Technology adoption and production organisation: Firm level evidence from India

Sourafel Girma and Sandra Lancheros[1]

Nottingham University Business School

Jubilee Campus, Wollaton Road

Nottingham, NG8 1BB

United Kingdom

Preliminary draft.

May, 2008.

Abstract

An emerging body of research in international economics is seeking to better understand the sources of firm heterogeneity and its relationship with the choice of production organisation. This paper contributes to this literature by providing a systematic empirical analysis of the impact of various production organisation strategies on the rate of technology adoption, a key driver of firm heterogeneity, using firm-level data from the software services and pharmaceutical industries in India. Our findings indicate the existence of heterogeneous effects resulting from the choice of production organisation on the dynamics of technology investment, highlighting the importance of taking industry characteristics, the interaction between the various forms of production organisation and the type of technology into account.

[1]Sourafel.girma@nottingham.ac.uk and Sandra.lancheros@nottingham.ac.uk

1. Introduction

A key feature of recent theoretical models in international economics is the insight that firms' heterogeneity influences their choice of production organisation such as exporting, importing, FDI and outsourcing (see Helpman, 2006 for a review). However, in spite of the remarkable empirical success of the pioneering models in this literature (e.g. Clerides et al. 1998 and Melitz, 2003), their fundamental assumption that firm heterogeneity is captured through exogenously determined and fixed productivity differentials remains unsatisfactory. This has led to the emergence of a body of work that seeks to understand the mechanisms by which firm heterogeneity is generated.

Yeaple (2005) offers a model in which heterogeneity results from firms' endogenous decision to employ alternative technologies and differentially-skilled workers. In a model of exports with heterogeneous firms, Bustos (2007) isolates technology investment as a key source of heterogeneity, while Lileeva and Trefler (2007) argue that exporting and investing in technology to raise productivity are both endogenous. Building a model of industry dynamics with innovation and export decisions, Constantini and Melitz (2007) show how anticipation of trade liberalisation leads firms to innovate in preparation for future participation in the export market. The model of Ederington and Mccalman (2008) predicts that heterogeneity arises in equilibrium as firms choose different dates to adopt a new technology. Atkeson and Burstein (2007) show conditions under which product and process innovation by monopolistically competitive firms shape their heterogeneity.

Focusing on firm level imports and productivity, Kugler and Verhoogen (2008, 2009) extend Melitz (2003) to generate a model in which heterogeneity in inputs leads to heterogeneity in productivity and output quality, and provide evidence that more productive plants purchase higher quality imported inputs. A much older literature stresses that firms engaged in foreign direct investment must possess some proprietary assets, such as a superior technology and knowledge that enable them to compete with local firms (e.g. Hymen, 1976). More recent papers have refined the theory of multinational firms by modelling jointly the relationship between knowledge capital, and the decision to engage in FDI and outsourcing (e.g. Chen et al., 2008).

We confront some of the predictions from the theoretical literature of technology investment and production organisation with recent firm level data from two highly globalised sectors in India, namely the software and pharmaceutical industries. Our analysis is also designed to inform future theoretical works geared toward the better understanding of the relationship between technology adoption and complex patterns of production organisation. To this end, we distinguish between trade in goods and services; inward and outward foreign direct investment, and outsourcing of professional and manual jobs

Our work is related to recent empirical papers on the impact of exporting on firms' innovation activity. Bustos (2007) provides empirical evidence from Argentina showing that firms in industries facing higher reductions in trade costs increase their investment in technology faster and exporters upgrade technology faster than other firms in the same industry. Baldwin and Gu (2004) and Aw et al. (2008, 2009) analyse the joint decision of exporting and innovation amongst firms in Canada and Taiwanese respectively, while Girma et al. (2008) conduct a comparative analysis of British and Irish firms' exporting

and innovation behaviour. We build on these works and contribute to the literature by considering a broader measure of technology investment that includes expenditures on in-house R&D, computers and software, royalty fees and imports of capital goods, as well as a fuller set of production organisation choices (exports, imports , outsourcing and FDI) within the context of a major emerging economy.

The policy relevance of this work stems from the fact that since 1990s Indian policy makers have been actively promoting international agreements and liberalising trade and FDI regimes in order to encourage technology acquisition by indigenous companies.

Controlling for unobserved firm heterogeneity and the endogeneity of the choice of production organisation, our analysis yields the following four core conclusions. Firstly, exporting intensity has a robust positive impact on the technology effort of Indian firms, although the magnitude of this impact varies according to the sector, ownership and type of exports. Secondly, the technology adoption ramifications of imports are more complicated. In general, the imports of services appear to substitute productivity-enhancing technology investment in the software service sector, this substitution effect being more pronounced amongst subsidiaries of outward and inward investors. By contrast, there is evidence of complementarities between the imports of intermediate goods and the rate of technology adoption. Thirdly, controlling for international trade effects, we uncover evidence of negative relationship between the share of foreign multinationals in local subsidiaries and the rate of technology investment in the software industry. But we also find an economically significant positive relationship between the level of outward FDI and domestic technology investment by Indian multinational firms in the pharmaceutical industry. Fourthly, we find that the outsourcing of professional jobs is associated with faster rates of technology adoption.

The next section illustrates how the interrelationship between firm heterogeneity, technology investment and choice of production has been modelled in the theoretical literature. Section 3 discusses the empirical model. Section 4 describes the dataset and sample characteristics. Section 5 discusses the main findings from the econometric estimations. Section 6 concludes.

2. Theoretical underpinnings

The theoretical underpinnings of this paper lie in models of exporting and investment developed, amongst others, by Bustos (2007), Lieeva and Trefler (2007) and Aw, Roberts and Xu (2009). As in Melitz (2003), we consider a single monopolistic competitive industry in which each of a continuum of heterogeneous firms produce a different brand. As described in Helpman (2006) the demand function for a particular firm's brand has a Dixit-Stiglitz form given by $x = Ap^{-\varepsilon}$, where x is the quantity, p is the price, A is an exogenous measure of the demand level, and $\varepsilon = \frac{1}{1-\alpha}$ is a constant elasticity of demand, with $0 < \alpha < 1$.

Before entering the market firms face uncertainty regarding their productivity level, θ. Upon entry they draw their productivity from a known cumulative distribution function, $G(\theta)$, and decide whether to exit the market or to start producing. If a firm chooses to produce, its profit-maximizing strategy is to charge $p = \frac{c}{\alpha\theta}$ when the variable cost per unit of output is $\frac{c}{\theta}$ and the fixed cost of production is cf_D, with c measuring the cost of production factors, which for simplicity is normalized to 1. The firm's operating profits can then be expressed as:

$$\pi = \varphi A - f_D \tag{1}$$

where $\varphi = (\varepsilon - 1)^{\varepsilon - 1} \varepsilon^{-\varepsilon} \theta^{\varepsilon - 1}$ is a transformed measure of firm's productivity, as in Lieeva and Trefler (2007).

