R&D SPILLOVERS AND PRODUCT MARKET COMPETITION

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ABSTRACT

The paper analyses R&D spillovers from Indian domestic firms under high competition and low competition market situations. Our initial investigation supports the earlier findings that significant R&D spillovers are present in Indian manufacturing industry. Furthermore, strong evidence has been found that spillovers are influenced by product market competition. However, results depend on the choice of the parameter used to measure competition level. When Price-Cost Margin (PCM) is used, we find that high R&D spillovers are significantly associated with low competition. Results are contrary to this when PCM is replaced by Herfindahl-Hirschman Index (HHI): large spillovers from R&D are observed when competition is high, with no significant spillovers in the less competitive market.

1. INTRODUCTION

Innovations, famously known as 'engine of growth', are outcomes of investments which generate knowledge. Although firms try to keep newly generated knowledge to themselves (by patenting or not disclosing it) in order to fully reap its benefits, yet it is often not possible in practice. A part of the created knowledge leaks out in the form of externalities or through imitation by rival firms. Thus, benefits from the innovation activities of a particular firm may also accrue to its rival firms. The benefits accruing to rival firms, through externalities or imitation, are called knowledge spillovers. Role of knowledge spillovers is widely discussed and empirically tested in endogenous growth theory (Bayoumi et al., 1996; Coe and Helpman, 1993; Grossman and Helpman, 1990). It is claimed that positive externalities can be generated by the persistent accumulation of inputs which can further be helpful in sustaining growth (see Grossman & Helpman, 1994).

Literature has discussed various types of knowledge spillovers that can be present in any industry. For instance, domestic firms can learn various cost-reducing or output-increasing production techniques from foreign firms. This suggests that the spillovers from Foreign Direct Investment (FDI) may increase Total Factor Productivity (TFP) of domestic firms. Kathuria (2002) finds that after liberalization, FDI firms in India benefitted scientific non-FDI firms in terms of the rise in productivity through technological spillovers from high-technology firms to low technology firms. Another type of knowledge spillover effect, which is widely discussed, is from R&D investments (domestic or international R&D). A firm can increase its technological efficiency or output by making use of knowledge generated from R&D investments of other firms in the industry.

Spillovers from R&D are regarded as a potential source of endogenous growth by various models of 'New Growth Theory' (see Griliches, 1992). Spillovers can also be defined as the social returns of a private R&D investment. R&D, up to certain extent, is said to have the character of public good (see Spence, 1984) and knowledge spillovers from R&D in a firm may serve as externalities to other firms. These types of spillovers occur when the R&D conducting firm cannot appropriate all the benefits of its R&D and these benefits leak out to other firms of the industry in the form of social benefits. It can be argued that knowledge spillovers from R&D are more likely to be effective in countries where patent laws are not strong enough or are implemented less effectively due to smaller expected legal costs involved in imitation.

The classification of R&D spillovers can be done on the basis of origin or channels through which their transmission takes place. R&D spillovers can be international or domestic in nature. International R&D spillovers are generated by R&D investments of firms established in other countries. The spillovers from foreign firms may affect the productivity of domestic firms as technical knowledge may be acquired by domestic firms through international trade of capital goods or other mutual practices/interactions with the foreign producers. Similarly, a firm may also gain from the R&D spillovers generated from innovative activities of other domestic firms. On the basis of the channel through which spillovers work, these are generally differentiated into rent spillovers and knowledge spillovers. When spillovers occur through business or economic transactions, these are referred to as rent spillovers. However, when there is no market transaction involved in the act of knowledge transfer, spillovers are called knowledge spillovers (see Griliches, 1979).

There is another branch of this research area which needs to be reflected upon before we proceed. R&D spillovers may also be studied in the context of geographical dimensions (see Jaffe et al., 1993; and Glaeser et al., 1992) and underlying market structures. These studies analyse R&D spillovers occurring due to the geographical proximity of firms at the local level. It is suggested that competition among firms at local geographical level may determine the extent of spillovers (detailed discussion is done in literature review section). Furthermore, it can also be argued that if the innovative behaviour of firms is associated with product market competition (see Aghion et al., 2005; Arrow, 1962; Schumpeter, 1943), then there are good chances that spillovers generated from these activities may also be related to competitiveness among firms. For instance, if a certain level of competitiveness leads to more innovations, one can expect larger spillovers emanating from the R&D investments at that particular competition level. This argument has been attributed to the view that generation of a larger stock of knowledge will generate more externalities.

There are many empirical studies in different countries which have tried to look into the issues related to R&D spillovers. Majority of these studies seems to be convinced that spillovers from R&D exist and may contribute substantially to output and productivity growth of firms (see Raut, 1995; Hanel, 2000; Saxena, 2011; Chen & Yang, 2005; Cincera, 2005). However, few studies have tried to conduct a macro analysis of R&D spillovers in the context of market competitiveness. The present paper attempts to fill this research gap and seeks to analyse R&D

spillovers from Indian domestic firms in highly competitive and less competitive industries. In this study, we are focusing mainly on knowledge spillovers emanating from R&D investments, which are one of the major sources of knowledge generation. For the empirical investigation, we will treat spillovers as knowledge spillovers only as it is quite difficult to separately observe rent and knowledge spillovers from R&D. Spillovers may also be inter-industry or intra-industry. For the purpose of this study, we will consider intra-industry spillovers from domestic R&D.

The paper is divided into seven sections. After the introduction, the second section systematically reviews the relevant literature; the third section suggests the model applied for empirical investigation; the fourth section provides detailed information on the data collection and variable construction; the fifth section reports and discusses the econometric results of our model; and the final section concludes the paper along with a few policy suggestions.

