: Year dummy variable.

$Industry_j$: Industry dummy variable at the 2-digit level.

In the empirical estimation, we apply TFP as the dependent variable in the above specification. In Data Appendix 1 we provide more detailed information on the calculation of the TFP measure.

The key variables in the specification are R&D expenditure and technology import. The R&D expenditure is the in-house effort on innovation made by firms. The technology import indicates more imitation-related S&T activities that are associated with better access to foreign technology and know-how in various forms. There are also other firm-level characteristics of interest included, however, merely as control variables.

The 2-digit industry dummy variables control for the variation in productivity between industries, so that the other explanatory variables capture the effect of intra-industry or inter-firm variation. The year dummy variables are also included to control for yearly fluctuations and other unobservable macroeconomic effects.

To assess the impact of S&T activities on the growth of productivity, the following model is also estimated:

$$\Delta \mathrm{In} X = InX_{i,t+1} - InX_{i,t} = \alpha + \beta_R R\&D_{i,t-n} + \beta_{im} \mathrm{Im}\, port_{i,t-n} + \lambda Firm_{i,t-n} + \sum \beta_w Ownership_i + \sum_{t=1} \beta_t Year_t + \sum \beta_{ind} Industry_{jt} + \varepsilon_{it} \quad (2)$$

To clarify, the effect of S&T activities on the level of productivity is examined in Equation (1), whereas Equation (2) exams the effect on the growth of productivity. Since conclusions obtained from the level and growth equations are to a large extent similar, we regard the growth estimation as a robustness check and the results can be found in Appendix 4. For conciseness, we focus our discussion on empirical results from the estimation of Equation (1).

Table 1.1. R&D expenditure, technology import and TFP

Variable	Full sample (without interaction) (1)	Full sample (with interaction) (2)
Lagged with one year		
R&D Expenditure	0.002 (0.94)	**0.004**** **(2.05)**
Tech import expenditure	**0.006**** **(2.57)**	**0.006**** **(2.71)**
R&D x Tech import		**0.0004**** **(2.17)**
Average wage	**0.094***** **(4.61)**	**0.094***** **(4.65)**
Skill share	0.133 (0.96)	0.162 (1.14)
SOE dummy	-0.011 (-0.30)	-0.011 (-0.29)
Joint Venture dummy	**0.117***** **(4.28)**	**0.114***** **(4.16)**
Year dummy	Yes	Yes
Industry dummy	Yes	Yes
Adjusted R^2	0.22	0.22
Observation	882	882
Lagged with two years		
R&D expenditure	**0.004*** **(1.94)**	**0.005**** **(2.11)**
Tech import expenditure	0.001 (0.37)	0.001 (0.46)
R&D x Tech Import		0.0002 (0.93)
Average wage	**0.093***** **(4.35)**	**0.092***** **(4.33)**
Skill share	0.213 (1.28)	0.229 (1.40)
SOE dummy	-0.018 (-0.41)	-0.018 (-0.41)
Joint Venture dummy	**0.124***** **(4.00)**	**0.124***** **(3.94)**
Year dummy	Yes	Yes
Industry dummy	Yes	Yes
Adjusted R^2	0.20	0.20
Observation	699	699

***Notes*:** Skill share, defined as the ratio of S&T employees to total employment, and the log of the average real wage are included as additional control variables at the firm level. In the comparison of SOE and Joint Venture, the F-tests for the coefficients are computed. When interaction terms are included, VIF tests are also calculated. White's heteroskedasticity-consistent t-statistics are given in brackets.
*** significant at the 1% level;
** significant at the 5% level.
* significant at the 10% level.