Surviving firms (that is, firms whose productivity level is above the cut-off point $\varphi_D = \frac{f_D}{A}$) self-select into different international activities according to their productivity level and the fixed and variable costs associated with each activity. For instance, as illustrated by Helpman (2006), exporting entails a fixed cost f_X, and a per-unit melting iceberg trading costs, $\tau > 1$, so that τ units of output have to be shipped for 1 unit to arrive in the foreign country. Assuming that the foreign demand function for a particular brand is given by $x^* = A^* p^{-\varepsilon}$ only firms with a high productivity level find it profitable to enter the export market (those firms with a productivity level above $\varphi_X = \frac{f_X}{\tau^{1-\varepsilon} A^*}$). The firm's maximum profits as a function of its exporting decision are given by

$$\pi(e) = \phi\left[A + e\tau^{-\varepsilon} A^*\right] - ef_E \tag{2}$$

with $f_E = f_D + f_X$ and e=1 if the firm exports and e=0 otherwise.

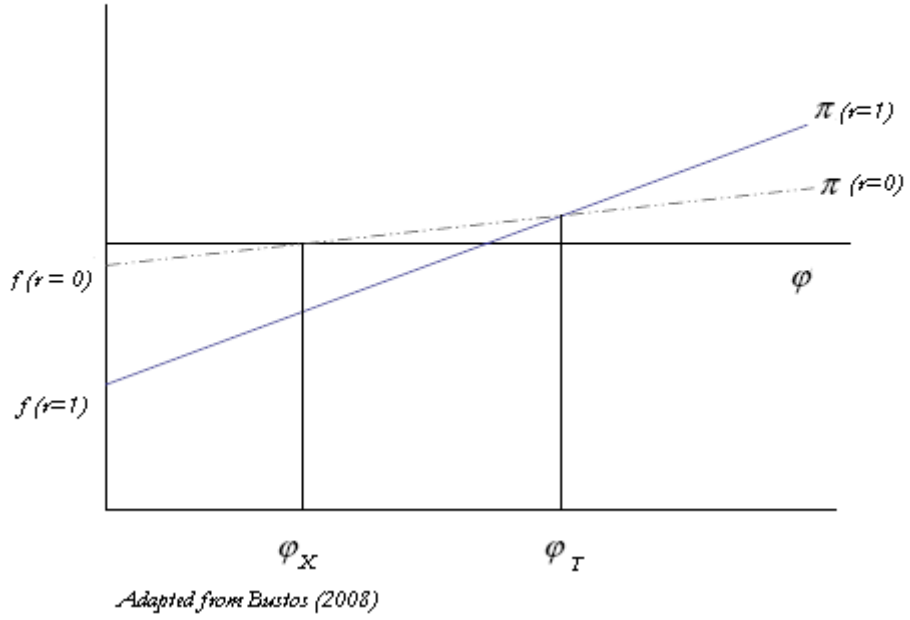
In addition to the exporting decision, firms can increase their productivity from φ to $\lambda\varphi$ $(\lambda > 1)$ by upgrading their technology, which requires the payment of an additional fixed cost f_I. The maximum level of profits for a firm investing in technology is given by:

$$\pi_r(e) = \lambda\phi\left[A + e\tau^{-\varepsilon} A^*\right] - ef_E - f_I \tag{3}$$

It follows that only firms with a productivity level above $\phi_T > \frac{f_I}{\left[A + e\tau^{-\varepsilon} A^*\right](\lambda - 1)}$ find it profitable to invest.

Bustos (2007) focuses on the case where the productivity level above which a firm finds it profitable to export and adopt a new technology is greater than the productivity level above which a firm is only induced to export, , that is, $\phi_T(e=1) > \phi_X$ (Figure 1). Under these restrictions, firms that only serve the domestic markets do not adopt a new technology and some firms find it profitable to export without technology upgrading.

Figure 1. Exporters' techology choice



Adapted from Bustos (2008)

Interestingly, Lieeva and Trefler (2007) consider the case in which f_I is large enough so that a firm will never invest in productivity enhancement without exporting. This situation is depicted in Figure 2 where firms are sorted according to their initial productivity, φ (expressed on the horizontal axis) and their productivity gains from investing, $(\lambda - 1)\varphi$ (represented on the vertical axis).

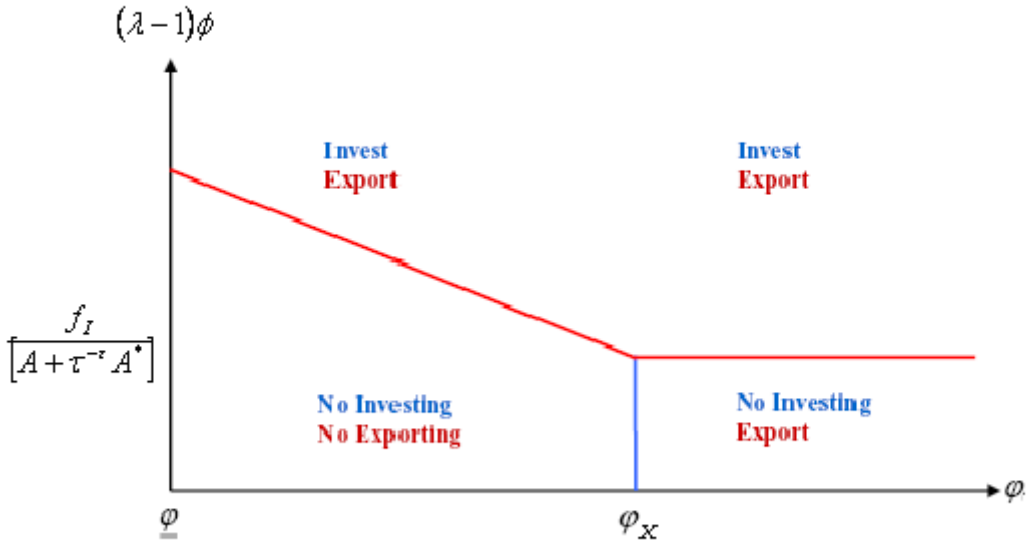
Lieeva and Trefler (2007) consider the following profits differences resulting from exporting and investing, and neither exporting nor investing

$$\pi_{e=1,r=1} - \pi_{e=0,r=0} = \left[\phi\tau^{-\varepsilon}A^* - f_X\right] + \left[(\lambda-1)\phi A - f_I\right] + \left[(\lambda-1)\phi\tau^{-\varepsilon}A^*\right] \quad (4)$$

This expression illustrates that the increase in profits is explained by the following three choices: (i) exporting without investing (first term in brackets), (ii) investing without exporting (second term brackets), and (iii) exporting and investing (third term in brackets). A firm chooses to export if $\varphi_X > \frac{f_X}{\tau^{1-\varepsilon} A^*}$, which is represented by the vertical line in Figure 2. Given that the firm is exporting, it decides to invest if the productivity gains are above the cut-off point $\phi_T(\lambda - 1) > \frac{f_I}{[A + \tau^{-\varepsilon} A^*]}$. This cut-off point is represented by the horizontal line in Figure 2. The region of interest for Lieeva and Trefler (2007) is where it is not profitable for the firm to export without investing or invest without exporting, so that the first two terms in (4) are negative. Firms that are indifferent between exporting and investing and neither exporting nor investing are located along the downward-sloping equation (5) in Figure 2:

$$(\lambda - 1)\phi = -\phi \frac{\tau^{-\varepsilon} A^*}{(A + \tau^{-\varepsilon} A^*)} + \frac{f_X + f_I}{(A + \tau^{-\varepsilon} A^*)} \qquad (5)$$

Figure 2. Optimal choices of exporting and investing



Adapted from Lieeva and Trefler (2007)

Our econometric model described in the next section accommodates more general modes of production organisation. Also unlike most theoretical models that express technology investment and exporting as binary choices for the sake of mathematical tractability, we use continuous variables.