2. LITERATURE REVIEW

Literature is reviewed under two subsections so as to discuss two different aspects of R&D spillovers. The first discusses the role of R&D spillovers in productivity increment, growth and related aspects. Subsequent sub-section will explore the role of market structure in determining the extent of R&D spillovers.

R&D Spillovers, Productivity and Growth

Many studies have provided detailed theoretical and empirical understanding of various issues related to R&D spillovers. There is a host of research work done in various countries to determine the effect of R&D spillovers on output and productivity. Wei & Liu (2006) found evidence of cross-region intra-industry and within-region inter-industry R&D spillovers from foreign firms to domestic Chinese firms during 1998-2001. The study suggested that firms' own R&D is an insignificant determinant of its productivity. Hanel (2000) also found significant domestic inter-industry R&D spillovers in Canada's manufacturing industries during 1974-1989. The study showed that firms' own R&D has a lesser impact on TFP than spillovers generated from aggregated R&D of industries. It argued that R&D's social returns are larger than private returns. While international R&D spillovers are found significant, domestic R&D spillovers and firms' own process related R&D have a greater effect on TFP growth.

A few studies have analysed the R&D spillovers in Indian manufacturing industry. Feinberg and Majumdar (2001) analysed the knowledge spillovers in India, generated through local R&D activities of Multinational Corporations (MNCs) in the Pharmaceutical industry during 1980-1994. The Indian firms are found to be relatively more R&D intensive than multinational corporations. This study, on the basis of interviews conducted with managers of both type of companies, points out that R&D share in total output is lesser in MNCs than their counterpart local firms. It is possible because MNCs spend on R&D largely to increase process efficiency which results in cost reduction or sometimes to make their products compatible/efficacious in the Indian context. Indian firms, on the other hand, invest in R&D with a broader scope in consideration such as molecular analysis, new manufacturing systems as well as process development. Finally, the study argues that technology spillovers from FDI are present in Indian pharmaceutical industry. However, the major benefit of these spillovers goes to MNCs themselves and Indian firms end up gaining little from it. Spillovers from R&D by domestic firms do not seem to benefit MNCs.

Saxena (2011) investigates spillovers from R&D activities and recently purchased machinery and equipment in India. The study finds that productivity of Indian manufacturing firms is positively influenced by technology and knowledge spillovers during 1994-2006. Contrary to earlier findings that only R&D intensive benefits from technology and R&D spillovers, the study observes productivity gains to both R&D intensive and non-R&D intensive firms. Similar results are found in case of capital intensive as well as labour intensive industries. It is emphasized that knowledge spillovers are economically more important in labour intensive or low technology firms and industries.

Basant and Fikkert (1996) analysed the effect of international and domestic R&D spillovers on the output of Indian manufacturing firms during the time period 1974-75 to 1981-82. Interestingly, they observed high private returns to technology purchased whereas no significant returns from firm's own R&D expenditure. At the same time, spillovers from international and domestic R&D are found. Raut (1995) conducted a similar study on Indian private firms during 1975-1986 to empirically test the presence of R&D spillovers. Industry level spillovers from R&D are found to be significant in most of the industries. Effect of firm's own R&D stock is also significant in the overall industry, however, in different sub-industries it is found to be insignificant. Hasan (2000) finds out that imported technologies appropriated through contracts with foreign firms enhanced the productivity of Indian manufacturing firms significantly during 1977-87. Firms own R&D has been reported less productive.

Another important argument is that only those firms gain from knowledge spillovers which have a minimum level of absorptive capacity in the form of human capital and their own R&D investments. Kathuria (2002) finds that in India, during 1990-1996 (immediate period after reforms), entry of foreign firms seems to have benefitted scientific non-FDI firms; however, no such effect was observed for non-scientific domestic firms. Results show that positive spillovers have benefitted only those firms which invested significantly in R&D activities to cross the threshold level. Hence it is argued that investment in human capital or capacity expansion may be required for absorption of knowledge spillovers.

Spillovers may play a significant role in increasing output and productivity of the firms in any industry. However, high spillovers may not be desirable in the sense that they can adversely impact the incentive to innovate. Katz et al. (1990) argue that technological spillovers can be a source of divergence between social and private returns to R&D. If social returns are greater than private returns, firms may find themselves reluctant to invest in R&D whereas if private gains surpass social benefits, firms will have more incentive to do so. Bernstein and Nadiri (1988) find social returns of R&D are approximately double than its private returns which mean that the technological and knowledge spillovers from R&D are reducing the incentive for the firms to invest in R&D.

R&D Spillovers and Market Structure

There are a few studies that have analysed externalities generated from R&D in different market structures at local level. Lucio et al. (2002) review Porter (1990), Jacobs (1970), Glaeser et al. (1992), MAR (Marshall, 1890; Arrow, 1962; Romer, 1986 and Romer, 1990) and explain how these studies deal with the concept of externalities in different market situations. Lucio et al (2002), Porter (1990), Jacob (1969), and Glaeser et al. (1992) have given their arguments in the context of local market structures of cities and smaller geographical areas whereas others are macro-level studies.

Table 1 has been taken from Lucio et al. (2002) and shows how different studies attribute high externalities to different competition levels.

Table 1: Typology of externalities

		High competition	Low competition
Predominant source of knowledge	Intra-industry (specialization)	Porter externalities Porter (1990)	MAR externalities Marshall (1890) Arrow (1962) Romer (1986, 1990)
	Inter-industry (diversity)	Jacobs externalities Jacobs (1969)	--

Source*: *Lucio et al (2002)

Porter (1990) and MAR are of the view that knowledge spillovers to a firm come from the same industry. However, Jacobs argues that spillovers are inter-industry in nature. These studies have also discussed different market structures which may facilitate knowledge spillovers. Porter (1990) and Jacobs (1969) suggest that high competition is conducive for spillovers. Whereas, Glaeser et al. (1992) argue on the basis of MAR approach that if spillovers come from same industry (intra-industry), concentration should facilitate knowledge transmission in the industry at the local level.

