R&D, Technology Imports and Total Factor Productivity in Indian Manufacturing: Revisited

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(Preliminary Draft)

Abstract:

The paper investigates into the impact of imported foreign technology and Total Factor Productivity on firm-level R&D intensity in Indian manufacturing during post-reforms. While determining the factors underlying R&D intensity, a firm specific model has been set up for econometric estimation. The role of foreign ownership is also studied. Hausman-Taylor estimation results show that Indian R&D is innovative for low technology industries but adaptive for high technology industries. This is also suggestive of the fact that the high technology industries do not get positively influenced by Total Factor Productivity. Older firms and small sized firms are found to invest in domestic R&D. Foreign ownership however, does not play any significant role in explaining R&D intensity of firms across sectors in Indian manufacturing.

Key words: R&D, Imported foreign technology, Total factor Productivity, Hausman-Taylor estimation.

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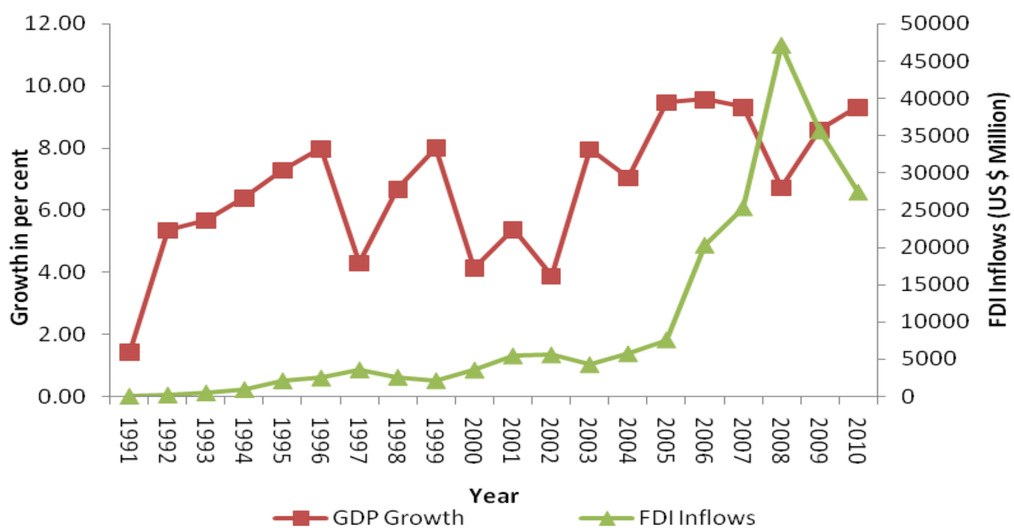
1. Introduction

This paper empirically investigates into the impact of imported foreign technology and Total Factor Productivity on local R&D and innovative activities of Indian manufacturing during post-reforms at the firm-level. With increasing FDI inflows, since liberalization, it is expected that there will be transfer of both embodied and disembodied technology through internalized modes to MNE affiliates and externalized modes of joint ventures, franchising, licensing, arm's length sales of capital goods, technical assistance, subcontracting or original equipment manufacturing. The technology choice set for firms thus widens. With increasing FDI inflows across sectors during post reforms India, domestic firms started reviewing their technology strategies by either investing in indigenous R&D or importing foreign technology or doing both. In this context two strands of arguments have emerged. First, there can be a rising dependence on imported technology, embodied and disembodied, in technology follower countries including India (Kumar and Saqib, 1996; Evenson and Joseph, 1999; Aggarwal, 2001). Second, in the face of competition, manufacturing industries often invest more in R&D to generate their own technology (Kumar, 1995). Technology activity across manufacturing sectors in India has evolved as a combination of technology generation and purchase, which is on account of a variety of reasons including improvement in the ability to assimilate foreign technology (Basant, 1993) as well as reaching a critical minimum level of R&D for the imported technology to be transferred (Katrak, 1994). Such choice of technology activity at the firm-level in the presence of MNEs can vary across sectors (Basant, 1997).