3. Empirical approach

In this section, we describe out empirical approach to identify the effects of various forms of international product organisation on the rate of technology adoption. We specificy the following dynamic panel data model of technology investment with firm-specific heterogeneity:

$$\Delta TECH_{it} = \alpha TECH_{it-1} + \beta_1 PROD_{it-1} + \beta_2 SIZE_{it} + \beta_3 AGE_{it} + \gamma_1 TRADE_{it} + \gamma_2 FDI + \gamma_3 OUTSOURCIN \quad G_{it} + f_i + D_i + \varepsilon_{it} \qquad (6)$$

here *i* and t index firms and time periods respectively. The dependent variable ΔTECH denotes change in technology investment[2]; PROD is productivity, SIZE and AGE are firm size and age respectively, *f* denotes time-invariant firm-specific heterogeneity, D is a vector of time dummies and ε is a random error term.

Various strands of the endogenous growth literature agree that innovation and technological change are the chief sources of economic progress. There is however disagreement regarding the importance of persistence in innovation. On the one hand, there is the view that technological change is largely due to the process of creative destruction (e.g. Aghion and Howitt,1992) suggesting low level of firm-level persistence and perpetual renewal of innovators. On the other hand, some scholars emphasise that

[2] Detail of the construction of all variables used in this paper is discussed in the next section and summarised in Appendix A.

persistent innovators are at the heart of a bulk of technical innovation (e.g. Romer, 1990). In terms of our empirical model, the lower (higher) the level of persistence in technology investment, the closer the parameter α is to minus one (zero).

In the presence of high level of persistence in technology investment, a one-off policy measure designed to stimulate firms' technological efforts will have longer lasting effects. In order to design optimal technology policy, however, it is important to make sure that persistence, if any, is due to true state dependence rather than unobserved firm heterogeneity or other firm-specific characteristics. It is this consideration which motivated us to specificity a dynamic model with unobserved firm-specific heterogeneity as well as a host of control variables such as productivity, size and age. Firm age captures learning-by-doing effects, whereas firm size reflects the extent to which economies of scale enhance firms' ability to undertake performance-enhancing investment. Another important control variable we deploy is the lagged value productivity. Productivity is hypothesised to impact on the rate of technology adoption in two opposing ways. On the one hand, more productive firms are more likely to afford investing in further productivity improvements (cf. Bustos, 2007). On the other hand, less productive firms deciding not to exit the market are likely to accelerate their rate of technology investment in order to catch-up with their competitors. This is also consistent with the notion of firm level productivity-convergence (e.g. Bernard and Jones, 1996).

As discussed in the Introduction, the chief focus of this study is on the impact of international trade, FDI and outsourcing on the rate of technology adoption. In our empirical model *TRADE* is a vector consisting of four variables, namely services exports, services imports, good exports and imports of intermediate goods, while *FDI* comprises of

two variables capturing outward and inward foreign direct investment. *OUTSOURCING* is a two-variable vector of outsourcing of professional and manual jobs.

In order to obtain consistent and efficient estimators of our model parameters, we employ the dynamic panel data estimator due to Blundell and Bond (1998). This estimator has three distinct features that are suitable for our model. Firstly, it controls for firm-specific effects and helps distinguish true state dependence driving the dynamics of technology investment from unobserved heterogeneity. Secondly, it allows for the endogeneity of the model regressors, providing a more accurate description of the causal effect of the choice of production organisation on the rate technology adoption. Thirdly, the technique simultaneously estimates level and first-differenced models within a GMM framework. This ensures that the estimator does not suffer from the problem of weak instruments, especially in cases where the dependent variable is highly persistent. We test the appropriate of this estimator for our model and data via two routine tests applied in the literature: the Hansen/Sargan test for the validity of the overidentifying restrictions and the Arellano and Bond (1992) test for the absence of serial correlation in the equation error.

4. Database description and sample characteristics

We draw on the Prowess database compiled from audited company balance sheets and income statements by the Centre for Monitoring the Indian Economy, which is an independent economic think-tank headquartered in Mumbai. Prowess covers both publicly listed and unlisted firms from a wide cross-section of manufacturing, services, utilities, and financial industries. About one-third of the firms in Prowess are publicly listed firms. The companies covered by the database account for more than 70% of

industrial output, 75% of corporate taxes and more than 95% of excise taxes collected by the Government of India.

In this study, we focus on two highly-globalised sectors in India , software services and pharmaceutical industries, and study patterns of technology investment over the period 1997-2007. Table 1 gives the frequency distribution of the firms in the sample by year, ownership and industry. The number of Indian multinational companies started to show a marked increase after 2000. This increase is largely due to significant improvements in the regulatory framework governing Indian outward investment. For example, since 2000 Indian companies have been allowed to make overseas investments by market purchases of foreign exchange without the approval of the Reserve Bank of India up to 100% of their net worth, compared to the previous limit of 50%[3].

The main variables used in the regression analysis are defined in Appendix A and their summary statistics are given in Table 2. The growth in technology investment, defined as the sum of real expenditures on own R&D, royalty fees, computers, software and the imports of capital goods, has shown a marked increase in the second half of the sample (2001-2007) in both sectors under consideration . Table 2 shows that the exports of pharmaceutical industry are overwhelmingly in goods. Amongst exporters, the average exporting intensity, defined as the share of exports in total sales, is quite high in the software industry, reaching 71.9% in the case services exports during 2001-2007. It is also interesting to note that more 60% of firms in the pharmaceutical industry have imported intermediated inputs during the sample period, and in both sectors a substantial proportion (greater than 40%) of firms have been importing services. Regarding multinational firms, Table 2 reveals that the overseas investments by Indian firms as a

[3]Bank of India Master Circular No 01/2008-09, July 1, 2008.

proportion of their sales is substantially higher in the software industry compared to the pharmaceutical industry. On the other hand, foreign multinationals in both sectors are majority investors in their Indian subsidiaries, as measured by the average share of foreign capital in firms' total equity. We can also see that the outsourcing of professional jobs has exhibited a noticeable increase over the years.