As mentioned above the focus of some of these is to study local markets and the underlying arguments may or may not hold in the context of macro studies. It is argued that ideas and knowledge from a firm are disseminated to other firms through spying, imitation, cooperation, and movement of highly skilled labour (see Lucio et al, 2002; Porter, 1990; Jacob, 1969; and Glaeser et al.,1992). The idea of local market structure and knowledge spillovers in these studies comes from the argument that level of competitiveness among the firms situated in geographical proximity may affect knowledge transmission through imitation, spying or labour movements. The same argument can be extended to macro level studies if it can be conveyed that firms in a country may be geographically distant but their proximity in terms of technological reach to each other is increasing. For instance, highly skilled workers may get more and better opportunity in the competitive market and they can move from one firm to another in search of more rewards to their skills. This way, competitive market will help spillovers to spread across the economy. Similarly, in competitive market, leader firms may try to innovate in order to stay at top position in the market and other firms may try to imitate or spy if cost of imitating or spying is lesser than conducting their own research (cost of imitation may be much lesser than cost of uncertainty in R&D investment, especially if patent laws are not strongly implemented). Furthermore, it can be argued that due to manifold increase in modes of communication and transport, availability of better human capital the proximity of firms is not confined to local geographical levels. Movement of skilled labour has become a common phenomenon and imitation of technology has become quite easier (due to easy availability of human capital and free/less costly knowledge through the internet and other means) even if firms are situated at geographically distant locations within a country like India.

In relation to how market structure can affect the level of innovative activities, there are three important arguments that have been put forward. One of the classical works in this regard is by Joseph Schumpeter. Schumpeter argues that markets with monopolistic structure are more conducive for the introduction of new technology than the competitive markets which are considered to be economically more viable and efficient by neoclassical school of thought (Schumpeter 1943). The underlying argument is that monopolistic market structure is capable of generating profits enough for financing research and development (R&D) activities whereas competitive environment does not generate an adequate surplus in the hands of producers for the same. Later, Arrow (1962) in one of his famous works puts forward another influential argument that monopoly, due to availability of sufficient funds for investment in R&D, may be more appropriate market structure to innovate than a competitive market, however it is the incentive to innovate that pushes the investors more to invest in innovation activities. He points out that incentive to innovate is more in a competitive market than in monopoly market.

Here, it is important to mention that both Schumpeter and Arrow mainly suggest a linear relationship between competitiveness and innovation activities. However, this may not be the actual situation in practice. Aghion et al. (2005) have shown that in firms established in the United Kingdom, there exists a nonlinear relationship between competition level and innovations. The paper argues that relationship between these two variables can be better explained by the inverted-U curve. In other words, initially innovation activities find boost when monopolies start vanishing and competition begins to increase but after a certain level, competition becomes so intense that it starts hindering investments in R&D and hence results in reduced innovations.

As pointed out earlier, if market competitiveness is associated with innovativeness of the firms, it is likely that spillovers from innovation activities may also vary in different market structures. If there is a larger aggregate stock of R&D in the industry at a particular level of competitiveness, this would mean that there is a larger stock of knowledge which can be utilized partially by others. Hence, it can be argued that more R&D may result in more spillovers. We suggest an empirical model in the next section to test the arguments discussed above.

3. MODEL SPECIFICATION

To analyse R&D spillovers from Indian domestic firms in high competition and low competition markets, we assume the production function to be of Cobb Douglas type (as suggested by Saxena, 2011), where

$$Y_{ijt} = A_{ijt}F(K_{ijt}, L_{ijt}, M_{ijt}) \quad (1)$$

Here, Y_{ijt}, output of i-th firm of industry j at the time period t, is the function of capital (K), labour (L) and raw material (M). A_{ijt} represents productivity of i-th firm in j industry at t time period and is determined by state of technology. We believe that state of technology of a firm can be determined from its technological stock which can be considered as vector of five variables as follows:

$$S = g(RD, RP, RPM, EQSPILL, RDSPILL) \quad (2)$$

Where, S is technological stock of i-th firm in j industry at t time period and is function of RD (R&D stock), RP (technical fees and royalty paid), RPM (recent purchase of machinery and equipment), EQSPILL (spillovers from recently purchased stock of equipment in industry, net of firm’s own stock of equipment) and RDSPILL (knowledge spillovers from recent R&D investments in industry, net of firm’s own investment in R&D).

Finally, to observe the effect of knowledge spillovers on the output of any firm, we have chosen log transformation of equation (1) after incorporating relevant variables which determine the state of technology as discussed above. The model takes the following form:

$$\log Y_{ijt} = \alpha + \beta_1 \log K_{ijt} + \beta_2 logL_{ijt} + \beta_3 logM_{ijt} + \beta_4 logRD_{ijt} + \beta_5 logRP_{ijt} + \beta_6 logRPM_{ijt} + \beta_7 logEQSPILL_{ijt} + \beta_8\, logRDSPILL_{ijt} + \varepsilon_{it} \quad (3)$$

Here, Y_{ijt} is output of i-th firm of j-industry at time t

K_{ijt} is capital stock of i-th firm of j-industry at time t

L_{ijt} is labour input in i-th firm of j-industry at time t

M_{ijt} is the raw material used in i-th firm of j industry at time t

RD_{ijt} is the R&D stock of i-th firm of j industry at time t

RP_{ijt} is royalty paid, technical know-how fee (technology purchased) by i-th firm of j industry at time t