In Table 1.1 we estimate Equation (1) using the full sample and applying OLS. To avoid the potential endogeneity problem, R&D and technical import are lagged with one and two years. As shown in Column (1), the results differ with the lag structure. The technical import lagged with one year has a significantly positive effect on TFP while a similar effect can only be observed for R&D expenditure lagged with two years. This difference may be explained by the fact that technology import generates a short-run positive effect on TFP while the return of R&D expenditure on productivity is more time-consuming. To examine the differential effect related to ownership structure, ownership dummy variables for SOEs and joint ventures are included while domestic non-SOEs are left out as a reference group. The joint venture firms have higher productivity levels compared to domestic non-SOEs, indicated by the positive and significant coefficients of the joint venture dummy variable, while SOEs do not have such productivity advantages.

In Column (2) we insert an interaction term between R&D and technology import. The interpretation of this interaction term can be twofold. First, it may reveal a substitute (indicated by a negative sign) or a complementary (indicated by a positive sign) relationship between these two factors. Alternatively, it can be interpreted as the effect of absorptive capacity when the higher technology import and the higher return on R&D expenditure. Despite the appealing theoretical motivation for including the interaction term, the methodological drawback is the multicollinearity induced by the interaction term. The positive effects of R&D expenditure, lagged with one and two years, are robust when the interaction terms are included. The positive effect of technology import remains significant in the one-year lag specification. It can be interpreted as the stronger the absorptive capacity, proxied by the interaction term, the higher the return on R&D expenditure as well. However, the positive effect of technology import disappears when it is lagged with two years. It may be partly due to multicollinerity, but mostly occurs because of the reduced sample size when one more lag is taken.

Furthermore, the skill share, defined as the ratio of S&T employees to total employment and average wage in logarithm, are also included in the model. The average wage yields the expected positive sign and the coefficients are highly significant in all specifications. It implies that high wages are positively associated with high productivity. On the other hand, the skill share does not have any positive effect on the TFP level. One plausible explanation is that the skill effect is captured by the R&D expenditure variable.

From Table 1.1 we have obtained evidence suggesting that both R&D expenditure and technology import have positive effects on the TFP level. However, the sizes of the elasticities are very small. The elasticity of R&D is in the range of 0.002–0.005 and the elasticity of technical import is 0.006. To assess the plausibility of these estimates, we compare our results to those in Hu et al. (2003), which is closely related to our study. They estimate a very similar specification using a much larger sample of Chinese manufacturing for the period 1995–1999.[11] The elasticity of R&D in their study is in the range of 0.005–0.007 and the elasticity of the technical import is 0.005. It is difficult to make a direct comparison of these estimates because of differences in sample size and specification. However, it provides some indication that estimates obtained in our study lie in a reasonable range.

In Table 1.2 we estimate the same model, but divide the full sample into low- versus high-technology sectors. The purpose of this division is to examine potential differential effects due to various technology standards. The classification of these two sectors is presented in Data Appendix 3. There are apparent similarities in the results in Table 1.2 compared to Table 1.1. On the other hand, there are a few interesting differences that we can observe. First, as expected, the R&D expenditure yields also a positive return in the high-tech sectors.[12] However, the most interesting differences observed are in coefficients of ownership dummy variables. In the high-tech sectors domestic non-SOE firms have some productivity advantages compared to SOEs, indicated by the significantly negative coefficient of the SOE dummy variable (- 0.087), while the productivity advantages of joint ventures over domestic firms are even larger (in the range of 0.157- 0.173) in Column (3) and Column (4).[13] Another important finding is that joint venture firms do not have significantly higher productivity than domestic firms in low-tech sectors, indicated by the insignificant coefficients of the joint venture dummy variables in Column (1) and Column (2). These results may indicate that investment motives of foreign firms are different in low- and high-tech sectors. In the low-tech sector, foreign firms enter the local manufacturing sector to take advantage of low production costs, such as labour costs. On the other hand, the higher productivity of joint venture firms in high-tech sectors reveals that foreign firms may bring the firm-specific and more advanced technology into the local manufacturing and aim at achieving market access and competitive advantage in the Chinese market.

[11] The differences between specifications in Hu et al. (2003) and in this study are the inclusion of the stock of domestic technology purchase (which has a negative effect on TFP) and a more detailed ownership classification. Furthermore, there is no other additional firm control included in their study.

