Journal of Quantitative Economics (2022) 20:379–399
https://doi.org/10.1007/s40953-022-00286-y

ORIGINAL ARTICLE

R&D Spillovers and Product Market Competition

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Accepted: 5 January 2022 / Published online: 28 January 2022

Abstract
The paper builds a theoretical framework suggesting that the product market competition may affect the benefits accruing to the firms from intra-industry R&D spillovers. We have used dynamic panel data modelling (system-GMM estimator) to test our hypothesis to avoid possible endogeneity. The empirical analysis based on panel data of Indian manufacturing firms supports the earlier findings that significant R&D spillovers are present in the Indian manufacturing industry. More importantly, the findings suggest that the product market competition may determine the extent of spillovers emanating from R&D investments. However, the results depend on the choice of the parameter used to measure the level of competition. When Price–Cost Margin (PCM) is used, we find that stronger R&D spillovers are present among the firms operating under low competition. The results are contrary to this when PCM is replaced by the Herfindahl–Hirschman Index (HHI).

Keywords R&D spillovers · Product market competition · Indian manufacturing industry

Introduction

Innovations, famously known as the 'engine of growth', are generally the outcomes of efforts or investments intended to generate knowledge. Although firms try to restrict newly generated knowledge to themselves (by patenting or not disclosing it) to fully reap its commercial benefits, yet it may not be entirely possible in practice. A part of the created knowledge leaks out in the form of externalities and the resulting benefits may accrue to the rival firms. The benefits accruing to rival firms, through externalities, are generally referred to as knowledge spillovers. The significance of knowledge spillovers has widely been discussed and empirically tested in the endogenous growth theory (Bayoumi et al. 1996; Coe and Helpman 1993; Grossman and

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Helpman 1990, 1994) Though there may be several sources of knowledge spillovers, here we are considering the ones originating from the R&D investments of the firms.

The spillovers from R&D investments are regarded as a potential source of endogenous growth by various models of 'New Growth Theory' (see Griliches 1992). R&D, up to a certain extent, is said to have the character of public good (see Spence 1984) as knowledge spillovers from R&D investments of a firm may serve as externalities to other firms. In this sense, the literature defines R&D spillovers as the social returns of a private R&D investment (Bernstein and Nadiri 1989). 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.

Imitation is an important way through which spillovers propagate (Takalo 1998). It can be argued that knowledge spillovers from R&D are stronger in developing countries where patent laws are not strong enough or are implemented less effectively (Helpman 1993). The weaker patent laws result in a lower expected legal cost of imitation leading to the stronger spillover effect. Imitation is difficult to fully restrict even in the developed countries (Helpman 1993), hence making this phenomenon inevitable at least to a certain extent even if strong patent laws exist and the overall legal system strives to limit it. There are other channels/processes apart from imitation, such as spying (Billand et al. 2010), labour mobility (Cooper 2001), cooperation (Cellini and Lambertini 2009) and other types of business interactions, technical meetings and interpersonal communications (Najib 1997), through which the spillovers may take place.

It can be argued that competition may influence various channels through which R&D spillovers take place, eventually affecting the magnitude of spillovers. For instance, increasing competition may create new opportunities for the R&D personnel and company executives, therefore encouraging them to move from one firm to another in search of higher rewards for their skills (Guadalupe 2007; Kaiser et al. 2015; Sørensen 1999). The transfer of skilled labour in many instances may help to spread knowledge in the form of spillovers (Guarino and Tedeschi 2006). Similarly, increased competition may encourage the firms to collaborate in their R&D-related projects to minimize the risk associated with the uncertain nature of R&D investments (Hagedoorn et al. 2000). The R&D collaboration may also allow for the free flow of knowledge among firms to a certain degree (Belderbos et al. 2004). Overall, the aforesaid arguments suggest that increased mobility of skilled workers and collaborative activities coupled with the pressure to sustain high competition are likely to provide a boost to imitation activities as well.[1]

Previously in the literature, R&D spillovers have been studied in the context of geographical dimensions (see Jaffe et al. 1993 and Glaeser et al. 1992) and underlying market structures. For instance, Jaffe et al. (1993) and Glaeser et al. (1992) analyse R&D spillovers occurring due to the geographical proximity of firms at

[1] We are not using the word 'imitation' in a completely strict sense in this paper. Imitation may be absolute or partial, and sometimes may result in new products/innovations as well. A more detailed discussion has been given in Singh & Chakraborty (2021).

the local level and suggest that competition among firms at the local geographical level may determine the extent of spillovers. The idea of local market structure and knowledge spillovers in these studies comes from the argument that the level of competition among the firms situated in geographical proximity may affect knowledge transmission through activities such as imitation, spying, or labour mobility. The same argument can be extended to macro-level studies if it can be conveyed that, in the contemporary world, firms in a country may be geographically distant but their proximity in terms of technological reach to each other is increasing (Eng 2004). It can be argued that due to a manifold increase in modes of communication and transport, and the availability of better human capital, the proximity of firms is not confined to local geographical levels. The 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. Revolutionary innovations in the telecommunication and related information technology sector have created valuable virtual platforms for interpersonal interactions among the managers and employees of the firms. Such technological improvements have made the transmission of knowledge relatively more feasible even in case of the firms situated far from each other.[2]