RPM_{ijt} is stock of recently purchased machinery by i-th firm of j industry at time t

$EQSPILL_{ijt}$ is spillovers available to i-th firm from equipment stock of j industry at time t

$RDSPILL_{ijt}$ is spillovers available to i-th firm from R&D stock of j industry at time t

4. DATA AND VARIABLE CONSTRUCTION

Firm-level data for this study has been extracted from PROWESS-CMIE for the year 2000-01 to 2015-2016. Data for 2501 firms registered under National Stock Exchange (NSE) and Bombay Stock Exchange (BSE) is used to make a balanced panel. After removing firms with missing values of required variables as well as firms producing diversified products, the final balanced panel consists of 163 firms. This leaves us with total 2608 observations for 15 years. Variables required for this analysis have been calculated as follows:

Output (Y): Output has been calculated by deflating current values of sales by wholesale price index (WPI) for different industries (according to 2-digit NIC-2008) at 2004-05 prices. WPI is made electronically available by the office of economic advisor, the government of India. This price index for initial years is available at 1993-94 prices that we converted into 2004-05 WPI using splicing method.

Capital (K): Capital has been captured by converting book values of gross fixed capital into capital stock suggested by Srivastava (1996). First, 2000-01 is chosen as the base year and historical values of gross fixed capital for this year are converted into replacement values. The replacement values for the base year are deflated at 2004-05 prices using WPI series on machinery and machine tools. For calculating capital stock for rest of the years, Perpetual Inventory Method (PIM) is used. Detailed procedure and calculations have been reported in Parameswaran (2002) and are given in appendix (A).

Labour (L): In prowess data on a number of employees contains a large number of missing values. So, we choose to calculate labour units by dividing each firm's emoluments (salaries, wages, bonus, ex gratia pf & gratuities paid) by average emoluments to employees in the corresponding major industrial group at the 2-digit level. Average emoluments have been computed by dividing each industry's "total emoluments to employees by "total number of employees". Data on total emoluments to employees and number of employees in the industry at 2-digit level is obtained from various issues published by Annual Survey of Industries which can be accessed electronically from the website of ministry of statistics and programme implementation (http://www.mospi.gov.in).

Data on wages have been deflated using consumer price index (CPI) for Industrial Workers (IW). This approach has a benefit over the use of reported 'number of employees' that quality aspect of workers is also captured.

Raw material (M): Raw materials have been calculated as the total real value of all intermediate inputs such as raw material, water, energy, stores and services. Current values of variables extracted from PROWESS have been deflated to 2004-05 prices using appropriate price index series for different sub-industries. Deflator series for this purpose is calculated from the input-output table for industries published by CSO, the government of India in 2007-08.

R&D stock (RD): Literature suggests us to treat R&D as a stock, rather than flow variable (see Griliches, 1979; Raut, 1994, Basant and Fikkert, 1996; Cincera, 2005; Chen & Yang, 2005). It is argued that investment in R&D continues to affect output even after the time period in which it is done. The PIM method is used to convert expenditure on R&D into a stock variable. As suggested in other studies, we assume that R&D stock depreciates at 15 percent per annum and its effect on output is realized after one year. Calculations are done considering that R&D ceases to affect output after five years (Griliches, 1979). Initially, for the year 2001, R&D stock is measured as follows:

$$RD_{i,\ 2001} = \sum_{n=0}^{5} RDEXP_{i,\ 2000-n}\ (1-\delta)^{n}$$

Here, $RD_{i,\ 2001}$ is R&D stock of i-th firm in 2001 and $RDEXP_{i,\ 2000-n}$ is R&D expenditure of i-th firm in 2000-n year. δ is depreciation rate. R&D stock (RD) calculated this way is then deflated using appropriate deflator series calculated by taking an average of WPI for capital and equipment and CPI for industrial workers. Now, for subsequent years, PIM is used to calculate R&D stock:

$$RD_{i,\ t+1} = RD_{it}\,(1-\delta) + RDEXP_{it}$$

Royalty, licences and technical know-how (RP): Similar to R&D stock, a stock variable for the royalty paid, licences, and technical know-how is created. PIM method with depreciation rate and lag period similar to that of R&D has been used. Values are deflated using R&D deflator.

Recent stock of plant and machinery (RPM): We have used the stock value of recently purchased plant and machinery to measure embodied technology. It can be defined as the cumulative past real expenditure on plant and machinery. Mathematically, it can be expressed as follows:

$$RPM_{it} = \sum_{n=0}^{4} LogR_{i,\ t-n}\,(1-\delta)^{n}$$

Here, R is real expenditure on plant and machinery. It is calculated as the difference between book values on expenditure on plant and machinery for two consecutive years. Values are converted into 2004-05 prices by using machinery and machine tools deflator. Depreciation δ is assumed to be six percent for plant and machinery. Following standard practice in literature, we have taken ratio of RPM to total fixed capital.

Equipment spillovers (EQSPILL): $EQSPILL_{it}$ can be defined as the aggregate stock of equipment (plant and machinery) in the corresponding industry minus firm i's stock. We have constructed Equipment spillovers variable as follows:

$$EQSPILL_{it} = \sum_{i} EQIP_{it} - EQIP_{it}$$

Equipment stock of industries has been calculated in a similar way as in case of firms by using PIM method.

R&D spillovers (RDSPILL): R&D spillovers are measured with the help of R&D stock of a firm and its corresponding industry. R&D stock of industry is calculated similarly to that of a firm's R&D stock. Symbolically, R&D spillovers can be calculated as follows:

$$RDSPILL_{it} = \sum_{i} RD_{it} - RD_{it}$$

Here $RDSPILL_{it}$ is aggregate R&D stock of firms in firm i's industry at 3 digit NIC-2008.

