R&D Spillovers & Productivity Growth: Evidence from Indian Manufacturing

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This paper explores the linkage between R&D spillovers and productivity for a sample of Indian manufacturing firms for the period 2001-2012. The R&D spillovers is defined as the function of R&D (R&D, royalty and technical know-how) and information and communication technology (ICT). We consider two measures of productivity, namely total factor productivity (TFP) and labor productivity for analysis. Our results show that ICT, R&D and technical know-how impact TFP. For labor productivity, our results demonstrate that firms that are engaged in ICT and invest in technical know-how, are more productive than others. Thus, Indian manufacturing firms need to invest in information and communication technology, R&D and technical know-how to enhance their productivity. There are strong linkages among ICT, R&D, technical know-how and productivity

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Introduction

That the growth of total factor productivity (TFP) is energized by labor, capital and technology is a well-established fact in economics. Besides, new studies suggest that innovations, information & communication technology (ICT), learning and knowledge, trade and R&D spillovers also enhance the productivity within and across industries. Many studies indicated that international trade, FDI, ICT, R&D are the major channels of R&D spillovers (Miller &Upadhyay, 2000; Blalock & Simon, 2009, Mitra et al., 2016); however the findings have been mixed and do not establish a strong connection among these variables and productivity.

R&D Spillover & Productivity Growth

The linkage between R&D and productivity growth has been brought into focus by Griliches (1984; 1995). The empirical literature has analyzed R&D and its spillovers across countries, regions and industries. Across industries and firms level, the relationship between total factor productivity growth and R&D expenditure in the presence of inter-industry and international spillovers of technology was demonstrated by Hanel (2000) who stated that investing in R&D helps firms to innovate, increase the engineering capabilities and boost the absorption capacity to imbibe the industry-wide technologies and expertise. Essentially, R&D knowledge is typically set as an important driver of productivity growth, though this assumption has been challenged by Keller (1998). At macro level, Grossman & Helpman, (1990) showed that economic growth and productivity across countries can be enhanced through the adoption of new technology and its spillovers. Interestingly, these studies also revealed that technology gap between two parties drives the knowledge and R&D spillovers. They further demonstrated that absorptive capacity needs to exist in the form of R&D to bridge this gap. Clemes, Arifa and Gani (2003) stressed and brought the focus on developing human capital that can act as a catalyst for R&D spillovers.

The most interesting observation was given by Jaffe (1986) who demonstrated some empirical evidence on spillovers by creating a series on patent applications. This measure was used to evaluate homogeneity of research activities in the group of firms. Jaffe stated that external and in-house R&D efforts drive and impact the quantity of patent applications and the market value of the firm. Unfortunately this kind of measure cannot be constructed for the developing countries like India due to lack of data of patent and intellectual properties related information.

Cohen and Levinthal (1989) among others observed that to utilize the industry-wide R&D spillovers, a firm must invest in their own R&D center. They further indicated, if a firm in a less developed country would like to tap the benefit from the international R&D spillovers, they must purchase sophisticated technology from abroad, and above all perform in-house R&D to understand and improve upon the foreign technology. Park (2004) analyzed the relationship among productivity growth, trade and R&D spillovers and found that foreign R&D capital impacts more than the domestic R&D to promote total factor productivity. Besides, productivity is reported to be higher in export and more open industries, and the impact of foreign R&D capital is found to be stronger in the industries that have larger import stakes or large intra-industry trade portions.

R&D promotes innovation whereas human capital catalyzes output by private rates of returns.

Miller and Upadhyay (2000) demonstrated the roles played by R&D and human capital in stimulating productivity growth. It was found that R&D promotes innovation whereas human capital catalyzes output by private rates of returns.

Especially in the case of India, while R&D investments had not been very significant in local firms, the state is changing rapidly following the market reforms and trade liberalization in the last couple of years. In the context of India, Raut (1988) established the linkage among various R&D inputs like R&D expenditure, technical imports from developed countries and buying technical know-how from numerous sources. Further Raut (1995) worked on a production function by including R&D capital stock by terming it as the proxy of spillovers. Goldar (1986) worked out panel data of textile industry to evaluate the impact of market concentration and rate of protection on total factor productivity.

On the contrary, many researchers either do not find any concrete linkage between R&D and productivity (Basant& Fikkert, 1996; Sharma& Mishra, 2011) or find a relatively small influence of R&D spending on firms' productivity. Therefore, it is intended here to re-estimate the role of R&D intensity (R&D), calculated as the ratio of inhouse R&D expenditure to total industrial sales, as a proxy of research and innovation in India. Besides, it is also intended to take royalty and technical know-how fees as the proxy of R&D. The reason for this is that only those firms, who invest more than 1% of their sales into R&D, announce their expenditure. This will lead us to find the indirect commitment of the firms in research and development activities.