[12] An F-test is constructed to compare estimated R&D expenditure parameters obtained from regressions applying the full sample and the high-tech subsample. However, the F-test indicates that the difference in R&D parameters between the full sample and the high-tech subsample is not statistically significant.

[13] The F-tests indicate that these differences in ownership dummy variables are statistically significant.

Table 1.2. R&D expenditure, technology import and TFP (*by Technology Standard*)

Variable	Low-tech sector		High-tech sector	
	Without interaction (1)	With interaction (2)	Without interaction (3)	With interaction (4)
Lagged with one year				
R&D expenditure	-0.004 (-1.03)	-0.0001 (-0.03)	0.003 (1.43)	**0.006** (2.43)**
Tech import expenditure	0.007 (1.62)	**0.008** (2.03)**	**0.006** (2.22)**	**0.006** (2.30)**
R&D x Tech import		0.0004 (1.29)		**0.0004** (2.13)**
Average wage	**0.072** (2.71)**	**0.071** (2.66)**	**0.098*** (3.20)**	**0.101*** (3.29)**
Skill share	**0.528** (2.83)**	**0.587** (3.11)**	0.044 (0.28)	0.074 (0.46)
SOE dummy	0.084 (1.39)	0.078 (1.30)	**-0.087** (-1.97)**	**-0.084* (-1.91)**
Joint Venture dummy	0.020 (0.51)	0.013 (0.34)	**0.157*** (4.24)**	**0.155*** (4.21)**
Year dummy	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes
Adjusted R^2	0.15	0.16	0.27	0.28
Observation	354	354	528	528
Lagged with two years				
R&D expenditure	-0.003 (-0.57)	0.0002 (0.04)	**0.006** (2.45)**	**0.007** (2.47)**
Tech import expenditure	0.002 (0.27)	0.004 (0.61)	0.001 (0.17)	0.001 (0.22)
R&D x Tech import		0.0004 (0.77)		0.0002 (0.76)
Average wage	**0.065** (2.25)**	**0.065** (2.24)**	**0.113*** (3.61)**	**0.112*** (3.58)**
Skill share	**0.653* (1.96)**	**0.697** (2.15)**	0.113 (0.63)	0.128 (0.72)
SOE dummy	0.066 (0.89)	0.063 (0.85)	-0.079 (-1.48)	-0.078 (-1.48)
Joint Venture dummy	0.024 (0.54)	0.021 (0.47)	**0.173*** (4.07)**	**0.173*** (4.05)**
Year dummy	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes
Adjusted R^2	0.12	0.12	0.25	0.25
Observation	283	283	416	416

See notes in Table 1.1.

Finally, in addition to the positive and significant effect of average wages on productivity, in the low-tech sector, coefficients of skill shares turn out to be positive and significant. In contrast, in the high-tech sector, we do not observe such skill effects, while positive effects of R&D and technology import remain robust. This difference between low-tech and high-tech sectors reveals that the development of technology may depend to a large extent on the improvement of labour quality and/or more labour-intensive activities in the low-tech sector.

Table 1.3. R&D expenditure, technology import and TFP (*by Ownership*)

Variable	Domestic		Joint venture	
	Without Interaction (1)	With Interaction (2)	Without interaction (3)	With interaction (4)
Lagged with one year				
R&D expenditure	-0.001 (-0.39)	**0.011** (2.05)**	0.002 (0.97)	0.002 (0.97)
Tech import expenditure	0.007 (1.44)	0.007 (1.46)	**0.004* (1.79)**	**0.005* (1.78)**
R&D x Tech import		**0.001** (2.99)**		0.0002 (0.10)
Average wage	**0.146*** (3.62)**	**0.138*** (3.38)**	**0.067** (2.91)**	**0.067** (2.91)**
Skill share	0.400 (0.21)	0.120 (0.62)	0.257 (1.39)	0.258 (1.38)
Year dummy	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes
Adjusted R^2	0.15	0.18	0.29	0.29
Observation	353	353	529	529
Lagged with two years				
R&D expenditure	0.003 (1.00)	0.008 (1.17)	0.003 (1.29)	0.004 (1.36)
Tech import expenditure	-0.001 (-0.23)	-0.002 (-0.24)	0.001 (0.38)	0.001 (0.38)
R&D x Tech import		0.0005 (0.88)		0.0002 (0.11)
Average wage	**0.129** (3.00)**	**0.124** (2.90)**	**0.072** (2.96)**	**0.073** (2.96)**
Skill share	0.124 (0.51)	0.157 (0.68)	0.320 (1.46)	0.322 (1.47)
Year dummy	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes
Adjusted R^2	0.12	0.13	0.28	0.28
Observation	279	279	420	420