Amongst the variables listed in Table 2 it is worth discussing the construction of the total factor productivity in more detail. The PROWESS dataset does not have a full set of labour input figures (e.g. number of total employees), but gives the total wage bill paid to employees instead. One practice adopted by researchers using this dataset is to impute employment by dividing the firm' total wages bill by average industry wage rates obtained from other sources. We do not follow this procedure in this paper since we conduct industry by industry analysis and industry wage rates are uninformative in the sense of being observationally equivalent to time dummies. We also think that imposing the implicit assumption of industry-wide equal wage rates is not realistic in light of well-documented evidence of substantial firm heterogeneity even within narrowly defined industries. Our approach for imputing employment consists of running a regression of the log of employment on the log of total assets and time dummies based on firms with *available* employment data[4], and using the elasticity from this regression to predict employment. We then estimate total factor productivity based on a three-input (labour, fixed capital and material inputs) production function using the Levinshon-Petrin (2003) technique. This technique has the advantage over more traditional fixed effect production function models in its ability to control for time-variant productivity shocks that are

[4] About 15% of the observations have employment data. As might be expected employment and total assets are highly correlated (more than 85% for both sectors) and the regressions give R-squared values of more than 75% and an elasticity of employment with respect to total assets equal to 0.92 for software services and 0.67 for the pharmaceutical industry.

correlated with the inputs. In order to check the sensitivity of our results to the construction of total factor productivity, we use an alternative measure of productivity, capital productivity, which is defined as the log of sales per fixed capital.

Table 3 gives average technology adoption premia to firms engaged in various forms of production organisation. Exporters, importers and multinational firms enjoy significantly higher rates of technology adoption as do outsourcing firms. The figures in Table 3 do not of course provide an accurate description of the relationships between technology and the choice of production organisation since they are based on simple pairwise t-tests without adequate control variables. Furthermore, as depicted in Figures 3 and 4, the majority of firms in both sectors are engaged in more than one mode of production organisation, and firms engaged in multiple production organisation activities account for a disproportionately high share of technology investment. In order to isolate the pure effects of each mode of production organisation on the rate of technology adoption, it is therefore important to control for a host of observable and unobservable firm characteristics. This is achieved within the dynamic panel data regression framework described in the previous section. We now turn our attention to the discussion of the regression results.

5. Empirical findings

The dynamic panel data estimates from our baseline model are reported in Table 4. It is reassuring to confirm that the GMM approach is appropriate as the diagnostic tests show the validity of the overidentifying restrictions and the absence of serial correlation in the equation error. We find that technology investment is moderately persistent both sectors, and there is evidence of conditional convergence with slightly faster convergence rate for the software industry. Interestingly, initial level of productivity has opposite effects on the

rate of technology adoption in the two sectors. For the software industry, lower productivity firms invest more in productivity improvement, possibly in order to catch-up with industry competitors. By contrast, initial productivity is positively associated with higher technology adoption rate in the pharmaceutical industry. Older firms exhibit higher rates of technology adoption in both industries, and firm size plays an economically significant role in firms technology upgrading. According to the point estimates from the dynamic panel data model, increasing firm size by 10% has the effect of increasing the annual rate of technology adoption by at least 2 percentage points in the short run alone.

Focusing on the relationship between exporting and technology investment, Table 4 shows that exporting intensity has a robust positive impact on the technology effort of firms. A 10 percentage point change in the intensity of goods exports would induce firms to increase their rate of technology investment by 1.11 to 1.76 percentage points, depending on industry and model specification. This is indeed an economically significant effect which is consistent with the notion that exporting is a channel of technology transfer. Service exports also enhance the process of technological upgrading, especially for pharmaceutical firms.

The results discussed above are based on regression models that do not distinguish between exports by multinational and non-multinationals firms. However, there is evidence in the literature of substantial intra-firm trade by multinational enterprises across various geographical locations (e.g. Hanson et al., 2005). This suggests that the technology investment implications of exports by multinationals enterprises are likely to depend on the location of production. Although we don't have data on the share of intra-firm trade, we explore this issue by interacting exporting and FDI in our technology adoption model.

The results from this experiment are reported in Table 5 and indicate that the technology-enhancing effects of goods exports are more pronounced amongst Indian multinational firms. By contrast foreign multinational firms exporting pharmaceutical services are engaged in less technology investment in the host country.

The econometric estimates reported in Table 5 provide evidence that imports of services appear to be substitutes for technology investment in the software industry. This substitution effect is stronger for foreign multinational firms, suggesting, albeit indirectly, that multinational enjoy high quality of services imports. By contrast, we find important complementarities between the imports of intermediate goods and the rate of technology adoption for non-multinational software firms. For the pharmaceutical industry, the overwhelming evidence is one of substitution between the imports of intermediate goods and the rate of technology investment. Taken together, these results point to the conclusion that the relationship between technology investment and importing in India is more complicated compared to the exports-technology nexus.

Controlling for exports and imports, does multinationality have any impact on the rate of technology upgrading? Based on the results reported in Table 5, the answer to this question depends on the sector in question whether the multinationals are Indian or foreign. For software industry firms, the higher the share of foreign multinationals the lower the rate of technology investment, all else constant. By contrast, for the pharmaceutical industry, we uncover strong evidence of a positive relationship between the amount Indian multinational firms are investing in their subsidiaries abroad and their technology investment at home. This is consistent with the notion of technology-seeking multinationals induced to invest in technology at home in order to increase the absorptive capacity of their domestic subsidiaries.

Table 5 shows that the outsourcing of professional jobs has beneficial effects on the technology upgrading in both industries, more so in the case of software services. This would appear to suggest that the sourcing of complex processes outside their core competencies offer firms the opportunity (via cost savings, for example) to invest in productivity-improving technology. We also found substantial technology upgrading effects resulting from the outsourcing of manual jobs in the pharmaceutical industries.

So far we haven't made the distinction between investment in physical and disembodied knowledge capital. To gain insight on the importance of the type of technology investment, we estimated separate models using knowledge investment (own R&D, royalty fees and software) and physical technology investment (imports of capital goods and computers purchases) as dependent variables. The findings from these exercises are reported in Tables 6 and 7. In general the type of technology investment matters for the magnitude and sometimes the sign of the estimated impact of the choice of production organisation. Noteworthy results include the finding of significant positive (negative) relationship between the share of foreign MNEs in their local subsidiaries and knowledge (physical technology) investment in the pharmaceutical industry. Thus it seems that the positive relationship between FDI and technology investment shown in Table 5 is largely driven by the beneficial impact of FDI on knowledge capital. It is also interesting to note that convergence rate in physical technology is faster compared to that in knowledge-based technology, perhaps a reflection of the higher barriers to undertaking R&D activities.