Competition: Competition has been measured with the help of Price-Cost Margin (PCM) as well as Herfindahl-Hirschman Index (HHI) in order to check the robustness of the results. Following formulas are used to calculate HHI and PCM

1) Price Cost Margin (PCM) = $\frac{\text{total output}-\text{total inputs}-\text{payroll}}{total\ output}$

2) Herfindahl-Hirschman index (HHI) is calculated as sum of the square of the market share of each firm at 3-digit National Industrial Classification (NIC)-2008. Mathematically, it can be written as follows:

$$HHI_{mt} = \sum_{i=1}^{N} S_{it}^{2}$$

$$where, \quad s_{it} = \frac{sales_{it}}{\sum_{i=1}^{N} sales_{it}}$$

PCM and HHI both are measures of market concentration. Their value lies between 0 and 1. If the value is 0, that means perfect competition prevails, whereas if it is 1, there is monopoly in the market. Both the indicators of market concentration are calculated in a very different way. HHI measures competition from domestic firms. It does not take into account competition from foreign firms. However, PCM, which is by definition calculated as the difference between price and marginal cost, reflects overall competition that a firm faces.

To convert PCM and HHI from measures of market concentration into measures of competition, we will subtract them from one for analysis purpose.

R&D Intensity: R&D intensity is measured as the ratio of R&D expenditure to sales of the firms.

$$R\&D\ Intensity = \frac{R\&D\ Expenditure}{Sales} \times 100$$

5. ECONOMETRIC RESULTS

For empirical investigation of the effect of R&D spillovers on output, we have decided to use linear dynamic panel data (DPD) model. All the results in this section are reported after opting for robust standard errors. We instrumented our model with difference and leveled GMM-type instruments in order to deal with possible endogeneity. Also, we checked for any possible autocorrelation among independent variables. No significant autocorrelation is found in all the models.

Following sub-sections will describe the production function estimates of the spillovers. First, we analyse the aggregate sample to find out the effect of spillovers on output and then we divide the sample into two parts on the basis of competition faced by firms in order to observe the role of spillovers in a high and low competitive environment.

We have shown the estimated results of our model in a step-wise manner to analyse how inclusion or exclusion of our spillover variables affect the econometric results of our model.

Spillovers in aggregate sample

Table 2 shows the estimated results of production function described in section 3. Model-1 includes all the variables in equation (3) except EQSPILL (equipment spillovers) and RDSPILL (R&D spillovers). Results show that labour, raw material, R&D initiatives and purchased disembodied technology are the significant variables which are positively affecting the output of a firm.

Table 2: Production function estimates of econometric model using linear DPD estimator

Variables	**Coefficients (standard error) Model-1**	**Coefficients (standard error) Model-2**	**Coefficients (standard error) Model-3**
Capital	0.029037 (0.029408)	0.052801** (0.026797)	0.054668* (0.029035)
Labour	0.129591*** (0.026887)	0.131112*** (0.02244)	0.129464*** (0.021804)
Raw Material	0.753816*** (0.048443)	0.713658*** (0.052744)	0.70829*** (0.051452)
R&D	0.109657*** (0.019048)	0.081235*** (0.025289)	0.096377*** (0.022962)
Technology Purchased	0.024265** (0.012411)	0.026395** (0.012075)	0.030298*** (0.011405)
Recently Purchased Machinery	0.001045 (0.005038)	0.002412 (0.004134)	0.004594 (0.004306)
R&D Spillovers		0.073207*** (0.021333)	0.06283*** (0.021001)
Equipment Spillovers			-0.02036* (0.010713)
Wald chi-square	5263.57	5381.46	5516.25

Note: ***, **, * signify significance of coefficients at 1, 5, and 10 percent respectively.

Source: Authors calculations using Prowess-CMIE data

In Model-2, we also include the R&D spillover variable along with other variables. With this inclusion, Wald Chi-square statistic shows an increase, which means Model-2 explains the results better than Model-1. Table 2 shows that R&D spillover is a highly significant variable and its benefits seem to be comparable to firms' own R&D initiative.

We follow the same process in Model-3 and incorporate equipment spillover in our model. Wald chi-square increases again. However, we do not find a positive relationship between firms' output and spillovers from equipment stock in the corresponding industry. This finding is not in line with Saxena (2011) which finds a positive impact of equipment spillovers on firm's output. However, R&D spillover coefficient remains significant and positive after inclusion of equipment spillover in Model-3.

Our model, after incorporating all the variables, suggests that capital stock, labour input, raw material, firms' own R&D stock, purchase of technology and intra-industry R&D spillovers from domestic firms are the factors which have a positive relationship with firms' output. Embodied technology proxied by expenditure on the stock of recently purchased machinery is found to be insignificant.

Spillovers and competition

We measure market competition faced by each firm in our sample by Herfindahl-Hirschman Index as well as Lerner Index (Price-Cost Margin or PCM) to see the impact of competitiveness on intra-industry R&D spillovers. For the purpose of analysis, we sort the aggregate sample according to competition faced by the firms and then divide the sample into two parts from the median. Finally, we estimate the production function using two different samples. The first sample consists of the firms which are facing high competition and the second with firms which experience low competition. The same exercise of dividing the sample into two parts has been done twice using two different measures of competition i.e. PCM and HHI.

Table 3 (competition measured by PCM) and Table 4 (competition measured by HHI) depict the results found from the estimation of spillovers under highly competitive and less competitive market structure. We have presented the results in a step-wise manner in the form of Model-1, Model-2 and Model-3 as previously done in case of estimation of the aggregate sample.