The Context

FDI inflows to India witnessed quantum increases since 1991. According to UNCTAD database, as Figure 1.1 shows, FDI inflows were higher during post-2000 as compared to the 1990s. Foreign direct investment inflows increased from US $ 75 million in 1991 to US $ 7622 million in 2005 and further to US $ 47, 139 million in 2008. FDI inflows declined thereafter to US $ 27, 431 million in 2010. Despite a slowdown after 2008, FDI inflows increased at an average annual rate of 50.53 per cent during 1991-2010. With higher FDI inflows, as Figure 1.1 shows, there has been a concomitant improvement in India's international competitiveness and growth. Herein lays the importance of technology choices.

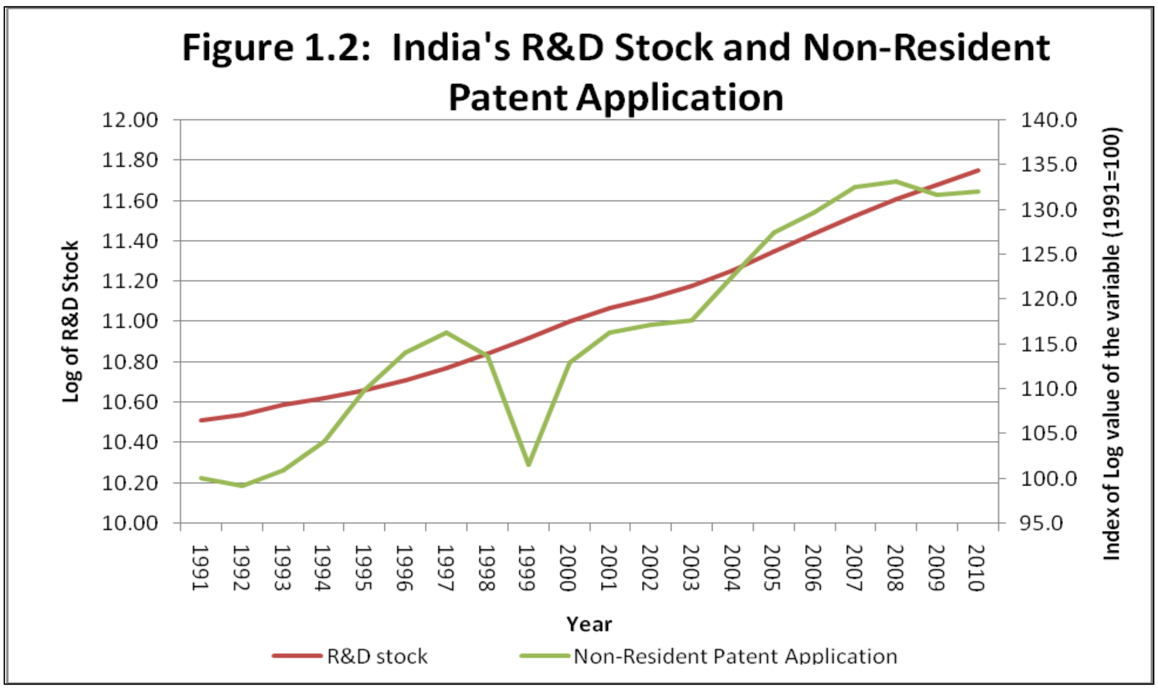
Figure 1.1: GDP Growth and FDI Inflows in India



Source: Reserve Bank of India and UNCTAD databases

The adoption of the WTO Agreement on the Trade Related Intellectual Property Rights (TRIPS) since the mid-1990s has significant implications for international technology markets and international technology transfer. India's technology indicators show improvements during post 1991 reforms. India's in-house R&D stock increased after 1991 along with an increase in non-residents patent applications in India during the same period, especially after 1999 (See Figure

1.2). Further, as Banerjee and Sinha Roy (2014) show, imports of embodied technology, capital goods in particular, increased significantly during this period. A rise in the R&D stock is indicative of an enhancing domestic technological capability, a rise in non-resident patent application in India corroborates to increasing multinational R&D activity in India. Further, such a pattern of development of technological capability in India can be explained, following Dinopolous and Segerstorm (2010), in terms of technology transfer within multinationals when IPR protection is strong in a southern country.