See notes in Table 1.1.

After having examined the dimension of technology, we continue our analysis to look at the dimension of ownership. We merge SOEs and domestic non-SOEs into the domestic sub-group. The estimation from both domestic and joint venture sub-groups yield very poor results. The comparisons of results from Table 1.2 and Table 1.3 indicate that it is not ownership, but technology standards that make for the largest differences in the return on S&T activities.

Before moving on to the second step analysis, there are some methodological weaknesses in the above modelling that we are aware of. First, due to the data constraint, firm-specific effects cannot be properly controlled for, even if we can catch some of the fixed effects at the firm level using an ownership dummy variable. As a robustness check, we have also tried to estimate the model using a fixed-effect estimator. Unfortunately for a short panel such as this dataset, most of the variation is in the cross-section dimension. Second, we use lagged values of R&D expenditure and technology import to avoid potential endogeneity problems. Preferably, one may use an external instrument that is correlated with firms' R&D expenditure and technology import, but is independent of firm-specific effects. However, it is not an easy task to find such an external instrument in practice. We regard two-year lagged S&T variables as our best option. The differences in the results using one- and two-year lags to some extent indicate that the auto-correlation can be regarded as moderate. Finally, the quality aspect of S&T activities cannot be properly controlled for. In manufacturing sectors in Shanghai (or in China), the joint venture firms may employ better quality R&D, technology import and labour than are employed in domestic firms. There are also such quality differences in technology inputs across industrial sectors. Dividing the samples into ownership and technology sub-samples is our attempt to address these issues within the framework that the dataset permits.

To summarize, despite the methodological weaknesses outlined above, there are very interesting findings that we observe from the results. We find evidence indicating positive effects of R&D expenditure and technology import. These effects are robust when other important firm-level variables, yearly fluctuations and industry fixed-effects are controlled for. Nevertheless, the significance and magnitude of these effects vary depending on the lag structure and sector classification.

5.2 S&T activities and overall economic performance

In this section, we examine the effect of S&T activities on overall economic performance, applying simultaneously three performance indicators: productivity, profitability and export performance. This approach can be justified by referring to both theoretical and methodological advantages. First, when a comparison in performance is made, the productivity is the most commonly applied indicator. However, the profitability and export performance are two important performance indicators that are more directly observable. It is hard to believe that there is no relation among these performance indicators. The export performance and profitability are in practice the most important policy targets in the reform and restructuring processes. Second, one of the largest difficulties in this empirical analysis is the small number of observations. Applying seemingly unrelated regressions (SUR), we can obtain a more efficient estimation by accounting for correlated errors of these performance equations and overcome part of the difficulty caused by the sample size. The application of the SUR estimation and modifications of the specification in Equation (1) are straightforward. Together with productivity we insert two additional dependent variables, which are defined as the following:

$Profit_{it}$: Profit to total sales ratio.
$Export_{it}$: Export of new products to total sales ratio.[14]

We thus estimate a simultaneous equation system with three equations, where productivity, profitability and export of new products are dependent variables. We apply the same regressors as in Equation (1) for all three equations. Alternatively one may also use a different specification in each equation. We choose to use the same regressors in order to make the comparison of effects of S&T activities on various performance indicators more straightforward. R&D expenditure and technology import are lagged with one year as well as two years. To make the presentation concise, we present results from specifications with a two-year lag structure as our preferred final results and regard other alternative specifications as robustness checks.[15]

In Table 2.1 we make a comparison of the SUR-model estimation between the full sample in Column (1) and the sub-sample of the high-tech sector in Column (2). The results from the productivity equations are similar to the results in Table 1.1 and Table 1.2. The only notable difference is that the estimates are more efficient and standard errors are smaller in the framework of the SUR model compared to the OLS. We observe a significantly positive effect of R&D expenditure and joint venture firms seem to have a productivity advantage.