Model-1 in Table 3 shows that capital, labour input, raw material and firms' own R&D are the significant variables which affect output of the firms in the manufacturing industry. When we include R&D spillover variable in Model-2, it is found that R&D spillovers are also significantly associated with firms' output. However, the coefficient of R&D spillover variable is relatively much lower in the highly competitive market than in a less competitive market. The gap further increases with the inclusion of equipment spillover variable in Model-3. R&D spillovers from domestic firms in the low competition are found to be three times stronger than spillovers in high competition.

Firms' own R&D is also less effective in high competition conditions. The coefficient of capital variable also shows diminishing returns when competition is high. However, capital has a significant effect on output in less competitive market situations. Competition level also affects the coefficient of disembodied technology variable (technology purchased) which is significantly positive in the less competitive market and insignificant when the competition is high.

We also find significant negative spillovers from equipment in the less competitive market. However, under high competition, equipment spillovers are insignificant.

Table 3: Production function estimates of econometric model using linear DPD estimator-in high and low market competition (measured by PCM)

Variables	**High competition (PCM) Model-1**	**Low competition (PCM) Model-1**	**High competition (PCM) Model-2**	**Low competition (PCM) Model-2**	**High competition (PCM) Model-3**	**Low competition (PCM) Model-3**
Capital	-0.05976*** (0.015627)	0.121564*** (0.03972)	-0.03198** (0.014485)	0.109031*** (0.043606)	-0.02883** (0.014039)	0.132393*** (0.046307)
Labour	0.071925*** (0.015242)	0.120736*** (0.033559)	0.081305*** (0.011774)	0.125795*** (0.028875)	0.074047*** (0.012482)	0.11741*** (0.028526)
Raw Material	0.939256*** (0.01666)	0.62787*** (0.079392)	0.929005*** (0.015056)	0.622493*** (0.078779)	0.93092*** (0.015283)	0.650309*** (0.071555)
R&D	0.061496*** (0.012122)	0.121068*** (0.023992)	0.023495* (0.013108)	0.080743*** (0.028224)	0.027977** (0.01333)	0.059449*** (0.024117)
Technology Purchased	-0.00237 (0.008598)	0.025844* (0.014209)	-0.00519 (0.007113)	0.03007** (0.014433)	-0.00506 (0.007111)	0.045477*** (0.014894)
Recent Machinery	0.004367 (0.002933)	-0.0103 (0.007988)	0.006389*** (0.002281)	-0.00645 (0.007503)	0.006729*** (0.00237)	0.001642 (0.007179)
R&D Spillovers			0.044533*** (0.009868)	0.106485*** (0.028874)	0.042475*** (0.009819)	0.133211*** (0.029081)
Equipment Spillovers					-0.00078 (0.003181)	-0.13713*** (0.035627)
Wald Chi-Square	20077.77	1207.55	20286.04	1221.18	22139.29	1267.52

Note: ***, **, * signify significance of coefficients at 1, 5, and 10 percent respectively.

Source: Source: Authors calculations using Prowess-CMIE data

When we use HHI measure of competitiveness, results are quite different from Table 3. High R&D spillovers are noticed in a more competitive market situation whereas there are no significant spillovers when the market is less competitive. The results are shown in Table 4.

Step-wise estimation in Table 4 shows that in the lesser competitive market, the effect of spillovers on output is approximately double than firms' own R&D when equipment spillovers variable is not included (see Model 2). With the inclusion of equipment spillovers variable, the coefficient of R&D spillovers becomes 5-6 times stronger than firms' own R&D investments. Another important finding is that disembodied technology (technology purchased) is significant only when high competition prevails. Embodied technology remains an insignificant factor.

Table 4: Production function estimates of econometric model using linear DPD estimator-in high and low market competition (measured by HHI)

Variables	**High competition (HHI) Model-1**	**Low competition (HHI) Model-1**	**High competition (HHI) Model-2**	**Low competition (HHI) Model-2**	**High competition (HHI) Model-3**	**Low competition (HHI) Model-3**
Capital	0.024563 (0.045049)	0.045329 (0.037359)	0.087248** (0.042912)	0.030812 (0.03753)	0.114064*** (0.045351)	0.022308 (0.040479)
Labour	0.156333*** (0.03492)	0.106416*** (0.030132)	0.149534*** (0.028069)	0.127422*** (0.034481)	0.160619*** (0.028656)	0.117812*** (0.035195)
Raw Material	0.696169*** (0.070909)	0.84061*** (0.033642)	0.658707*** (0.074209)	0.844401*** (0.029559)	0.662769*** (0.06699)	0.856773*** (0.030571)
R&D	0.120005*** (0.019942)	0.065267*** (0.021105)	0.051817** (0.025977)	0.062761*** (0.023074)	0.027861 (0.026428)	0.068281*** (0.023558)
Technology Purchased	0.042986*** (0.016699)	0.010819 (0.017178)	0.047075*** (0.014078)	0.005387 (0.017614)	0.050451*** (0.013606)	0.008598 (0.016454)
Recent Machinery	-0.00634 (0.007152)	0.0000578 (0.005468)	0.000382 (0.005445)	-0.00384 (0.00527)	0.005084 (0.00521)	-0.00819 (0.005396)
R&D Spillovers			0.107304*** (0.031277)	0.017431 (0.026987)	0.125814*** (0.031865)	0.000999 (0.030247)
Equipment Spillovers					-0.11955*** (0.02995)	0.008234 (0.007282)
Wald chi-square	2180.64	4072.92	1962.19	5092.64	2498.42	5207.20

Note: ***, **, * signify significance of coefficients at 1, 5, and 10 percent respectively

Source: Authors calculations using Prowess-CMIE data

The difference in result in Table 3 and Table 4 may be because of the difference in characteristics of PCM and HHI. We have already discussed that both of these indicators are measured quite differently. PCM represents price competition faced by a firm, both from the foreign and domestic market. However, HHI is measured using relative shares of the firms in the domestic market and is a measure of domestic competition only. Taking into account the definition of PCM and HHI, it can be argued that overall price competition contracts spillovers from R&D, whereas spillovers are high when domestic market is competitive.