Source: Based on Banerjee and Sinha Roy (2014). Note: R&D stock is arrived at using the perpetual inventory method with a 20% depreciation rate on R&D expenditure at constant prices series available from Government of India, Department of Science and Technology Yearbook and UNESCO Statistical Yearbook. Data on Patents Application in number are obtained from World Intellectual Property Organisation (WIPO) database.

With increase in MNE operations in India since 1991, the hitherto protected domestic firms facing competition had to review their technology strategies. As technology followers, on one hand, it was expected that there would be a huge dependence on imported technology. Such imported technology might affect the total factor productivity of a firm leading to cost competitiveness. This might have a negative impact on the domestic R&D efforts. While on the other, it was also argued that the inward looking policies followed by India in the first three decades after independence have enabled the manufacturing industries to develop a high capital base. Hence, firms are likely to invest in local R&D as well.

The empirical literature on the issue of the impact of foreign technology imports and domestic R&D efforts have spawned into two different directions. The first approach finds a link between technology imports and local R&D while the second relates to the diffusion of the imported technology through knowledge and productivity spillovers to the locally owned firms. The nature of the relationship between technology imports and local R&D has been a matter of debate. For some (Blumenthal, 1979; Lall, 1993; Katrak, 1985), the relation is complementary while for some others (Kumar, 1987; Basant and Fikkert, 1996; Kathuria and Das, 2005; Chuang and Lin, 1999; Fan and Hu 2007) foreign technology import substitutes local R&D. One school of thought establishes that foreign firms can contribute directly or indirectly to the technological activities in the host country in order to adapt to local conditions, while the domestic firms in presence of competition from foreign firms may invest in technological activities. Lall (1983), Nelson (2004), Toimura (2003), Sasidharan and Kathuria (2011), Basant and Mishra (2014) and Kumar and Aggarwal (2005) provide evidence on complementarity. The other view is skeptic about the technological efforts of foreign firms in the host country as MNEs have easy access to the parent firm's technology (Globerman and Meredith, 1984; Fan and Hu, 2007) and domestic firms' in-house R&D, given huge costs and gestational lags. A large number of studies including Kumar (1987), Basant and Fikkert (1996), Kathuria and Das (2005), Veugeler and Van den Houte (1990), Lee (1996), Fan and Hu (2007), among others, find substitutability between technology imports and domestic R&D. The evidence is thus not conclusive with regards to the relationship between imported technology and domestic R&D. This is particularly intriguing when there is a difference in the behavioral pattern of the MNEs and domestic firms, as observed by Caves (1974). In a slightly different approach, Schmookler (1966) shows the impact of R&D growth on technological progress. This study reveals that technological progress could be result of R&D "embodied" in intermediate goods purchased by the sector apart from the R&D performed by the sector. Scherer (1982) for US manufacturing and Griliches and Lichtenberg (1984) empirically derive similar results.

There further exists a large empirical literature relating domestic R&D with factor productivity (Griliches 1988; Coe and Moghadam 1993). Literature support a positive and significant relationship between a firm's R&D investment and its productivity (Griliches and Mairesse, 1984; and Griliches, 1986, 1988). Mansfield (1980), using data across manufacturing industries of the US, shows that there exists a statistically significant and direct relationship between the R&D expenditure of a firm or an industry and its rate of increase in Total Factor Productivity. However, this relationship is found to be weaker at the industry level than at the firm level (Zhang et al., 2003). Chuang and Lin (1999) using firm level data from Taiwan find that a one percent increase in R&D intensity generates a 19.1 percent to 41.7 percent increase in firms' productivity. Hanel (2000) also finds a positive and significant relationship between industry's total R&D expenditure and the growth of total factor productivity (TFP). Coe and Helpman (1995) link productivity and R&D and suggest that a country's TFP not only depends on its own domestic R&D capital stock but also on its trade partners' R&D capital stock.