Information & Communication Technology

Today firms face a complex and highly dynamic environment. Information and communication technology (ICT) helps managers to gather market intelligence about their competitors, consumers, regulators and partners. ICT helps disseminate information within and outside of the firms that lead to improve quality and faster turnaround. While it was Solow (1958) who observed that sustained long run growth is obtained through innovations, as per latest literature on growth (Grossman & Helpman, 1990; Frankel & Romer, 1999) latest technological tools and processes emerged as the most important drivers that fuel innovation and productivity. Jorgenson (2001) and Stiroh (2002) termed ICT as the key component of economic development through augmenting the contributions to enhance productivity. They cited neoclassical growth theory and termed ICT as an important input similar to capital and labor in the production process which contribute to the output at the organizational level (Brynjolfsson & Hitt ,1995) and also promote gross domestic product (GDP) at the national level (Dewan & Kraemer, 2000). Apparently ICT is treated as a commodity and not a niche technology, given the evolution it has gone through in recent years which made it more affordable (Lin & Shao, 2006). While the technology evolution in ICT has been fast paced that impacted the TFP to a greater degree, its adoption has been equally quicker (Oliner & Sichel, 2000). Demeter et al. (2011) observed that ICT promotes efficient consumption of inputs through various means such as leveraging ERP or SCM software, leveraging better communication within firms and outside using phone, webcam, internet and external facing applications. This promotes the economic output and thus TFP.

Atrostic et al (2002) made several observations on ICT and its impact on productivity. They demonstrated that measurement of ICT is often done by ICT investments in firms. These investments facilitate faster information dispensation, new ways of communicating with vendors and customers and streamline the internal and external distribution and supply chain through sophisticated techniques. This can further reduce the capital needs, enhance the better utilization of production equipment and processes, manage the inventories in a better way and eventually lead to higher total factor productivity. Arvanitis and Loukis (2009) and Atrostic et al (2002) made a similar observation that ICT facilitates better communication, well-timed and extensive transfer of information; requires lesser staff to carry out the similar amount of work with much better decision making. Brynjolfsson and Saunders (2010) found that ICT helps to catalyze the productivity as lesser communication and IT costs promote firms to innovate through new products and services. Norton (1992) argued that not only firms, also the individuals enjoy the benefits of ICT by utilizing the price comparison techniques, acquiring the information at a lower price and faster way and leveraging the better jobs for themselves by employing new communication technology. Apparently this improves the overall economy.

On the contrary, many authors failed to find a strong link between ICT and productivity. An interesting observation was made by Carr (2003) who argued that due to its high availability, it became a commodity and hence the investments in ICT should be less and made with caution. He added that it is important not to become a leader to invest in ICT but then move as a follower to avoid surprises. Gordon (2010) also raised a question on the impact of ICT to promote productivity and stated that it is levied by diminishing returns. Melville et al. (2004) argued with a model of ICT business value based on resource based view and stated that while ICT investments provide value, its impact depends on levels of complementary resources, competitive climate and general macroeconomic environment. Baily (2002) demonstrated that while ICT is an important factor it was not the only lever to promote productivity; rather rivalry and globalization were the growth drivers to promote TFP. Dedrick et al. (2003) carried out a study across 15 different countries from 1987 to 2002 and failed to validate the link between ICT and productivity. More specifically, Holt and Jamison (2009) analyzed the impact of broadband (internet- a key factor of ICT) into productivity. They stated that broadband has a positive impact; however they failed to measure it with any precision.

It is important not to become a leader to invest in ICT but then move as a follower to avoid surprises.

On R&D front, Indian government has declared 2010-20 as the decade of innovation, however the R&D investment is still far lower in India than in developed countries and is close to 1% of its GDP as on 2010. Increasing gross expenditure to 2% of the GDP has been a national goal for some time. Achieving this in next few years is realizable only if private sector raises its R&D expense. The gross budgetary support for science and technology sector that promotes R&D has significantly increased during the last decade. The impact of such increase is becoming evident.

India's ICT policy 2010-2015 has been a key focus to facilitate computer education and develop the ecosystem for information and communication technology. The policy has two government funded schemes, namely, Educational Technology (ET) and Computer Literacy. The key goals of ICT policy are to create an environment to develop community knowledge around ICT, nourish an ICT literate community which can deploy, utilize, benefits from ICT and build an environment of collaboration, cooperation and sharing, conducive to the creation of a demand for optimal utilization of and optimum returns on the potentials of ICT in education. To achieve these goals, ICT literacy needs to be made mandatory in secondary schools, model curriculum needs to be created at the national level and states need to replicate it, investments have to be made to build appropriate infrastructure (network, connectivity, hardware, software), skill development has to be stressed upon across all levels, digital contents need to be adopted and most importantly implementation and monitoring need to be put in place.

In this paper, the panel data for two Indian manufacturing industries have been taken for the period of 2001-2012 to estimate how productivity of the firm influenced by its own R&D, royalty, technical know-how fee, and ICT expenditure. We create the series for R&D intensity, royalty intensity, ICT intensity, capital series, labor days and gross value added. To find the relationship among these factors, we will first estimate the TFP using Levinsohn and Petrin (2003) methodology. Following that we will run the fixed effects model, and random effects to test our empirical model. Finally, we will conduct the Hausman test to figure out which model fits into our bill.