One of the explanations of our results is that the firms, which are facing larger part of a competition from foreign products, do not have much incentive to imitate/learn from other domestic rival firms as this will not help them compete with high technology firms situated abroad. A similar argument may work for results shown in Table 4. When competition is with domestic firms (measured by HHI), firms have a good incentive to learn from other domestic firms. Hence, it can be argued that the nature of the competition faced by a firm also determines the extent to which it can gain from domestic R&D spillovers.

Contrasting results in case of disembodied or purchased technology are also found in Table 3 and 4. When price competition is low (measured by PCM), technology purchased is a significant variable. However, it is insignificant in high competition market. The results are completely different if competition is measured by HHI. Disembodied technology becomes significant in high competition situations and insignificant when the competition is low. Again, the difference in results due to the choice of measure of competition can be attributed to the fact that PCM and HHI are measured in a different way. High profits, when the competition is low (measured by PCM), may help the firms to purchase costly and advanced foreign technology. On the other hand, if firms are experiencing low profits due to high competition, they may invest in cheap and outdated technology.

Similarly, when competition from domestic rival firms is strong, firms have the incentive to purchase technology from abroad. If domestic competition is weak, firms may not invest in expensive foreign machinery.

6. CONCLUSION

Spillovers are considered important for the growth of an economy. In fact, many studies have found that R&D spillovers are the main determinant of growth and technological improvement in various countries. Spillover coefficients have been found to be consistently and significantly comparable to firm's own R&D investments in a number of studies done across the world.

Our model shows similar outcomes. We found robust evidence about the presence of strong R&D spillovers in Indian manufacturing industries during 2001-2016. Additionally, we extended our work to analyse the role of spillovers in different competitive situations. Our results indicate that magnitude of R&D spillovers depends upon the level of market competition faced by the firms. However, contrasting results have been found when different indicators of competition are used (PCM and HHI). This may be because of different type of impact of domestic or international market competition on the level of innovative activities and on channels through which R&D spillovers transmit. Furthermore, we do not find sufficient evidence that recently purchased equipment (embodied technology), or spillovers from equipment have any relationship with the output. The study observes that effect of purchased technology on a firm's output is also conditional on the extent or nature of competition faced by the firms.

7. POLICY IMPLICATIONS

The findings of this paper have important policy implications. India's Science, Technology and Innovation Policy (STI) 2013 puts greater emphasis on the need to invest more in innovations for the faster growth. In fact, the decade 2010-2020 has been declared as the 'decade of innovation". The policy aims to increase R&D expenditure from one percent to two percent of GDP in the next five years. It has been mentioned in the policy document that the aim to increase Gross Expenditure in Research and Development (GERD) to two percent is attainable if private sector increases its R&D expenditure. The present share of private R&D investment is less as compared to the public R&D investments. In 2013, the ratio of private sector R&D investment to public sector R&D investment was 1:3. The STI policy also stresses upon sharing of risk element in R&D investments by the government and encouragement to public-private partnership along with other measures so that investment in R&D can be increased.

Firstly, the aforementioned objectives of STI policy mainly focus on increment in R&D expenditure. The fact that technology diffusion is also crucial along with direct R&D investments has been ignored. Stoneman and Diederen (1994) argue that policymakers, even after realizing the role of technology diffusion in creating productive potential, often bypass the opportunity to improve it. STI policy seems to have done the similar mistake. Mani (2011) suggests that in developing countries like India, the industrial sector comprises of a skewed distribution of firms with a large number of small and medium firms. These firms invest less in R&D but nevertheless introduce a range of innovations. If STI policy 2013 considers itself to be an innovation policy and not an R&D policy, it should include a number of other measures for enhancing the non-R&D route to innovation (see Mani, 2013). The findings of the present paper are in agreement with Mani (2013)'s argument and suggest that R&D policy should also focus on technology diffusion by making use of externalities emanating from R&D investments.

Secondly, we calculated average R&D intensity of the firms in all the samples which we earlier used to find out the coefficient of spillovers and observed that R&D intensity may be affected by competition level. The coefficient of average R&D intensity in all the five samples has been shown in Table 5.

Table 5: Average R&D intensity of the firms in the samples of firms facing high and low competition

All firms	High Competition (PCM)	Low Competition (PCM)	High Competition (HHI)	Low Competition (HHI)
0.373112679	0.496976	0.312925	1.119173	0.273709

In previous sections, it has been argued that when PCM is used as a measure of competition, the magnitude of spillovers is much lesser in high competition market segment than in low competition. In the same samples, we observe that average R&D intensity in case of firms facing high competition is more than in case of firms facing lower competition. The results suggest that low spillovers may be associated with higher R&D intensity in highly competitive environment, whereas, high spillovers may be associated with low R&D intensity in the less competitive environment. The relationship suggests that in highly competitive environment, actual social benefits from innovations may be relatively less even when R&D intensity is high. Whereas, boosting R&D investment more in firms which face low competition may stimulate more spillovers in the economy.