For Indian firms, Siddharthan (1992) finds out the determinants of in-house R&D and the effect of technology transfer on R&D. Considering R&D intensity as the dependent variable he finds a complementary relationship between R&D and technology imports. Similar results were derived by Katrak (1985), Odagiri (1983) and Siddharthan (1988). Furher, Basant and Fikkert (1996) suggest that R&D and technology purchase expenditures have significant impact on productivity of firms contradicting Ferrantino (1992).

Any further research on the issue in an emerging country such as India has to investigate into the role of imported foreign technology on the local innovative activities at a further disaggregate level as technology decisions in manufacturing are taken at the firm level rather than at the industry level. Again, as with technology imports factor productivity of firms get affected, this is likely to impact on the domestic R&D efforts of firms. The studies reviewed above do not take this fact into consideration in particular. This research work specifically revisits the various dimensions of impact of technology imports and Total Factor Productivity on the local R&D activities of Indian manufacturing from 2001-2010. In doing so, the study highlights on factors like foreign ownership, age and size of the firms in initiating domestic R&D. This is where the study, in particular, contributes to the existing literature.

The paper is organized as follows. Section 2 discusses the analytical framework, the empirical model and method, and the database for analyzing the determinants of R&D of Indian manufacturing. Section 3 presents the empirical results. Section 4 summarizes the major findings of the paper.

2. Analytical framework

2.1 The Theoretical Model

Suppose the production function of a representative firm is expressed as:

$$Y_{it} = A_{it} L_{it}^{\alpha} K_{it}^{\beta} I_{it}^{\gamma} \tag{2.1}$$

where Y_{it} is total sales of the i[th] firm at time t, A is TFP of the i[th] firm at time t, L_{it} is labour employed by the i[th] firm at time t, K_{it} is physical capital stock of the i[th] firm at time t, and I_{it} is imported inputs (import of capital goods and raw materials) by the i[th] firm at time t.

Replacing K, L and I by their respective demand functions[2], we get

$$Y_{it} = A_{it} C_{it}^{\alpha+\beta+\gamma} \frac{1}{(\alpha+\beta+\gamma)^{\alpha+\beta+\gamma}} \left(\frac{\alpha}{w}\right)^{\alpha} \left(\frac{\beta}{r}\right)^{\beta} \left(\frac{\gamma}{e}\right)^{\gamma} \qquad (2.2)$$

where C is the total cost, w, r and e are unit price of labour, capital and imported input respectively. The above equation can be modified to get the cost function as follows:

$$C_{it} = (\alpha+\beta+\gamma) \left(\frac{Y_{it}}{A_{it}}\right)^{\frac{1}{\alpha+\beta+\gamma}} \left(\frac{w}{\alpha}\right)^{\frac{\alpha}{\alpha+\beta+\gamma}} \left(\frac{r}{\beta}\right)^{\frac{\beta}{\alpha+\beta+\gamma}} \left(\frac{e}{\gamma}\right)^{\frac{\gamma}{\alpha+\beta+\gamma}} \qquad (2.3)$$

Dividing both sides by Y_{it} gives us an expression for ratio of cost to sales, denoted by C'_{it}, say.

$$C'_{it} = (\alpha+\beta+\gamma)\, A_{it}^{-\left(\frac{1}{\alpha+\beta+\gamma}\right)}\, Y_{it}^{\left(\frac{1}{\alpha+\beta+\gamma}-1\right)} \left(\frac{w}{\alpha}\right)^{\frac{\alpha}{\alpha+\beta+\gamma}} \left(\frac{r}{\beta}\right)^{\frac{\beta}{\alpha+\beta+\gamma}} \left(\frac{e}{\gamma}\right)^{\frac{\gamma}{\alpha+\beta+\gamma}} \qquad (2.4)$$