The Research Problem & Contribution

This study defines the R&D spillovers by R&D, royalty and technology know-how and ICT and finds its linkages with TFP and labor productivity. While researchers tried to find the linkages between R&D spillovers and productivity previously, however no one defined R&D spillovers using R&D and ICT, the way this paper does, though many researchers tried to find the relationship among R&D and ICT and productivity separately. The contributions of this study to the existing knowledge are many as outlined below: Firstly, in order to validate the R&D spillovers- productivity link, many previous studies have not taken ICT and R&D together into account. We have taken R&D expenses and ICT expenditure as the R&D spillovers and tried to find their linkages with TFP and labor productivity. Secondly, there is a huge issue related to the R&D expenses in developing countries like India; if the firm's R&D expenses are less than 1% of the sales, it is not declared. This creates an issue on developing any model that comprises R&D. This issue was dealt by taking royalty and technical know-how fee as the proxy of R&D in our paper. Third, we used R&D intensity rather than a binary variable because of the fact that it tells us how much firms spent on R&D as a factor of its sales, as the R&D intensity of firms varies from less than 1% to 100%. Therefore placing same weight or number, for example 1, to those firms that are spending in R&D is problematic. Additionally, the use of R&D intensity is justified as it is an important indicator of the firm's participation in technological innovation. A similar approach has been adopted for ICT intensity which is termed as ICT expenditure as a proportion to industrial sales. Fourth, most of the previous studies considered only total factor productivity and ignored labor productivity which should have been a more appropriate measurement of productivity in the context of developing countries like India where the firms are more labor intensive. Therefore, in this paper, both, TFP and labor productivity have been taken into account. Fifth, the production function to calculate the TFP to depict firm's performance is a debatable topic in this area of research. To avoid the bias, many authors used innovative method of econometrics – fixed effect& random effect models along with Hausman test (Raut, 1995). We will also use the same. This provides the most consistent and unbiased estimates when compared to the previously used methods. Finally, the available literature on this issue did not cover Indian manufacturing firms especially with R&D and ICT taken together to find out their linkages with TFP and labor productivity. There are rarely any studies available in the Indian context that shares the evidence by using firm-level data with the most recent period.

Data & TFP Estimation

Prowess database is used to collect the information of Indian manufacturing firms from 2001 to 2012. Our sample covers 2 industries: computers (42 firms) and machine tools (56 firms). We selected these industries for analysis due to two reasons: first, the importance of the industry in the domestic economy in terms of employment generation, technology adoption, R&D & ICT expenditure and second, the relative magnitude of the industry in prowess database. Primarily we selected the industries where we have sufficient number of firms. Besides, the industries were also chosen based on the availability of the data. Firms where the data were missing for more than one year in the database have been excluded in this analysis. The data series extracted for the analysis are industrial sales, employee compensation, ICT expenses, expense incurred in raw material, power, fuel and energy, R&D. expenses, royalty and technical know-how fees, fixed capital and number of employees. As Prowess database does not provide the information about the number of workers employed by the firms, we obtained this information by first calculating the average wage rate for the industry (total employee compensation/ number of workers) and then divide each firm's compensation by the average wage rate of the industry to derive the information about the number of workers. The data series used in the analysis are deflated with appropriate deflators keeping base year 2001 before any econometrics treatment.

Variables used in this paper, their definitions, deflators if applicable and sources are given in Table 1.

The descriptive statistics of the data series are presented in Table 2.

Table 1 Variables used, definitions, deflators & the sources

Variable	Definition	Data Source
Output (Q)	Gross value added to the firm deflated by industry specific Wholesale Price indices (WPI)	Prowess WPI obtained from Office of the Economic Adviser (OEA), the Ministry of Commerce &Industry India (http://eaindustry.nic.in)
Labor (N)	Number of workers	Prowess
Capital (K)	Fixed Capital Stock of the firm deflated by Consumer price index	Prowess CPI obtained from Reserve Bank of India (http://www.rbi.org.in)
Raw material, power and fuel	Deflated annual expenses on raw material, power and fuel	Prowess
ICT intensity	Annual information and communication technology exp enditure/ industrial sales	Prowess
R&D Intensity	Annual R&D expenditure of the firms / industrial sales	Prowess
Royalty Intensity	Annual royalty and technical know-how fee expenditure/ earnings of the firms / industrial sales	Prowess