[14] One may argue the validity of this variable as a measure of export performance. First, this is the only indicator of exports since the volume of total exports is not available. Second, if R&D and technology imports are used in both production and/or product innovation, it is reasonable to assume that exports of new products have resulted from these S&T activities.

Table 2.1. Impact of S&T activities on TFP, profitability and export performance

Variable	Full sample (1)	High-tech sector (2)
Productivity equation		
R&D expenditure (2-year lag)	**0.004**** **(2.15)**	**0.006**** **(2.68)**
Tech import expenditure (2-year lag)	0.001 (0.43)	0.001 (0.20)
SOE dummy	-0.018 (-0.42)	-0.079 (-1.33)
Joint Venture dummy	**0.124***** **(3.20)**	**0.173**** **(3.06)**
Profitability equation		
R&D expenditure (2-year lag)	0.001 (0..65)	0.001 (0.73)
Tech import expenditure (2-year lag)	**-0.003*** **(-1.82)**	-0.002 (-1.01)
SOE dummy	**-0.068**** **(-2.18)**	**-0.082*** **(-1.91)**
Joint Venture dummy	0.042 (1.48)	**0.083**** **(2.02)**
Export performance equation		
R&D expenditure (2-year lag)	**0.001**** **(2.28)**	**0.001*** **(1.78)**
Tech import expenditure (2-year lag)	0.001 (1.15)	0.001 (0.90)
SOE dummy	-0.018 (-1.59)	-0.035 (-1.90)
Joint Venture dummy	0.001 (0.10)	-0.016 (-0.88)
Year dummy	Yes	Yes
Industry dummy	Yes	Yes
Observation	699	416
Breusch-Pagan test of Independence	Chi2 (3)= 74.9 Pr = 0.00	Chi2 (3)= 41.3 Pr = 0.00

***Notes*:** in all three equations the skill share and the log of the average real wage are included as additional control variables at the firm level. In the comparison of SOE and Joint Venture, the F-tests for the coefficients are computed. T-statistics, adjusted for the small sample, are given in brackets.
*** significant at the 1% level;
** significant at the 5% level.
* significant at the 10% level.

[15] Results from these robustness checks are available upon request from the authors.

In the profitability equation we do not observe any positive effect of R&D expenditure. On the other hand, technology import seems to have a negative effect on profitability in Column (1). Furthermore, SOEs have lower profitability compared to domestic non-SOEs, indicated by the significant and negative coefficients at the value of -0.068 in the full sample and -0.082 in the high-tech sector. Moreover, joint venture firms have higher profitability only in the high-tech sector compared to domestic firms.

Regarding export performance, R&D expenditure has a positive effect. The significant and positive coefficient at the value of 0.001 can be interpreted as an increase in 1% R&D expenditure yields a 0.1% increase in the export of new product to sales ratio. However, no differences in export performance associated with ownership structure can be observed.

The general impression from the SUR model estimation is that R&D expenditure and technical import do have some impact on productivity as well as on profitability and export performance. The joint ventures have not only productivity, but also profitability advantages compared to domestic firms, particularly in the high-tech sector. Why technology import has a negative effect on profitability is less clear. By dividing the sample into domestic versus joint venture sub-samples, some very interesting differences are revealed.