On the other hand, when we use HHI as the measure of competition, we observe high spillovers in highly competitive market section and low spillovers when the competition is low. At the same time, the difference between R&D intensity in high competition market and R&D intensity in low competition market is much higher than the difference when PCM is used to measure competition (see Table 5). Here, the results suggest that high spillovers may be associated with higher R&D intensity in highly competitive environment, whereas, low spillovers may be associated with low R&D intensity in the less competitive environment. In this case, results show that the market segment facing high competition from within the domestic industry may benefit from R&D spillovers if the share of R&D is increased. On the other hand, increase in R&D investment of firms which face low competition from other domestic firms may not generate large externalities.

The results point out that magnitude of spillovers may be different in different market structures and R&D intensity may not be positively associated with spillovers at certain competition levels. Therefore, the R&D policy should be designed keeping in mind that increase in R&D investments in different market segments may lead to more or less benefits in terms of technology diffusion.

Though a detailed investigation is required to check robustness of this relationship, the initial results suggests that the government policies related to science, technology and innovations should be designed after considering the role of technology diffusion in fostering scientific temperament, role of externalities in diffusion of knowledge, and factors which affect R&D spillovers at different competition level.

Appendix (A)

Measurement of Capital stock by PIM method: Parameswaran (2002) has explained the method to measure capital stock by Perpetual Inventory Method (PIM) used by Srivastava's (1996) as follows:

Data on Gross Fixed Assets (GFA) has been used to measure stock of capital. First, we take the difference between the current and lagged values of GFA which gives the actual investment that enters into the production process. This enables us to use perpetual inventory method to construct capital stock, as given below:

$$K_{t+1} = K_t + I_{t+1}$$
$$K_t = K_{t-1} + I_t$$
$$K_{t-2} = K_t - I_t - I_{t-1}$$

And so on.

Here, K_{t+s} and I_{t+s} are the capital stock and the investment respectively at time t+s. The method to calculate capital stock requires a base year capital stock K_t at replacement cost instead of reported GFA which is measured in historical cost. For this, we have to choose one base year and revalue that year's capital stock. In this study, 2000-01 has been chosen as the base year.

Capital Stock at Replacement Cost in the base year

Parameswaran (2002) argues that there is no perfect way of revaluating base year data on capital to replacement cost and any method used is an approximation. The method that has been used is based on the following assumptions:

1. No firm has any capital stock in the base year 2000-01 of a vintage earlier than 1980-81. The year 1980-81 is chosen because the life of a machinery is assumed to be twenty years, as noted in the report of the Census of Machine Tools (1986) of the Central Machine Tool Institute Bangalore ('National Accounts Statistics: Sources and Methods' New Delhi: Central Statistical Organisation, 1989). For firms incorporated before 1980-81, it is assumed that the

earliest vintage capital in their capital mix dates back to the year of incorporation. As stated by Srivastava (1996), the year of incorporation and the vintage of the oldest capital in the firm's asset mix may not coincide for some firms, but the assumption is made for want of a better alternative.

2. From 1980-81 or from the date of incorporation of the firm (whichever is later) up to 2000-01 (base year), the price of capital has changed at a constant rate, π

$$\pi = \frac{P_t}{P_{t-1}} - 1$$

Values for p were obtained by constructing capital formation price indices from the series for gross fixed capital formation in manufacturing obtained from various issues of the National Account Statistics of India. The constant inflation rate p is not firm specific but it varies with the year of incorporation, provided the firm was incorporated after 1980-81.

3. Investment has increased at a constant rate for all firms in sample and the rate of growth of investment (g) is

$$g = \frac{I_t}{I_{t-1}} - 1$$

Here the rate of growth of gross fixed capital formation (GFCF) in manufacturing at 2004-05 prices is assumed to apply to all firms. Different average annual growth rates are obtained for firms established after 1980-81.

These assumptions will enable us to calculate the revaluation factor R^G for the base year as follows:

Revaluation Factor for Gross Fixed Assets R^G

Let us denote GFA_t^h and GFA_t^r are gross fixed asset at historical costs and replacement costs respectively and I_t is the real investment at time t. By definition and making the assumptions mentioned above.

$$GFA_t^h = P_t I_t + P_{t-1} I_{t-1} + P_{t-2} I_{t-2} + \ \dots$$

$$= P_t I_t \left(\frac{(1+g)(1+\pi)}{(1+g)(1+\pi) - 1} \right)$$

And

$$GFA_t^r = P_t I_t + P_t I_{t-1} + P_t I_{t-2} \ \dots$$

$$= P_t I_t \left(\frac{(1+g)}{g} \right)$$

Defining R^G

$$R^G = GFA_t^r / \ GFA_t^h$$

Then

$$R^G = \left(\frac{(1+g)(1+\pi) - 1}{g \ (1+\pi)} \right)$$

If it is assumed that the capital stock does not date back infinitely, but that the capital stock of the earliest vintage is t period old, then we can derive the revaluation factor as follows.

$$R^G = \frac{[(1+g)^{t+1} - 1](1+\pi)^t [(1+g)(1+\pi) - 1]}{g\{[(1+g)(1+\pi)]^{t+1} - 1\}}$$

Now, the balance sheet value of assets in the base year is scaled up by the revaluation factor to obtain an estimate of the value of the capital stock at replacement costs as follows:

Replacement Cost of Capital = R^G x [Value of Capital Stock at Historic Cost]

Values of capital stock are deflated by wholesale price index for machinery and machine tools with base 2004-05 =100. For calculation of capital stock at replacement cost for rest of the years, Perpetual Inventory Method is used.

Finally, data on gross fixed asset of the firm has been used rather than a net fixed asset. For estimating the net fixed asset of the firm we need information on accounting and economic rate of depreciation. Reliable data on accounting and economic rate of depreciation are not available in India. Further, Dennison (1967) argues that the correct measure of the capital stock falls between the gross and net stock of capital, and advocates the use of a weighted average of the two with higher weight for the gross asset as the true value is expected to be closer to it.

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