Now, $Y_t = \sum_i Y_{it}$ is the total industry output at time t. For the sake of simplicity we assume that $Y_t = 1$. Then we might interpret Y_{it} as the size of the firm, i.e., the ratio of sales of the firm to the industry sales. Logarithmic transformation of the above equation is as follows:

$$lnC'_{it} = ln\varphi - \left(\frac{1}{\alpha+\beta+\gamma}\right) lnA_{it} + \left(\frac{1}{\alpha+\beta+\gamma} - 1\right) lnY_{it} + \left(\frac{\alpha}{\alpha+\beta+\gamma}\right) lnw + \left(\frac{\alpha}{\alpha+\beta+\gamma}\right) lnr + \left(\frac{\alpha}{\alpha+\beta+\gamma}\right) lne \qquad (2.5)$$

In literature[3], the evolution of R&D capital stock over time is described as follows:

$$R_{it} = \sum_{k=1}^{n} \mu_k E_{t-k} + (1-\delta) R_{i,t-1} \qquad (2.6)$$

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[2] Input demand functions are obtained by maximizing production function subject to the cost constraint, $C_{it} = wL_{it} + rK_{it} + eI_{it}$. Sufficient conditions are examined.

[3] See Griliches (1980), Nadri (1980) and Goto and Suzuki (1989) for example.

R&D of the i^{th} firm at time t is the sum of all past R&D expenditures and depreciated R&D capital at time t-1. Here, μ_k is a distributed lag and δ is the rate of depreciation of R&D capital. However, we are considering R&D as the current period expenditure on R&D. It is very difficult to measure the growth of R&D expenditure for a firm (Mansfield, 1980); therefore it is customary to assume that a firm's expenditure on R&D during a particular year, approximately equal to that year's change in the firm's stock of R&D capital, rate of depreciation being significantly small (Griliches, 1980; Terleckyj, 1973). Since rate of depreciation is very small, we can assume that change in current year's R&D stock is approximately equal to current year's expenditure on R&D. Our assumption in this regard doesn't substantially differ from that of Griliches (1980), Terleckyj (1973) or Mansfield (1980). Thus, R&D is treated in our study as a sunk cost following many other similar studies[4]. Here, we distinguish between three types of costs, viz. production cost, marketing cost, and cost due to R&D denoted by ${C'}^{P}_{it}$, ${C'}^{M}_{it}$ and ${C'}^{R}_{it}$ respectively. Then equation (2.5) can be rewritten as:

$$ln{C'}^{R}_{it} = ln\varphi - ln{C'}^{P}_{it} - ln{C'}^{M}_{it} - \left(\frac{1}{\alpha+\beta+\gamma}\right) lnA_{it} + \left(\frac{1}{\alpha+\beta+\gamma} - 1\right) lnY_{it} + \left(\frac{\alpha}{\alpha+\beta+\gamma}\right) lnw + \left(\frac{\alpha}{\alpha+\beta+\gamma}\right) lnr + \left(\frac{\alpha}{\alpha+\beta+\gamma}\right) lne \qquad (2.7)$$

Hence we derive our estimable model as follows.

2.2 The Estimation Model

The model in the estimable form is as follows:

$$R\&D_{it} = \alpha_0 + \alpha_1(size_{it}) + \alpha_2({size^2}_{it}) + \alpha_3(age_{it}) + \alpha_4(mktcost_{it}) + \alpha_5(emtech_{it}) + \alpha_6(disemtech_{it}) + \alpha_7(own_{it}) + \alpha_8(TFP_{it}) + u_{it}$$

[4] For a detail note see Matraves (1999).

(2.8)

where, $\alpha_i > 0$ for i = 3, and $\alpha_i < 0$ for i = 4, 5, 6 and 8.

R&D: Ratio of R&D expenditure to sales.

size: Ratio of firm sales to industry sales.

age: Absolute age of the firm in number of years

mktcost: Ratio of summed up advertising expenditure, marketing expenditure and distribution expenditure to sales.

emtech: Ratio of the sum of expenditure on import of capital good, import of raw materials to sales.

disemtech: Ratio of import of foreign technical know-how to sales.

TFP: Total Factor Productivity measured by the semi parametric method of Levinsohn-Petrin.

own: A dummy variable, taking the value 1 if the firm is foreign, and 0 otherwise.