Table 2.2, Impact of S&T Activities on TFP, Profitability and Export Performance (*by Ownership*)

Variable	Domestic **(1)**	Joint venture **(2)**
Productivity equation		
R&D expenditure (2-year lag)	0.003 (1.14)	0.004 (1.60)
Tech import expenditure (2-year lag)	-0.001 (-0.33)	0.001 (0.42)
Profitability equation		
R&D expenditure	0.003 (1.24)	-0.0001 (-0.09)
Tech import expenditure (2-year lag)	**-0.016*** (-4.61)**	**0.004** (2.12)**
Export performance equation		
R&D expenditure (2-year lag)	0.001 (1.06)	**0.002** (2.26)**
Tech import expenditure (2-year -lag)	**0.002** (2.95)**	-0.0003 (-0.29)
Year dummy	Yes	Yes
Industry dummy	Yes	Yes
Observation	279	420
Breusch-Pagan test of Independence	Chi2 (3)= 63.26 Pr = 0.00	Chi2 (3)= 36.0 Pr = 0.00

See notes in Table 2.1.

Comparing results from domestic firms and joint ventures in Table 2.2, we observe that while technology import has a positive effect on productivity indicated by the significantly positive coefficient at a value of 0.004 in Column (2), the opposite emerges in domestic firms in Column (1), where we have a significantly negative coefficient at a value of -0.016. It may explain that the negative effect observed in the full sample is actually driven by these domestic firms. However, this result has to be interpreted with caution since the negative coefficient of technology import can be caused by two factors. First, there may indeed exist a negative relationship between technology import and profitability for domestic firms. Second, it may also be the case that domestic firms, particularly some SOEs, in general have much lower and even large negative profits, which drive this result.

To check this potential possibility of the later effect and the robustness of the negative relationship between profitability and technology import, we experiment with excluding domestic firms with the largest negative profits at the 10% and 20% percentiles. Re-estimations of the same model with the truncated sample yield the significantly negative signs as well.[16] Finally, it can also be the case that these low-profit firms show also lower productivity compared to other domestic and joint venture firms. Inspecting the correlation between the profit and productivity of these low-profit domestic firms, the correlation coefficient at a value of 0.05 does not support this hypothesis.[17] Taking this result as robust, the difference between domestic firms and joint ventures has important policy implications. When domestic firms rely on technology imports to achieve technical competitiveness in the market, they have to bear the increased costs related to these imports. This increased production cost in turn will affect their profitability negatively. In contrast, technology imports have a positive instead of a negative effect on profitability for joint ventures. It implies that joint ventures may have achieved not only a technology advantage, but also greater market success compared to their domestic counterparts, which makes them more profitable through technology imports. These differences can be explained by the following factors. First, in joint ventures, the foreign partners may have better knowledge of and access to more appropriate technology in the international market. Second, the intra-firm trade and the legal connection between foreign partners and their parent firms may also provide more efficient utilisation of technology and better international market access.

Furthermore, there is another interesting difference in export performance associated with ownership structure. For domestic firms, they rely on technology import while it is R&D expenditure that contributes to export performance for joint ventures. The significant and positive coefficient at the value of 0.002 in Column (2) can be interpreted as a 1% increase in R&D expenditure yields a 0.2% increase in the export of new products to sales ratio for joint ventures, while the same improvement in export performance is achieved by a 1% increase in the technology import of domestic firms in Column (1).

Finally, Breusch-Pagan tests in all these specifications indicate that the residuals of their performance equations are highly correlated. In other words, it is methodologically justified for the SUR model.

[16] The results from these robustness checks are available upon request from the authors.
[17] The correlation coefficient between productivity and profit is 0.19 for all domestic firms and 0.32 for all joint venture firms.

6 Concluding remarks

Given the speed and importance of the ongoing reform and the increasing attention paid to innovation as a new driving force for economic growth in China, it is important to investigate how S&T activities in various forms have contributed to industrial development and the implication of ownership structure on economic performance. Based on both aggregate information at the industry level regarding S&T activities and detailed firm-level information on a sample of manufacturing firms in Shanghai, we make an empirical assessment of the impact of in-house R&D expenditure and technology import on productivity, profitability and export performance.