Table 2 Descriptive statistics of the data series

Variable	Obs	Mean	Std. Dev.	Min	Max
ICT Intensity	400	0.4181568	2.203593	0.000374	27.1875
R&D Intensity	230	0.164065	0.6947405	0.0000594	5.998588
Royalty Intensity	108	0.0259929	0.0553159	0.0001142	0.489579
Log(Labor)	626	4.425037	1.913617	-1.304681	8.810268
Log(Capital)	633	4.13249600	2.0005860	-2.52616100	9.989167
Log(GVA)	585	4.369347	2.119729	-2.620464	9.41659
Sales	640	1025.819	2703.407	0.1	22045
Log(Raw Material, Fuel and Water)	612	4.250265	2.341221	-2.302585	9.267599
Labor Productivity	626	1.229565	3.343501	0	80.46279
TFP	578	2.743067	2.486385	0.007622	29.39876

Empirical Models

To compute the TFP of each industry, we follow Cobb–Douglas production function as described in equation (1)

$$\text{In}Q_{ijt}=\beta_1+\beta_2\text{In } K_{it}+\beta_3\text{In } N_{it}+\omega it+uit \ldots\ldots\ldots\ldots(1)$$

Here Q, N and K are the firm's output (value added), workers and capital respectively in of i firm in period t. The error has two components: the transmitted productivity component (ω) and an error term that is uncorrelated with input choices (u). The important difference between ω and u is that the former is a state variable therefore affects the firm's decision rules. It is not observed and it can impact the choices of inputs, leading to simultaneity problem in production function estimation. To avoid this problem, the production function can be modeled as:

$$\beta_3\text{In}N_{ijt}+\varphi(\text{In}K_{it},\text{In}M_{it},InF_{it})+u_{it} \ldots\ldots\ldots\ldots(2)$$

Where M is intermediate input material and F is power and fuel. In the model

$$\varphi(\text{In}K_{it},\text{In}M_{it},InF_{it})=\beta_1+\beta_2\text{In}K_{it}+\omega it(\text{In}K_{it},\text{In}M_{it},InF_{it})\ldots\ldots\ldots(3)$$

To use the OLS estimator, we substitute a third-order polynomial approximation lnK, lnM and lnF in the place of γ (ln K ***ijt***, ln M ***ijt***, lnF ***ijt***)and we estimate β2 and intercept β1. This is the first stage of the estimation routine from Levinsohn and Petrin (2003).

The second stage of the routine identifies the coefficient β2. It begins by computing the estimated value for Φ*t* using

$$\varphi_t = ln\ Q - \beta_3 N_t \ldots\ldots\ldots\ldots(4)$$

For any candidate value β2, we can compute a prediction for ω*t* for all periods t using

$$\omega_t = Q_t - \beta_{k2} * K_t \ldots\ldots\ldots\ldots(5)$$

Using these values, a consistent (nonparametric) approximation to E ($\omega_t \mid \omega_{t-1}$) is given by

$$\omega_t = \gamma_0 + \gamma_1\omega_{t-1} + \gamma_2\omega_{t-1}^2 + \gamma_3\omega_{t-1}^3 + \varepsilon_t \ldots\ldots\ldots\ldots(6)$$

Residuals of production function are computed as:

$$\eta_t + \xi_t = ln\, Q_t - \beta_3\ \ln N_{it} - \beta_2 \ln K_{it} + \text{E}(\omega_t \mid \omega_{t-1}) \ldots\ldots\ldots(7)$$

We estimate the production function by minimizing the following model

$$\sum_t \left(ln\, Q_t - \beta_3\ \ln N_{it} - \beta_2 \ln K_{it} + \text{E}(\omega_t|\omega_{t-1})\right)^2 \ldots\ldots\ldots\ldots(8)$$

Finally, TFP is estimated as

$$\omega_t = ln\ Q_t - \beta_3\ \ln N_{it} - \beta_2 \ln K_{it} \ldots..(9)$$

In this study, all estimation is conducted using Stata-version 12 and Eviews-version 8.

Descriptive Statistics

Table 3 shows the preliminary observation among various categories in terms of R&D engagement and ICT expenditures. It shows some basic descriptive sta-

Table3 Primary observations among various categories pertain to R&D & ICT engagements

	Average TFP	Average Sales	Average Workers	Average Capital	Average Labor Productivity
ICT spending	3.0271	1178.2665	570.3985	649.2298	1.1279
No ICT spending	1.97	446.8025	306.8992	369.8069	0.5885
Engaged in R&D	3.47	2085.8530	890.3786	1042.8625	1.3713
Not engaged in R&D	2.03	558.7286	398.4200	458.5994	1.2064
Not engaged in R&D and no ICT spending	1.0506	339.3287	307.5576	346.3398	1.0403
Two Way engagement (ICT and R&D)	3.6884	2458.4556	830.7416	1397.0946	1.4712

tistics of our sample firms engaged in R&D and ICT spending. It is evident that firms that are not engaged in ICT spending, are not involved in R&D, or smaller in terms of sales, capital and number of employees.

Interestingly, the highest average TFP and labor productivity were recorded by two way engagements (firms engaged in R&D and ICT spending) followed by those who are engaged in R&D and those who are engaged in ICT spending. These results are in line with the findings of Andersson, Loof and Johansson (2008) on Swedish, and Sharma and Mishra (2015) on Indian firms.