Method of Estimation and Data:

In our analysis we have used the Hausman-Taylor estimation technique. The Ordinary Fixed and Random Effect estimation methods are initially used to identify the control variables. Mundlak (1978) argued that the Random Effect models assume exogeneity of all regressors and the random individual effects. While, the Fixed Effect estimation models allows for endogeneity. Hausman and Taylor (1981) proposed estimation procedure where some of the regressors are correlated with the individual effects. The resulting Hausman-Taylor estimator bases upon an instrumental variable estimator which uses both between and within variations of the strictly exogenous variables as instruments (Baltagi et al. 2003, Cameron and Trivedi, 2010).

Specifically, the individual means of the strictly exogenous regressors are used for instruments for the time-invariant regressors that are correlated with the individual effects. As fixed effect models do not generate coefficients of time-invariant regressors, the Hausman-Taylor estimation becomes appropriate.

Firm-level data across sectors are obtained from Prowess Database published by the Centre for Monitoring Indian Economy (CMIE) for the period 2001-2010. A total of 5016 observations for Indian manufacturing as a whole include both domestically owned and foreign owned firms. 1942 firms for the chemical, 570 for the food and beverages, 1021 for the machinery, 202 for metal 821 for textile and 460 firms for transport equipment industry are considered for sector-wise analysis. The PROWESS database provides information on salaries and wages and provides no information on the number of employees. In order estimate Total Factor Productivity, labour data was required. We make use of the Annual Survey of Industries (ASI) database of the Central Statistical Organization (CSO) to mitigate the problem. The data on Total emoluments and Total persons engaged for the relevant industry were collected from the ASI database. This requires data matching. Such matching has been done at the two digit level. Since the time period under consideration is 1991 to 2010, concordance between NIC 1998, NIC 2004 and NIC 2008 classification of industries at two digit level has been done.

3 Estimation Results

Estimation results of Equation (2.8) presented in Table 1 provide certain important insights regarding the role of imported technology and Total Factor Productivity on R&D intensity of Indian manufacturing during post-reforms. Estimation results suggest that technology imports in disembodied form have a positive and significant relationship with R&D intensity for the Indian manufacturing as a whole. This is an indication of complementarity between imported technical know-how and local R&D. However, we find a nuanced view across sectors. Technology imports in disembodied form are negative for low tech industries like food, metal and textile and positive for high tech industries like chemical and transport equipments. This might suggest that Indian R&D is innovative for low technology industries but adaptive for high technology industries. Imported embodied technology remains insignificant across sectors. The only exception is the case of textiles where imported embodied technology significantly substitutes local R&D. Earlier studies, including Blumenthal (1979), Katrak (1990) and Kumar and Siddharthan (1997) also show that import of technology substitute in-house R&D activity. The influence of Total Factor Productivity is positive for most low tech industries like food and textiles but negative for high tech industries like chemical, machinery and transport equipment indicating that in-house R&D in high tech industries are not innovative and therefore does not get positively influenced by Total Factor Productivity. Older firms are found to invest in R&D across sectors, as age is found to have a significantly positive relation with firm-level R&D. This is an expected result as in the literature age of a firm shows the extent of a firm's learning experience leading to greater experimental and tacit knowledge (Bhaduri and Ray, 2004). The only exception in this respect is the metal industry where newer firms significantly invest in R&D. The estimation results also suggest that small sized firms tend to invest more in domestic R&D. This is against the common contention of size being considered to be a proxy for resource base, risk perception and economies of scale that crucially determines R&D activities of a firm (Kumar and Pradhan, 2003). Significant non-linear relationship also does not exist in this case. Foreign ownership doesnot play any significant role in explaining R&D intensity of firms in Indian manufacturing. This is true across sectors excepting the transport equipment industry where ownership significantly explains R&D intensity of this sector. It is interesting to note that transport equipments show an increase in export intensity in the post liberalized era. This is of particular importance as many joint ventures have been set up in India with foreign technical and financial collaboration. Expenditure on marketing, advertising and distribution significantly reduces R&D intensity of transport equipments while significantly negative for metals. However, for Indian manufacturing as a whole this relationship is significantly positive.