First, S&T activities are positively related to manufacturing firms' productivities and have also positive effects on the growth of productivity. Generally speaking, technology import yields a return to productivity within a shorter time span while in-house R&D expenditure takes a longer time. Looking at the ownership dimension of productivity, our empirical results suggest that joint ventures are more productive than their domestic counterparts. However this superior performance of joint ventures cannot be observed in the sectors with a relatively low technology standard. It may indicate that ownership itself does not necessarily imply any technology advantage and the advantageous performance is the outcome of a combination of foreign participation and superior technology. It also explains why the government in Shanghai (or in China) is getting increasingly selective regarding joint venture formation and the joint ventures are more and more targeted in high-tech sectors.

Second, in addition to the direct effects of R&D expenditure and technology import, we also find evidence indicating a complementary relationship between these two factors. The implication, particularly for domestic firms, is that in the process of imitating and adopting existing technology, the absorptive capacity and the potential to innovate may also be enhanced. In other words, we share the view from Cohen and Levintal (1989) that the leaning effect, as a by-product of various S&T activities, is important for firms to improve their efficiency of technology transfer and upgrading in developing countries such as China.

Finally, when the effects of S&T activities on overall performance are investigated, we find also positive effects of R&D expenditure and technology import on export performance. The improvement of export performance is related to R&D expenditure in joint ventures while domestic firms rely on technology import instead. This difference reveals that exports of joint ventures may have higher value-added or better quality than exports of domestic firms. However, the results from the profitability equation are somehow mixed. While technology imports yield higher profitability for joint ventures, the domestic firms have lower profitability due to higher costs associated with technology imports.

These differences in overall performance have several important implications for future developments in manufacturing in Shanghai. First, joint ventures seem be to be successful in their S&T activities and they achieve superior performance in various respects. The advantages in productivity, profitability and export performance create necessary and promising conditions for potential spill-over effects in the domestic market. From domestic firms' point of view, the challenges facing them are prevalent. The catch-up process will not only be determined by their improved efficiency of technology adoption but also by their ability to gradually conduct their own innovation. For the time being their technology development is still to a large extent relying on imitation. Moreover, competitiveness has to be achieved not only through the upgrading of technology standards but also through market success. The negative link between technology import and profitability will eventually limit the financial possibilities of domestic firms to conduct innovation and will in turn impede the technology catch-up process.

To summarize, in this study we have focused on the direct and indirect effects of S&T activities on the performance of firms with various ownership structures. The differences in performance among domestic firms and joint ventures are to various extents related to differences in efficiency in technology adoption and in capability of knowledge creation. One important missing piece in this analysis is the pro-competitive effect that emerges in the process of industrial restructuring. Both technology transfer and intensified competition are important channels through which foreign participation and foreign ownership affect industrial development in the host country. In technology- and R&D-intensive sectors, the pro-competitive effect is particularly crucial. Empirical analyses that take both of these effects into account will be carried out on this topic as a further step in our future research.

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Table 1a. Summary statistics by ownership

	SOE		Domestic non-SOE		Joint venture	
Year	**1998**	**2003**	**1998**	**2003**	**1998**	**2003**
Value added/employee	0.09	0.15	0.30	0.70	1.05	1.97
Fixed Assets/employee	0.70	1.00	0.87	1.20	2.40	2.98
R&D investment/employee	0.27	2.88	0.19	1.75	2.37	4.98
Technology import/employee	0.11	1.50	0.01	0.28	1.27	3.19
S&T employee/total employee	0.09	0.06	0.05	0.06	0.04	0.06
No. of Employees per firm	1038	585	1236	865	867	944
No. of firms (total: 189)	45	45	29	29	115	115

The nominal variables are in 1000 yuan.