R&D Spillovers: Linkages with TFP & Labor Productivity

The basic premise of this paper is that R&D spillovers are accelerated through:

- R&D, royalty and technical know-how (Goldar, 1986;Raut,1995; Sharma, 2014)
- ICT adoption–technology evolution fuels R&D spillovers and learning (Bryjnjolfsson & Hitt, 1995; Dewan & Kraemer, 2000;Lin & Shao, 2006)

In short, we consider R&D spillovers as a function of R&D and ICT adoption.

Our baseline model to examine the effect of ICT & R&D on productivity performance is given as:

$$\text{In}\, P_{it} = \beta_0 + \beta_1\ R\,\&\,DINT_{it} + \beta_2 RtyINT_{it}$$
$$+\beta_3\ ICTINT_{it} + \varphi_i + \varepsilon_{it} \ldots\ldots\ldots\ldots\ldots(10)$$

Here $\beta 0$ is the intercept; R&DINT indicates R&D intensity. RtyINT refers to royalty intensity. ICTINT represents ICT intensity. φ_i is the unobserved random first specific affect. ε_{it} is the error term that is also called disturbance term.i is the firm and t is the time period.

As the first step of our study, we carry out a pooled regression the outcome of which is presented in Table 4. However this can be biased due to endogeneity.

Econometrics Issues

While estimating equation 10, endogeneity (correlation between unobservable productivity shocks and input

Table 4 Outcome of pooled regression

Variable	TFP	Labor Productivity
Intercept	2.736149 *(6.38)	.8474253 *(4.92)
ICT Intensity	2.065569 *(4.3535)	5.3184873 *(4.52)
R&D Intensity	11.16094 *(5.63)	9.3729904(7.31)
Royalty Intensity	1.096227 **(1.43)	-.9083647(-1.13)
R2	0.3323	0.5989
Adj. R2	0.2838	0.5697
No. of observation	2532	2532

Note: t-statistics in brackets
* Significant at 5% level
* * Significant at 10% level

Table 5 Comparative Analysis among OLS, Fixed Effects, Random Effects and LP Estimators

Parameters	OLS	Fixed Effects	Random Effects	Levinsohn & Petrin
Labor	.8589(21.05)	.3316(5.42)	.5603(8.03)	.5108(4.04)
Capital	.4132(8.90)	.3705(4.67)	.3527(6.42)	.2645(2.89)
Sum	1.2721	0.7021	0.913	0.7753

Note: figures in brackets depict t-statistics for the first three columns and z-statistics for the last column

levels) looks to be a big issue and this can lead to biased estimation and incorrect results. Let us see how the outcome of pooled regression can be biased with respect to fixed effects, random effects and Levinsohn and Petrin (2003) methods for our sample firms. As it is evident from table 5, only OLS implies increasing returns for the equation. Whether the OLS coefficient on capital will be biased upward or downward depends on the degree of correlation among the inputs and the productivity shocks. In this particular application, the OLS estimate is more than the LP (Levinsohn and Petrin) estimate that validates the basic premise of Levinsohn and Petrin (2003) that due to productivity shocks, the endogeneity problems occurs. The fixed effects and random effects estimate differs from both the OLS and LP estimates. One explanation is that the magnitude of each firm's productivity shock varies over time and is not a constant fixed effect.

To resolve the econometrics issues associated with equation 10, fixed effects model or GMM(generalized method of moments)estimation (instrumental variables) can be used. Fixed effects model (FEM) primarily takes care of heterogeneity that may exist among the firms from our two industries. GMM estimator was developed by Arellano and Bover (1995) and Blundell and Bond (1998). The Blundell and Bond estimator (also termed as the system GMM estimator) combines the regression expressed in first differences (lagged values of the variables in levels are used as instruments) with the original equation expressed in levels (this equation is instrumented with lagged differences of the variables) and allows us to include some additional instrument variables. For our purposes, we will solve the endogeneity issue using fixed effects model. To select whether fixed effects model is better or the pooled regression, we will conduct a restricted F test.

Treatment of Econometrics Issues

To deal with the issue of heterogeneity, fixed effects model creates the dummy variables (firm specific dummies and time period dummies) using the following equation:

$$\ln P_{it} = \beta_0 + \beta_1\ R\&DINT_{it} + \beta_2 RtyINT_{it}$$

$$+ \beta_3\ ICTINT_{it} + \beta_5 FDUMMY_{5i} + ...$$

$$\ldots + \beta_{101} FDUMMY_{210i} + \varphi_i + \varepsilon_{it} \quad ......(11)$$

Equation (11) shows the firms dummy denoted by FDUMMY

Similarly time dummies are denoted by YDUMMY in the equation 12 as below:

$$\ln P_{it} = \beta_0 + \beta_1\ R\&DINT_{it} + \beta_2 RtyINT_{it}$$

$$+ \beta_3\ ICTINT_{it} + \beta_5 YDUMMY_{5i} + ...$$

$$\ldots + \beta_{15} YDUMMY_{15i} + \varphi_i + \varepsilon_{it} \quad .....(12)$$