6. Conclusion

An emerging body of research in international economics is seeking to better understand the sources of firm heterogeneity and its relationship with the choice of production organisation. This paper contributes to this literature by providing a systematic empirical analysis of the impact of several modes of production organisation strategies on the rate of technology adoption, a key driver of productivity and hence firm heterogeneity, using firm-level data from the software services and pharmaceutical industries in India.

Using a dynamic panel data model of technology investment that accounts for unobserved firm heterogeneity and the endogeneity of the choice of production organisation, we uncover robust evidence that the exports of goods and services enhance firms' rate of technology adoption, while the imports of services substitute productivity-enhancing technology investment in the software services industry, especially for FDI firms. Our econometric estimates also reveal noticeable complementarities between the imports of intermediate goods, outsourcing and the rate of technology adoption. Furthermore we find a significant positive relationship between the share of foreign MNEs in their local subsidiaries and the growth in knowledge technology investment in the pharmaceutical industry.

Overall, our analysis shows the existence of heterogeneous effects resulting from the choice of production organisation on the dynamics of technology investment, highlighting the importance of taking industry characteristics, the interaction between the various forms of production organisation and the type of technology into account. The findings documented in this study have implications not only for the design of a well-targeted technology policy, but also for theories seeking to understand the channels

through which the choice of production organisation shapes firms' competitive advantages.

References

Aghion P. and Howitt P. (1992). "A Model of Growth through Creative Destruction". *Econometrica*, 60, 323-351.

Arellano, M. and S. Bond. 1991. "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations". *The Review of Economic Studies* 58: 277-97.

Atkeson, A. and Burstein, A. (2007), "Innovation, firm dynamics, and international trade," *NBER Working Paper* 13326.

Aw, B.Y., Mark J. R. and Daniel Y. X (2008), "R&D Investments, Exporting, and the Evolution of Firm Productivity," *American Economic Review, Papers and Proceedings*, Vol. 98, No.2 (May), pp. 451-456.

Aw, B. Y, Roberts, M.J and Xu, D. Y. (2009), "R&D investment, exporting, and productivity dynamics" *NBER Working Paper* 14670.

Baldwin, J. R. and Gu, W. (2004) "Trade liberalization: Export-market participation, productivity growth and innovation" , *Oxford Review of Economic Policy* 20(3), 372–392.

Bernard, A.B. and Jones, C.I., (1996). " Comparing apples to oranges: Productivity convergence and measurement across industries and countries", *American Economic Review* **86**, 1216–1238.

Blundell, R., and S. Bond (1998). "Initial conditions and moment restrictions in dynamic panel data models". *Journal of Econometrics* 87: 115-43.

Bustos, P (2007) "Multilateral Trade Liberalization, Exports and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinean Firms" *Working Paper,CREI*, Universitat Pompeo Fabra.

Chen Y, Horstmann, J. I and Markusen, J. R. (2008). " Physical capital, knowledge capital and the choice between FDI and outsourcing", *NBER Working Paper* 14515.

Clerides, S., Lach, S. and Tybout, J. R (1998) " Is learning by exporting important? micro-dynamic evidence from Colombia, Mexico, and Morocco". *Quarterly Journal of Economics*, 113(3), 903–947.

Constantini, J.A. and Melitz, M.J. (2008) "The Dynamics of Firm-Level Adjustment to Trade Liberalization" in Helpman, E., D. Marin, and T. Verdier(eds), *The Organization of Firms in a Global Economy*, Harvard University Press.

Helpman, Elhanan. 2006. "Trade, FDI and the organization of firms". *Journal of Economic Literature*, XLIV(3):589–630.

Ederington, Josh and McCalman Phillip (2008). "Endogenous firm heterogeneity and the dynamics of trade liberalization" *Journal of International Economics*, 74, 422–440.

Girma, S., Görg. H. and Hanley, A. (2008) "R&D and Exporting: Comparison of British and Irish firms" *Review of World Economic,* 144(4), 750-773.

Hanson, G., Mataloni, R. and Slaughter, M (2005). "Vertical Production Networks in Multinational Firms." *Review of Economics and Statistics* 87, 664-678.

Hymer, S. (1976), *The International Operations of National Firms: A Study of Direct Investment*, MIT Press, and Cambridge, MA.

Kugler, M and Verhoogen, E (2008), "The Quality-Complementarity Hypothesis: Theory and Evidence from Colombia". *NBER Working Paper* 14418.

Kugler, M and Verhoogen, E (2009) "Plants and imported Inputs: New facts and an interpretation Forthcoming, *American Economic Review Papers and Proceedings*.

Lileeva, A. and Trefler, D. (2007). " Improved Access To Foreign Markets Raises Plant-Level Productivity....For Some Plants" *NBER Working Paper* 13297

Levinsohn, J. and A. Petrin (2003), "Estimating production functions using inputs to control for observables", *Review of Economic Studies*, 70, pp. 317-34

Melitz, Marc J. 2003. "The Impact of Trade on Intra-Industry Reallocations and Aggregate Industry Productivity." *Econometrica*, 71(6), 1695-1725.

Romer , P. M. (1990). "Endogenous Technological Change", *Journal of Political Economy*, 98,S71-S102.

Yeaple, S. (2005), "A Simple Model of Firm Heterogeneity, International Trade, and Wages", *Journal of International Economics*, **65**, 1–20.

Figure 3: Technology investment and firm-year observations by number of production organization activities