Table: 1 Hausman-Taylor estimation results

	Manufacturing Sector as a whole	Chemical	Food	Machinery	Metal	Textile	Transport
Ownership	0.0085493 (0.11)	0.1484874 (1.14)	0.0287194 (0.14)	-0.1227007 (-0.71)	0 .0520682 (0.23)	-0.0292313 (-0.20)	0.218899* (1.69)
Age	0.010817*** (13.60)	0.0099797*** (7.41)	0.0102429*** (4.65)	0.0185*** (9.61)	-.0155352** (-2.00)	0.003079*** (3.38)	0.0086507*** (4.73)
Size	-1.183271*** (-4.60)	-2.737944*** (-3.29)	-1.038373** (-2.06)	-1.913312*** (-3.16)	-0.1934946 (-0.53)	-0.0279013 (-0.07)	-0.8734346* (-1.96)
$Size^2$	0.0092916 (1.57)	0.0304946 (1.38)	0.0368618 (1.46)	-0.0201823 (-0.68)	-0.2260966 (-0.85)	0.0004366 (0.10)	-0.0216775 (-0.32)
Marketing Cost	0.0003017* (1.76)	-0.0892899 (-0.47)	-0.3740535 (-1.17)	-0.2850425 (-1.34)	0.018079*** (3.32)	-0.0036659 (-0.14)	-0.9530344* (-1.74)
Total factor productivity	-0.0032314* (-1.84)	-0.0036654 (-1.10)	0.0053868 (1.44)	-0.0113671** (-2.45)	-0.0064443 (-1.17)	0.0000421 (0.02)	-0.0020118 (-0.47)
Disembodied Foreign Technology	0.0115402*** (4.67)	0.0116678*** (3.65)	-223.3827*** (-3.25)	-0.4489904 (-0.29)	-15.75066 (-1.44)	-0.2638944 (-0.21)	3.033907 (1.41)
Embodied Foreign Technology	-0.0000213 (-0.56)	-0.0016062 (-0.06)	0.0050309 (0.05)	-7.28e-07 (-0.02)	0.0002106 (0.40)	-0.0010744*** (-5.37)	0.0031417 (0.04)
Constant	-0.1673625*** (-5.29)	-0.0813501* (-1.78)	-0.1673245*** (-2.36)	-0.3823574*** (-4.20)	-36.22958*** (-3.32)	-0.0247055 (-0.99)	-0.0587569 (-1.24)
Wald χ^2	227.87***	83.69***	43.52***	104.06***	21.43***	41.36***	35.02***
No of observations	5016	1942	570	1021	202	821	460

Note: (1) Z statistics are given in parentheses.
(2) Models are estimated considering total factor productivity and marketing cost as endogenous variables and Ownership as a time invariant variable.
(3)***denotes 1% level of significance, ** denotes 5% level of significance,* denotes 10% level of significance.

4. Conclusion

With liberalization and MNE operations, the hitherto protected Indian firms faced severe competition. The issue of technology acquisition and choices became very important in this context. R&D stock in India increased since 1990s, indicating improvements in technological capabilities of firms. At the same time, dependence on imported technology is evident. With MNEs operating in the Indian manufacturing, access to frontier technology is likely to affect the total factor productivity of firms. This might have a role in the technology choice of firms in terms of investing in R&D in particular; as such investments are generally sunk in nature. This paper tries to revisit the understanding of the factors determining R&D intensity of Indian manufacturing at the firm-level during post reforms. In this context the role of imported foreign technology, total factor productivity and foreign ownership in determining R&D intensity is understood. Hausman-Taylor estimation for the period 2001-2010 suggests that with MNE operations and technology inflow in Indian manufacturing during the post liberalized regime, research and development has turned out to be innovative for low technology industries but adaptive for high technology industries. Again, Total Factor Productivity is positive for most low tech industries but negative for high tech industries. This is suggestive of the fact that in-house R&D in high tech industries in Indian manufacturing is not innovative and therefore does not get positively influenced by Total Factor Productivity. Age of firms significantly explain R&D intensity of firms in Indian manufacturing suggesting that older experienced firms take the risk of investing in R&D. Small sized firms tend to invest more in domestic R&D and non-linearity does not hold good in this relationship.