Table 2a. Distribution of joint ventures

Ownership	No. of firms
Joint venture Hong Kong, Taiwan & Macao	**26**
Joint venture Other countries	**71**
Foreign-owned	**18**
Total	**115**

Data appendix 1. TFP calculation

We calculate (log) TFP as

$$InTFP_{it} = \ln Y_{it} - \alpha_{Kj} \ln K_{it} - \alpha_{mj} \ln M_{it} - \alpha_{Lj} \ln L_{it}$$

where Y is real gross output, K real capital, L the number of employees and M the real material use. The α :s are shares of each factor in gross output. We deflate output, capital stock and material by the appropriate price deflators for Shanghai. Following Foster et al. and Disney et al. (2000), we calculate the factor shares at the 2-digit industry level to minimize the effect of measurement errors.

Data appendix 2. Ownership classification

In the original dataset, the ownership has a very detailed classification and totally 23 ownership indicators are included. In our empirical analysis, we merge and re-classify the firms into three subgroups:

Subgroup1 SOE	**Subgroup 2 Domestic non-SOE**	**Subgroup 3 Firms with foreign participation**
State-owned enterprises	Collective-owned enterprises	Foreign invested enterprise
	Private enterprises	Hong Kong-, Taiwan-, Macao-invested enterprises
	Limited liability enterprises	Foreign-owned enterprises
	Jointly operated enterprises	
	Stock-incorporated enterprises	

Data appendix 3. Sector classification

The industry codes in the dataset are at the 2- and 3-digit levels according to the ISIC, rev. 3 classification. Following the approach applied in Griliches (1984) and Hu et al (2003), we split the full sample into the following low- versus high-tech sectors:

Low-tech sectors	**High-tech sectors**
15: Food and beverage	241:Basic chemicals
16: Tobacco	244: Pharmaceuticals, medicinal chemicals and botanical products
17: Textiles	243: Man-made fibres
18: Clothing/Apparel	29: Machinery
19: Leather, footwear	30: Office machinery & computers
20: Wood products	31: Electrical machinery & apparatus
21: Pulp and paper	32: Radio, television, communication equipment
22: Publishing, print	33: Medical, precision instrument
23: Refined petroleum products	34: Motor vehicles, trailers
25: Rubber and plastics	
27: Metals and metal product	
36: Manufacture n. e. c	
No. of firms in the sample: 70	**No. of firms in the sample: 119**

Appendix 4. Additional results

R&D Expenditure, technology iport and TFP growth

Regressors			*By ownership*	
	Full sample (TFP growth)	**High-tech sector (TFP growth)**	**Domestic (TFP growth)**	**Joint venture (TFP growth)**
Lagged with one year				
R&D expenditure	0.002 (0.97)	0.003 (1.02)	-0.001 (-0.26)	0.004 (1.40)
Tech import expenditure	**0.006** (2.46)**	**0.006** (2.12)**	-0.001 (-0.13)	**0.010** (3.36)**
SOE dummy	**-0.096* (-1.75)**	-0.022 (-0.06)	-	-
Joint Venture dummy	0.052 (1.15)	**0.628** (2.05)**	-	-
Year dummy	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes
R^2	0.17	0.24	0.19	0.26
Observation	806	478	304	502
Lagged with two years				
R&D expenditure	**0.006** (2.31)**	**0.007** (2.36)**	0.011** (2.35)	0.005 (1.50)
Tech import expenditure	0.002 (0.47)	0.000 (0.02)	-0.005 (-0.81)	0.004 (1.2)
SOE dummy	-0.101 (-1.53)	**-0.220** (-2.28)**	-	-
Joint venture dummy	0.044 (0.81)	0.125 (1.45)	-	-
Year dummy	Yes	Yes	Yes	Yes
Industry dummy	Yes	Yes	Yes	Yes
Adjusted R^2	0.16	0.23	0.19	0.24
Observation	634	372	235	399

***Notes*:** in all the TFP growth equations, the lagged skill share and lagged average real wage in logs are included as additional control variables at the firm level. In the comparison of SOE and Joint Venture, the F-tests for the coefficients are computed. White's heteroskedasticity-consistent t-statistics are given in brackets.
*** significant at the 1% level.
** significant at the 5% level.
* significant at the 10% level.

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