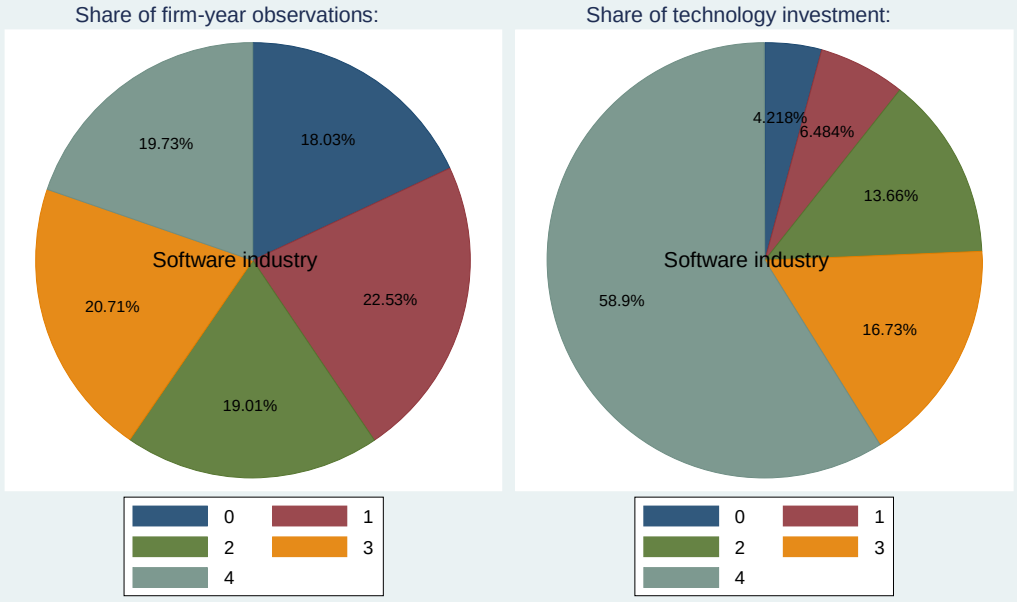
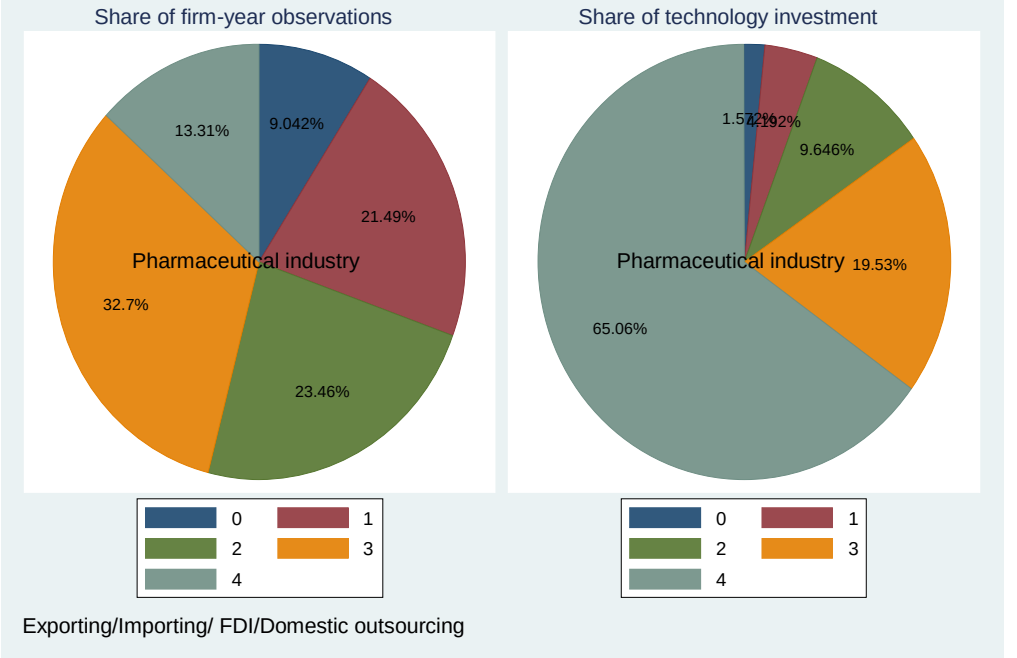


Figure 4: Technology investment and firm-year observations by number of production organization activities



Note: The industrial organisation activities under consideration are exporting, importing, FDI and domestic outsourcing. So, for example, a firm undertaking all of these activities will have a value of 4.

Table 1
Frequency distribution of firms
by year, ownership and industry

	Software industry				Pharmaceutical industry			
year	Non-MNEs	Indian MNEs	Foreign MNEs	Total	Non-MNEs	Indian MNEs	Foreign MNEs	Total
1997	112	1	8	121	217	1	25	243
1998	131	1	9	141	221	2	25	248
1999	211	2	12	225	238	2	27	267
2000	263	21	18	302	253	4	29	286
2001	245	55	21	321	223	20	31	274
2002	235	90	27	352	212	25	29	266
2003	285	91	30	406	243	29	26	298
2004	319	93	32	444	260	31	27	318
2005	263	106	28	397	236	33	27	296
2006	223	90	46	359	204	38	37	279
2007	154	87	47	288	152	36	34	222
Total	2,441	637	278	3,356	2,459	221	317	2,997

Table 2

Summary statistics of main variables of interest:

	Software industry				Pharmaceutical industry			
	1997-2000		2001-2007		1997-2000		2001-2007	
	mean	Std dev.	mean	Std dev.	mean	Std dev.	mean	Std dev.
Growth in technology investment	0.052	0.614	0.104	0.611	0.014	0.488	0.074	0.448
Log of technology investment	0.343	0.769	0.537	1.034	0.439	0.833	0.626	1.168
Total factor productivity	-2.958	1.466	-3.026	1.614	-4.205	0.928	-3.73	1.115
Capital productivity	-0.115	1.61	-0.257	1.708	0.288	1.43	0.221	1.488
Size	2.541	1.681	2.549	2.138	3.334	1.485	3.297	1.9
Log of age	1.992	0.706	2.266	0.671	2.701	0.806	2.937	0.705
Services exports dummy	0.399	0.49	0.497	0.5	0.078	0.268	0.113	0.316
Services exports intensity	0.569	0.378	0.719	1.133	0.019	0.084	0.027	0.083
Goods exports dummy	0.167	0.373	0.092	0.288	0.624	0.485	0.595	0.491
Goods exports intensity	0.423	0.398	0.398	0.404	0.22	0.267	0.274	0.266
Goods export /Total export	0.27	0.434	0.131	0.33	0.976	0.12	0.966	0.15
Services imports dummy	0.394	0.489	0.476	0.5	0.438	0.496	0.471	0.499
Services imports intensity	0.183	0.397	0.268	0.71	0.012	0.033	0.023	0.063
Intermediates imports dummy	0.237	0.426	0.116	0.32	0.681	0.466	0.606	0.489
Intermediates imports intensity	0.11	0.148	0.112	0.165	0.136	0.149	0.128	0.147
Services imports dummy	0.334	0.434	0.129	0.299	0.894	0.232	0.808	0.31
Indian multinationals dummy	0.035	0.185	0.296	0.456	0.009	0.092	0.123	0.328
Indian multinationals intensity	0.135	0.208	3.84	28.422	0.086	0.074	0.11	0.236
Foreign multinationals dummy	0.06	0.237	0.09	0.286	0.102	0.302	0.108	0.311
Foreign multinationals intensity	0.587	0.386	0.523	0.368	0.631	0.369	0.555	0.391
Outsourcing of professional jobs	0.045	0.326	0.084	0.351	0.003	0.023	0.028	0.249
Outsourcing of manual jobs	0.004	0.048	0.004	0.037	0.004	0.02	0.01	0.024

Note: see Appendix A for the exact definition of the variables used in this study

Table 3
Growth of technology investment:
Premia to exporters, importers, multinational and outsourcers

Group	**Software industry**	**Pharmaceutical industry**
Services exporters	0.396***	0.425***
Goods exporters	0.099***	0.452***
Services importers	0.413***	0.444***
Goods importers	0.273***	0.473***
Indian multinationals	0.364***	0.430***
Foreign multinationals	0.274***	0.256***
Outsourcers of professional jobs	0.250***	0.146***
Outsourcers of manual jobs	0.024	0.132***
Total observations	2536	2382

Notes:

a. All tests are based pairwise t-tests where the firms belonging to the group of interest is compared with all other firms.
b. significant at 10%; ** significant at 5%; *** significant at 1%