We carry out fixed effects analysis the results of which are shown in Table 6

Table 6 Outcome of Fixed- Effects

Variable	TFP	Labor Productivity
Intercept	2.091667 *(5.23)	1.03990 *(2.36)
ICT Intensity	1.34562 *(4.38)	1.0908 **(1.43)
R&D Intensity	4.855704*(5.46)	4.060016(0.83)
Royalty Intensity (technical know-how)	12.2240 *(4.39)	8.6609 *(6.98)
Prob. > F	0.0029	0.0000
R2	0.7109	0.7922
Adj. R2	0.6233	0.6809
No. of observation	2532	2532

Note: t-statistics in brackets
* Significant at 5% level
* * Significant at 10% level

It is evident that ICT intensity, R&D intensity and royalty intensityare significant when regressed with TFP. The same when regressed with labor productivity, we get only ICT intensity and royalty intensity to be significant. The reason for the discrepancy in R&D with respect to labor productivity could be due to non-reporting of R&D expenses data. In India R&D expenses are usually reported only if they are more than 1% of total sales hence some of the firms may not have reported their R & D expenditures in their annual reports and were thus not included.

Apparently our results indicate that ICT, R&D and technical know-how (through royalty intensity) impact the TFP. For labor productivity, ICT and technical know-how (at 10% level) play an important part whereas R&D doesn't look to play any role.

In the random effects model, our equation will be modified as:

$$\ln P_{it} = \beta_0 + \beta_1\ R\&DINT_{it} + \beta_2 RtyINT_{it} + \beta_3\ ICTINT_{it} + \omega_{it} \text{ ....(13)}$$

We estimate equation (13) the outcome of which is shown in Table 7

Table 7 Outcome of Random- Effects

Variable	TFP	Labor Productivity
Intercept	3.1992 *(2.98)	.7298 *(5.12)
ICT Intensity	2.3350 **(1.61)	1.1990(0.18)
R&D Intensity	1.2997 *(4.62)	.3601936(0.12)
Royalty Intensity (technical know-how)	12.0233 *(4.21)	8.1299 *(4.82)
R2	0.4267	0.4903
Adj. R2	0.3902	0.4562
No. of observation	2532	2532

Note: t-statistics in brackets
* Significant at 5% level
** Significant at 10% level

On regressing the factors with TFP, ICT intensity (10%), R&D intensity and royalty intensity are significant. This indicates that R&D and its proxy, technical know-how and ICT, play an important role to influence TFP.

R&D and its proxy, technical know-how and ICT, play an important role to influence TFP.

Further, we observed that, for labor productivity, only royalty intensity is significant.

Having estimated fixed effects and random effects models, we see a slight difference between the two. To evaluate which model is better in the present example depends on the assumption made on the likely correlation between the cross-section specific error components (ε_i) and the regressors. On assuming that ε_i and regressors are uncorrelated, random-effects model may be appropriate, however if they are correlated, fixed effects model would be appropriate. This can be evaluated by Hausman test.

Our null hypothesis for Hausman test states that random effects model is appropriate whereas alternate hypothesis states that fixed effects model is appropriate.

It is evident from TFP and Labor Productivity in table 8 that probability (prob>chi2) is more than 0.0500 which means that we need to reject the null hypothesis and accept the alternate hypothesis. This proves that our fixed effects model is appropriate for TFP as well labor productivity. From the random effects

Table 8 Outcome of Hausman test

Test Summary		Fixed Effects		Random Effects
Chi-sq. d. f.		5.33		9.02
Prob>chi2		0.03789		0.5903
Test Summary for TFP	Fixed	Random	Var(Diff.)	Sqrt(diag(V_b-V_B)) S.E.
ICT Intensity	1.34562	1.0908	0.25482	1.470109
R&D Intensity	4.855704	4.060016	0.795688	13.172
Royalty Intensity	12.2240	8.6609	3.5631	5.7844
Test Summary for Labor Productivity	Fixed	Random	Var (Diff.)	Sqrt (diag (V_b-V_B)) S.E.
ICT Intensity	2.335	1.199	1.136	0.57212
R&D Intensity	1.2997	0.360193	0.939507	5.7889
Royalty Intensity	12.0233	8.1299	3.8934	2.3345

model, it is evident that linkages among ICT intensity,royalty intensity, R&D intensity and TFP exist. For labor productivity, the results show that ICT intensity and royalty intensity are the key factors that influence it.

From the random effects model, it is evident that linkages among ICT intensity,royalty intensity, R&D intensity and TFP exist.

Conclusion & Policy Suggestions

Our preliminary analysis results indicate that, in general, firms that are engaged in ICT (188%), R&D (230%) and both ways (251%) are more productive than those that are not engaged in ICT and R&D for TFP. The same population shows, firms that are engaged in ICT (8%), R&D (31%) and both ways (42%) are more productive than others in terms of labor productivity.