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Appendix

Notes:

Recently, econometricians doing micro-econometric research have paid great attention to the problem of measuring total factor productivity (TFP). Presence of correlation between unobservable productivity shocks and input levels make OLS estimator biased. Use of investment as a proxy for these unobservable shocks might help (Olley and Pakes, 1996). However, this may produce inconsistent estimator especially when investments of firms are lumpy. In a semi-parametric model, using intermediate inputs instead of investment, Levinsohn and Petrin (2003) have addressed this simultaneity problem described by Marschak and Andrews (1944). Using intermediate input proxies instead of investment has many advantages. Since intermediate inputs are not state variables, it renders a simple link between the estimation strategy and the economic theory. From a practical point of view, one may say that use of intermediate inputs as proxies avoids truncating all the zero investment firms, as investment proxy is only valid for firms reporting nonzero investment. In our study, presence of large number of zero observation on investment impelled us to use Levishon-Petrin (2003) method to estimate total factor productivity considering use of energy as the proxy for unobservable productivity shocks. The brief idea of the estimation technique is as follows:

Here, we consider logarithmic version of a Cobb-Douglas type production function as follows:

$$\ln Y_t = \beta_0 + \beta_1 \ln L_t + \beta_2 \ln K_t + \beta_3 \ln M_t + \omega_t + \eta_t \tag{1}$$

where Y_t is the firm's output, commonly measured as the gross value added; L_t and $M_t$are labour and intermediate inputs respectively; and K_t is the use of capital. The two components of the error – the transmitted productivity component and the other component that is uncorrelated with input choices are denoted by $\omega_t$and η_t respectively. OLS estimation technique ignores correlation between ω_t, a state variable with other state variables considered in the production function engendering inconsistent results. Demand for intermediate input m_t[5] can be expressed as a monotonically increasing function of ω_t:

$$m_t = m_t(k_t, \omega_t) \tag{2}$$

To get the function for the unobserved productivity term, the above function can be inverted as follows:

$$\omega_t = \omega_t(k_t, m_t) \tag{3}$$

Finally we impose an identification restriction following Olley and Pakes (1996) that productivity is governed by a first order Markov process:

$$\omega_t = E[\omega_t | \omega_{t-1}] + \xi_t \tag{4}$$

where ξ_t is an innovation to productivity that is uncorrelated with k_t but not necessarily with l_t.

Now, equation (1) can be rewritten as:

$$\begin{aligned} y_t &= \beta_0 + \beta_1 l_t + \beta_2 k_t + \omega_t + \eta_t \\ &= \beta_1 l_t + \phi_t(k_t, \omega_t) + \eta_t \end{aligned} \tag{5}$$

[5] Variable written in small letters is the logarithm of the actual variable

where $\phi_t(k_t, \omega_t) = \beta_0 + \beta_2 k_t + \omega_t(k_t, m_t)$. Estimation is carried out in two stages. In the first stage, replacing $\phi_t(k_t, \omega_t)$ by a third order polynomial, equation (5) is estimated using OLS technique. In the second stage, estimated value of $\phi_t(k_t, \omega_t)$, say $\hat{\phi}_t$ and hence $\widehat{\omega}_t$ are calculated. Then, to calculate SEs of $\hat{\beta}_1$ and $\hat{\beta}_2$ a Bootstrap approach is used. Then finally appropriate moment conditions are used to estimate $\hat{\beta}_0$ and $\hat{\beta}_3$. When all $\hat{\beta}$ are estimated, we get the estimated values of TFP from the following equation :

$$\ln TFP_t = \ln Y_t - \hat{\beta}_1 \ln L_t - \hat{\beta}_2 \ln K_t - \hat{\beta}_3 \ln M_t - \hat{\beta}_4 \ln E_t$$