Table 4

Rate of technology adoption and production organisation:
Baseline model

Dependent variable: yearly change in log of technology investment

	Total factor productivity		**Capital productivity**	
	Software industry	**Pharmaceutical industry**	**Software industry**	**Pharmaceutical industry**
Lagged technology investment	-0.687***	-0.640***	-0.690***	-0.651***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Productivity	-0.021***	0.009***	-0.025***	0.040***
	(0.000)	(0.000)	(0.000)	(0.000)
Size	0.215***	0.246***	0.240***	0.242***
	(0.000)	(0.000)	(0.000)	(0.000)
Age	0.243***	0.143***	0.240***	0.147***
	(0.001)	(0.001)	(0.001)	(0.001)
Services exports	0.048***	0.370***	0.041***	0.432***
	(0.001)	(0.001)	(0.001)	(0.001)
Goods exports	0.164***	0.111***	0.176***	0.140***
	(0.001)	(0.000)	(0.001)	(0.000)
Services imports	-0.023***	0.876***	-0.012***	0.954***
	(0.001)	(0.002)	(0.001)	(0.001)
Intermediates imports	-0.060***	-0.572***	0.081***	-0.692***
	(0.004)	(0.002)	(0.003)	(0.001)
Indian multinationals	0.001***	0.150***	0.001***	0.163***
	(0.000)	(0.001)	(0.000)	(0.000)
Foreign multinationals	-0.223***	0.530***	-0.211***	0.437***
	(0.001)	(0.002)	(0.001)	(0.001)
Outsourcing of professional jobs	0.124***	-0.006***	0.142***	0.009***
	(0.001)	(0.000)	(0.001)	(0.000)
Outsourcing of manual jobs	-0.876***	0.436***	-0.811***	0.361***
	(0.002)	(0.002)	(0.002)	(0.003)
Total observations	2535	2380	2535	2382
Number of firms	594	454	594	454
Sargan test (p-value)	0.191	0.118	0.677	0.710
Serial correlation test (p-value)	0.940	0.926	0.628	0.597

Notes:
a. All results based on the "system-GMM " dynamic panel data estimator
b. Standard errors in parentheses
c. significant at 10%; ** significant at 5%; *** significant at 1%
d. All specifications include the full set of time dummies

Table 5
Rate of technology adoption and production organisation:

Dependent variable: yearly change in log of technology investment

	Total factor productivity		**Capital productivity**	
	Software industry	**Pharmaceutical industry**	**Software industry**	**Pharmaceutical industry**
Lagged technology investment	-0.734***	-0.738***	-0.734***	-0.745***
	(0.001)	(0.001)	(0.001)	(0.001)
Productivity	-0.040***	-0.002	-0.033***	0.067***
	(0.001)	(0.001)	(0.001)	(0.001)
Size	0.205***	0.228***	0.236***	0.242***
	(0.002)	(0.002)	(0.001)	(0.002)
Age	0.274***	0.164***	0.286***	0.137***
	(0.003)	(0.003)	(0.003)	(0.004)
Services exports	0.065***	1.598***	0.058***	1.347***
	(0.007)	(0.016)	(0.005)	(0.023)
Services exports * Indian MNE	0.039***	3.417***	0.047***	3.055***
	(0.005)	(0.031)	(0.004)	(0.031)
Services exports * Foreign MNE	0.221***	-1.107***	0.239***	-0.916***
	(0.005)	(0.024)	(0.006)	(0.029)
Goods exports	0.071***	0.240***	0.092***	0.244***
	(0.007)	(0.005)	(0.005)	(0.006)
Goods exports * Indian MNE	0.041***	1.328***	0.037***	1.313***
	(0.005)	(0.005)	(0.006)	(0.007)
Goods exports * Foreign MNE	0.286***	0.299***	0.269***	0.350***
	(0.008)	(0.011)	(0.006)	(0.008)
Services imports	-0.136***	0.765***	-0.130***	1.154***
	(0.009)	(0.022)	(0.008)	(0.021)
Services imports * Indian MNE	0.039***	-0.667***	0.009	-1.080***
	(0.010)	(0.036)	(0.009)	(0.028)
Services imports * Foreign MNE	-0.045***	-0.056	-0.004	0.093*
	(0.005)	(0.032)	(0.008)	(0.038)
Intermediates imports	1.650***	-0.676***	1.529***	-0.856***

	(0.028)	(0.018)	(0.026)	(0.013)
Intermediates imports * Indian MNE	-0.267***	-0.690***	-0.085***	-0.512***
	(0.029)	(0.006)	(0.024)	(0.007)
Intermediates imports * Foreign MNE	-3.121***	0.635***	-2.877***	0.489***
	(0.026)	(0.020)	(0.027)	(0.014)
Indian multinationals	-0.0001***	0.097***	-0.0001***	0.142***
	(0.00001)	(0.004)	(0.00001)	(0.005)
Foreign multinationals	-0.393***	0.309***	-0.391***	0.290***
	(0.005)	(0.007)	(0.006)	(0.009)
Outsourcing of professional jobs	0.096***	0.040***	0.092***	0.036***
	(0.002)	(0.001)	(0.003)	(0.001)
Outsourcing of manual jobs	-0.713***	0.799***	-0.727***	0.585***
	(0.004)	(0.018)	(0.005)	(0.020)
Total observations	2535	2380	2535	2382
Number of firms	594	454	594	454
Sargan test (p-value)	0.528	0.507	0.959	0.984
Serial correlation test (p-value)	0.867	0.855	0.966	0.869

Notes:

a. All results based on the "system-GMM " dynamic panel data estimator
b. Standard errors in parentheses
c. significant at 10%; ** significant at 5%; *** significant at 1%
d. All specifications include the full set of time dummies

Table 6
Disembodied knowledge investment and production organisation:

Dependent variable: yearly change in log of knowledge investment

	Total factor productivity		**Assets productivity**	
	Software industry	**Pharmaceutical industry**	**Software industry**	**Pharmaceutical industry**
Lagged knowledge investment	-0.703***	-0.738***	-0.692***	-0.741***
	(0.001)	(0.000)	(0.001)	(0.000)
Productivity	-0.076***	-0.019***	-0.055***	-0.025***
	(0.000)	(0.001)	(0.001)	(0.001)
Size	0.244***	0.171***	0.301***	0.189***
	(0.001)	(0.001)	(0.001)	(0.001)
Age	0.159***	0.161***	0.164***	0.173***
	(0.002)	(0.002)	(0.002)	(0.002)
Services exports	0.028***	0.697***	0.019***	0.796***
	(0.002)	(0.005)	(0.003)	(0.004)
Services exports * Indian MNE	-0.120***	7.926***	-0.121***	7.345***
	(0.002)	(0.016)	(0.003)	(0.016)
Services exports * Foreign MNE	0.516***	-0.237***	0.529***	-0.458***
	(0.004)	(0.014)	(0.003)	(0.013)
Goods exports	0.178***	0.065***	0.227***	0.067***
	(0.003)	(0.004)	(0.005)	(0.003)
Goods exports * Indian MNE	-0.396***	1.725***	-0.446***	1.731***
	(0.003)	(0.004)	(0.006)	(0.003)
Goods exports * Foreign MNE	0.283***	0.014*	0.243***	-0.130***
	(0.004)	(0.006)	(0.003)	(0.005)
Services imports	-0.141***	1.348***	-0.137***	1.254***
	(0.004)	(0.007)	(0.005)	(0.009)
Services imports * Indian MNE	0.255***	-1.609***	0.307***	-1.710***
	(0.005)	(0.015)	(0.006)	(0.013)
Services imports * Foreign MNE	-0.191***	-1.047***	-0.234***	-0.089**
	(0.003)	(0.040)	(0.004)	(0.029)
Intermediates imports	0.573***	-0.683***	0.531***	-0.641***
	(0.010)	(0.008)	(0.013)	(0.009)
Intermediates imports * Indian MNE	-0.502***	-1.662***	-0.350***	-1.746***
	(0.010)	(0.005)	(0.012)	(0.004)
Intermediates imports * Foreign MNE	-1.154***	1.380***	-0.958***	1.392***
	(0.010)	(0.010)	(0.018)	(0.010)
Indian multinationals	-0.001***	0.330***	-0.001***	0.340***
	(0.000)	(0.001)	(0.000)	(0.001)
Foreign multinationals	-0.365***	0.956***	-0.351***	1.000***

	(0.004)	(0.004)	(0.003)	(0.007)
Outsourcing of professional jobs	0.140***	-0.028***	0.117***	-0.039***
	(0.001)	(0.000)	(0.001)	(0.000)
Outsourcing of manual jobs	-0.862***	1.154***	-0.942***	0.603***
	(0.006)	(0.012)	(0.008)	(0.010)
Total observations	2586	2418	2586	2420
Number of firms	595	456	595	456
Sargan test (p-value)	0.639	0.649	0.962	0.966
Serial correlation test (p-value)	0.712	0.761	0.344	0.338

Notes:

a. All results based on the "system-GMM " dynamic panel data estimator
b. Standard errors in parentheses
c. significant at 10%; ** significant at 5%; *** significant at 1%
d. All specifications include the full set of time dummies

Table 7
Investment in physical technology and production organisation:

Dependent variable: yearly change in log of physical technology investment

	Total factor productivity		**Assets productivity**	
	Software industry	**Pharmaceutical industry**	**Software industry**	**Pharmaceutical industry**
Lagged physical tech investment	-0.960***	-0.919***	-0.960***	-0.950***
	(0.001)	(0.001)	(0.001)	(0.002)
Productivity	-0.061***	0.042***	-0.121***	0.208***
	(0.002)	(0.001)	(0.004)	(0.002)
Size	0.241***	0.262***	0.367***	0.453***
	(0.003)	(0.007)	(0.003)	(0.007)
Age	-0.560***	-0.112***	-0.600***	-0.408***
	(0.006)	(0.008)	(0.008)	(0.011)
Services exports	-0.076***	1.477***	-0.109***	0.281***
	(0.005)	(0.024)	(0.009)	(0.019)
Services exports * Indian MNE	0.573***	7.080***	0.558***	8.623***
	(0.004)	(0.086)	(0.009)	(0.116)
Services exports * Foreign MNE	0.537***	-2.733***	0.439***	-2.480***
	(0.008)	(0.041)	(0.007)	(0.043)
Goods exports	-0.568***	0.293***	-0.486***	0.182***
	(0.011)	(0.014)	(0.015)	(0.018)
Goods exports * Indian MNE	1.143***	0.924***	1.199***	1.149***
	(0.013)	(0.015)	(0.015)	(0.016)
Goods exports * Foreign MNE	0.851***	0.300***	0.675***	0.101***
	(0.012)	(0.049)	(0.011)	(0.029)
Services imports	0.137***	0.198***	0.174***	0.960***
	(0.009)	(0.037)	(0.013)	(0.061)
Services imports * Indian MNE	-0.030***	5.634***	-0.182***	3.534***
	(0.008)	(0.095)	(0.014)	(0.131)
Services imports * Foreign MNE	-0.516***	-4.328***	-0.350***	-2.995***
	(0.005)	(0.193)	(0.008)	(0.204)
Intermediates imports	-0.522***	-1.124***	-0.354***	-1.406***
	(0.033)	(0.032)	(0.029)	(0.034)
Intermediates imports * Indian MNE	0.854***	0.662***	1.031***	0.409***
	(0.042)	(0.010)	(0.057)	(0.018)
Intermediates imports * Foreign MNE	-0.256***	2.363***	-0.392***	2.630***
	(0.030)	(0.067)	(0.030)	(0.084)
Indian multinationals	0.001***	-0.721***	0.000***	-0.648***

	(0.000)	(0.011)	(0.000)	(0.014)
Foreign multinationals	0.327***	-0.671***	0.515***	-0.402***
	(0.011)	(0.039)	(0.013)	(0.031)
Outsourcing of professional jobs	0.116***	0.006**	0.083***	0.221***
	(0.005)	(0.002)	(0.003)	(0.002)
Outsourcing of manual jobs	-0.537***	2.665***	-0.450***	1.809***
	(0.011)	(0.078)	(0.008)	(0.086)
Total observations	2586	2418	2586	2420
Number of firms	595	456	595	456
Sargan test (p-value)	0.963	0.987	0.984	0.998
Serial correlation test (p-value)	0.497	0.507	0.05	0.02

Notes:

a. All results based on the "system-GMM " dynamic panel data estimator
b. Standard errors in parentheses
c. significant at 10%; ** significant at 5%; *** significant at 1%
d. All specifications include the full set of time dummies

Appendix A

Variable	Definition
Technology investment	The sum of real expenditures on own R&D, computers and software, royalty fees and imports of capital goods.
Knowledge investment	The sum of real expenditures on own R&D, software and royalty fees.
Physical technology investment	The sum of real expenditure on computers and imports of capital goods.
Size	Log of total assets
Capital productivity	Log of sales divided by fixed capital.
Total factor Productivity	Log of total factor productivity estimated based on 3-input (labour, fixed capital and material inputs) production function using the Levinshon-Petrin (2003) technique.
Age	Log of firm age since incorporation.
Services exports	Services exports/total sales
Goods exports	Goods exports/total sales
Services imports	Services imports/total sales
Intermediates imports	Intermediates goods imports/total sales
Indian MNE	Investment by Indian multinationals in their overseas subsidiaries divided by total sales.
Foreign MNE	The share of foreign finance in the firms' total equity.
Outsourcing of professional jobs	The value of outsourced professional jobs divided by total sales.
Outsourcing of manual jobs	The value of outsourced manual jobs divided by total sales.