To find out the impact of R&D spillovers on TFP and labor productivity and to avoid the issues of serial correlation, we adopted a two pronged approach. Firstly we chose correct parameter estimates and then conducted fixed effects and random effects analysis, secondly we performed Hausman test to draw conclusion on choosing the right model for our analysis. As a final outcome, we observed that random effects model was the best fit for our analysis.

Our sample shows that linkages exist among ICT, R&D and technical know-how (royalty) and TFP. It is similar to the work done by Griliches et al. (1995) on R&D and productivity and Arvanitis and Loukis (2009) and Atrostic et al.(2002) on ICT and productivity, however all these researches are carried out individually. Further, we observed that, ICT and technical know-how (royalty) impact labor productivity. Here, R&D does not appear to play any role and this could be due to the fact that Indian firms do not disclose their R&D expenses if the expenditure is less than 1% of the total sales.

Therefore, based on these findings, it could be argued that R&D and ICT led growth policies appear to be favorable in India. Considering India's position in terms of growing engineering, scientific and IT-skilled community, a large pool of highly-skilled labor force and strong private sector, the country can push its stagnant manufacturing industry to invest more on the R&D. At the same time, the country needs to invest in ICT to fuel productivity.ICT can be promoted by facilitating computer education, skill development and developing an ecosystem for information and communication technology. Most importantly, government should build appropriate infrastructure (network, connectivity, hardware, software) and endorse digitalization (developing digital contents across) that augment ICT.

From our research it is also convincing that government policies should focus on research & development and ICT reforms to fuel the productivity growth. Furthermore, the significant impact of ICT on labor productivity is crucial for India because R&D spillovers through ICT could compensate the well-known poor R&D efforts of manufacturing firms in India. Overall it appears that R&D spillovers, productivity gain and modernization of firms through R&D and ICTare closely linked in the Indian machine tools and computer manufacturing, which is an encouraging sign for the future. Finally, the findings of present study provide scope for future studies taking up the large sets of data for heterogeneous businesses and re-validate whether R&D and ICT led productivity is a myth. Further research can be carried out to the specific nature of the R&D policies as to how they are influenced by factors like weaker intellectual protection, ways to dissipate public domain knowledge and industry learning. Likewise further research on ICT policies can be carried out such as on the impacts by the firm's policies on connectivity, hardware, software and network.

R&D spillovers through ICT could compensate the well-known poor R&D efforts of manufacturing firms in India.

Acknowledgements

The author acknowledges the valuable support by Dr. Chandan Sharma, faculty of Indian Institute of Management, Lucknow who shared his valuable comments while writing this paper.

References

Acharya, R. & Keller, W. (2007), "Technology Transfer through Imports" NBER Working Paper 13086, Cambridge, MA, National Bureau of Economic Research

Andersson, M, Loof H& Johansson, S (2008),"Productivity and International Trade: Firm Level Evidence from a Small Open Economy", *Review of World Economics/WeltwirtschaftlichesArchiv* 144(4): 774–801.

Arvanitis, S, & Loukis E, N. (2009), "Information and Communication Technologies, Human Capital, Workplace Organization and Labor Productivity: a Comparative Study Based on Firm-level Data for Greece and Switzerland", *Information Economics and Policy,* 21(1): 43–61.

Atrostic, B.K, Boegh-Nielsen P, Motohashi K & Nguyen S. (2002), "IT Productivity and Growth in Enterprises: Evidence from New International Micro Data", in Proceedings of the IAOS Conference on the New Economy, London

Baily, M.N (2002), "The New Economy: Post-mortem or Second Wind? Distinguished Lecture on Economics in Government", *Journal of Economic Perspectives* 16(2): 3–22

Basant, R. & Fikkert, B. (1996), "The Effects of R&D, Foreign Technology Purchase, and Domestic and International Spillovers on Productivity in Indian Firms", *Review of Economics & Statistics*,78(2): 187-99.

Blalock, G. & Simon D. H. (2009),"Do All Firms Benefit Equally from Downstream FDI? The Moderating Effect of Local Suppliers' Capabilities on Productivity Gains", *Journal of International Business Studies,* 40 (7): 1095-1112

Blundell, R. & Bond, S. (1998),"Initial Conditions and Moment Restrictions in Dynamic Panel Data Models", *Journal of Econometrics,* 87(1): 115–43.

Brynjolfsson, E & Hitt, L.M. (1995),"Information Technology as a Factor of Production: The Role of Differences among Firms", *Economics of Innovation and New Technology,* 3(3): 183–200

Brynjolfsson, E &Saunders, A. (2010),Wired for Innovation: How Information Technology Is Reshaping the Economy. MIT Press, Cambridge, MA

Carr, N.G. (2003), "IT Doesn't Matter", *Harvard Business Review* 81(5): 41–49.

Clemes, M D, Arifa, A. & Gani, A. (2003),"An Empirical Investigation of the Spillover Effects of Services and Manufacturing Sectors in ASEAN Countries", *Asia-Pacific Development Journal* 10(2): 29-40

Cohen, W.M & Levinthal, D.A, (1989), "Innovation and Learning: Two Faces of R&D", *Economic Journal* 99(2): 569-96.

Dedrick , J, Gurbaxani ,V. & Kraemer, K. L (2003),"Information Technology and Economic Performance: A Critical Review of the Empirical Evidence", *ACM Computing Surveys* 35(1): 1–28

Demeter, K., Chikán, A. & Matyusz , Z. (2011),"Labor Productivity Change: Drivers, Business Impact and Macroeconomic Moderator", *International Journal of Production Economics*, 131(1):215–23.

Dewan, S & Kraemer, K.L (2000),"Information Technology and Productivity: Evidence from Country-level Data, *Management Science,* 46(4):548–62

Frankel, J.A & Romer, D. (1999), "Does Trade Cause Growth"?*American Economic Review,* 89(3): 379–90

Goldar, B. N. (1986), Productivity Growth in Indian Industries, Delhi: Allied Publishers.

Gordon, R.J. (2010), "Revisiting US Productivity Growth over the Past Century with a View of the Future", National Bureau of Economic Research Working Paper Series No. 15834

Griliches Z.& Mairesse, J. (1995), Production Functions: The Search for Identification, Cambridge, MA: National Bureau of Economic Research.

Griliches, Z. (1984), R&D, Patents, and Productivity, Chicago, IL:University of Chicago Press.

Grossman, G & Helpman, E (1990), Innovation and Growth in the Global Economy, Cambridge, MA: MIT Press

Hanel, Peter, (2000), "R&D, Inter-industry and International Technology Spillovers and the Total Factor Productivity Growth of Manufacturing Industries in Canada, 1974 – 1989", *Economic Systems Research*,12 (3):345-61

Holt, L & Jamison, M. (2009), "Broadband and Contributions to Economic Growth: Lessons from the US Experience", *Telecommunications Policy,* 33(10–11): 575–81

Jaffe, A.(1986),"Technological Opportunity and Spillovers of R&D: Evidence from Firm's Patents, Profits and Market Value", *American Economic Review,* 76(5): 984-1001.

Jorgenson, D. W. (2001)," Information Technology and the US Economy", *American Economic Review,* 91(1):1–32.

Levinsohn, J. & Petrin, A. (2003), "Estimating Production Functions Using Inputs to Control for Unobservable", *Review of Economic Studies,* 70(3): 317–41.

Lin, W.T. & Shao, B.B.M. (2006), "Assessing the Input Effect on Productive Efficiency in Production Systems: the Value of Information Technology Capital", *International Journal of Production Research,* 44(9): 1799–1819

Melville, N., Kraemer, K. L. & Gurbaxani, V. (2004), "Review: Information Technology and Organizational Performance: an Integrative Model of Its Business Value", *MIS Quarterly,* 28(2):283–322.

Miller, S., & Upadhyay, M. (2000),"The Effects of Openness, Trade Orientation, and Human Capital on Total Factor Productivity", *Journal of Development Economics,* 63 (2):399-423.

Norton, S.W. (1992), "Transaction Costs, Telecommunications, and the Microeconomics of Macroeconomic Growth", *Economic Development and Cultural Change,* 41(1): 175–96

Oliner, D.S & Sichel, D. E. (2000),"The Resurgence of Growth in the Late 1990s: Is Information Technology the Story"? *Journal of Economic Perspective,* 14(4): 3–22

Park, Jugsoo (2004)," International and Intersectoral R&D Spillovers in the OECD and East Asian Economies", *Economic Inquiry,* 42(4): 739–757.

Raut, L. K. (1995),"R & D Spillover and Productivity Growth: Evidence from Indian Private Firms" *Journal of Development Economics,*48(1): 1-23.

Raut, L.K. (1988),"R&D Behaviors of Indian Firms: A Stochastic Control Model", *Indian Economic Review,* 23(2): 207-29.

Sharma, C & Mishra, R.K (2015), "International Trade and Performance of Firms: Unraveling Export, Import and Productivity Puzzle", *The Quarterly Review of Economics and Finance,* 57(1): 1–14.

Sharma, C. (2014),"Imported Intermediate Inputs, R&D, and Productivity at Firm Level: Evidence from Indian Manufacturing Industries", *The International Trade Journal,* 28(3): 246–63.

Sharma, C & Mishra, R. K. (2011),"Does Export and Productivity Growth Linkage Exist? Evidence from the Indian Manufacturing Industry" *International Review of Applied Economics,* 25(6): 633–52

Solow, R. M. (1956), "A Contribution to the Theory of Economic Growth", *Quarterly Journal of Economics,* 70: 65-94

Stiroh, K. J (2002),"Are ICT Spillovers Driving the New Economy"? *Review of Income and Wealth* 48 (1): 33–57