Moreover, if the innovative behaviour of firms is associated with low/high competition (Schumpeter 1942; Arrow 1962), one can expect stronger spillovers emanating from the R&D investments at that particular competition level. This argument has been attributed to the assumption that more investments in R&D or the generation of a larger stock of knowledge should generate more externalities assuming other factors constant. In other words, greater aggregate R&D investments in an industry should produce more potential spillovers. Additionally, the nature of competition faced by the firms will also determine the benefits accruing to the firms in the form of spillovers. For instance, if the firms are facing high competition in the domestic market in terms of their relative market shares, the firms may have the incentive to learn from their rivals and increase their share in the market. The factors, such as geographical[3] and technological reach are likely to assist the domestic firms operating under high competition to absorb more spillovers through channels such as imitation, labour mobility, and cooperation. However, if the firms face intense price competition from the rivals (including foreign and domestic), there may be similar incentives but the firms may not have adequate funds left with them to establish absorptive capacity which has been considered to be an important prerequisite for the assimilation of spillovers (Cohen and Levinthal 1989). It should be pointed out here that high competition in terms of firms' domestic market shares may not necessarily worsen their financial situation (Cattó 1980; E. W. Anderson

[2] This does not imply that geographical proximity has become insignificant. Instead, the argument attempts to convey that with the technological advancement has practically made it possible for the far away firms to absorb spillovers at least to a certain extent. The closely situated firms may still benefit more.

[3] Kaur and Singh (2017) find that geographical proximity helps the firms to absorb more spillovers.

et al. 1994), whereas intense price competition does it explicitly (Porter 1980). Furthermore, it can be argued that the higher competition in both situations should provide the firms situated in developing countries with an incentive to absorb spillovers from domestic R&D, however, the incentive is likely to be greater when the competition is with domestic firms. A firm may not have an equally strong incentive to learn from domestic firms when the competition is with technologically advanced foreign firms. The incentive to absorb spillovers coupled with sufficient financial capability is likely to provide significantly greater benefits. The positive spillover effect of high competition through imitation, labour mobility, and cooperation is likely to be greater when the domestic competition is taken into account as factors like geographic, political, and cultural boundaries are limited (e.g., visa restrictions, language barriers) and do not excessively limit knowledge transmission.

There are several empirical studies in different countries including India which have attempted to look into the issues related to R&D spillovers. The majority of these studies seem to be convinced that spillovers from R&D exist and may contribute substantially to the output and productivity of firms (see Raut 1995; Hanel 2000; Saxena 2011; Chen and Yang 2005; Cincera 2005). However, few studies have attempted to observe the R&D spillovers in the context of product market competition. The present paper attempts to fill this research gap and seeks to study benefits from R&D spillovers accruing to the Indian manufacturing firms operating under high and low competition market conditions.

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 empirical results; the sixth section discusses some policy implications of the results; and the final section concludes the paper.

Literature Review

Literature is reviewed under two sub-sections to discuss two different aspects of R&D spillovers. The first sub-section discusses the role of R&D spillovers in the increment of firms' output. The subsequent sub-section will explore the role of market structure in determining the extent of R&D spillovers.

R&D Spillovers and Firms' Output

The literature provides a detailed theoretical and empirical understanding of various issues related to R&D spillovers and their influence on the output of the firms Aiello and Cardamone (2008), for instance, use the production function approach and argue that R&D spillovers are an important determinant of firms' output. The empirical findings suggest that output elasticity with respect to R&D spillovers is always positive and significant. Wieser (2005) has also suggested the presence of a strong relationship between technological spillovers and output of the firms. In fact, social benefits accruing through R&D investments of the firms are found to be greater than private benefits. Wei and Liu (2006) finds the presence of cross-region intra-industry and within-region inter-industry R&D spillovers benefits to domestic Chinese firms. Interestingly, the study suggests that firms' own R&D is an insignificant determinant of output. Similarly, several studies have confirmed empirically that spillovers from R&D exist and influence the firms' output significantly (Griliches 1992; Hall et al. 2010; Park 1995; Yao 2006; Bayoumi et al. 1996; Kim and Lester 2019; Lee 2005).

The influence of R&D spillovers in Indian industries has also been observed in the Indian manufacturing industry (see Basant and Fikkert 1996; Feinberg and Majumdar 2001; Kathuria 2000; Raut 1995; Saxena 2011; Shukla 2018). Saxena (2011) observes spillovers from R&D activities and recently purchased machinery and equipment in India. The study finds that the output of Indian manufacturing firms has been positively influenced by technology and knowledge spillovers during 1994–2006. Contrary to earlier findings that only R&D intensive firms benefit from technology and R&D spillovers, the study observes gains to both R&D intensive and non-R&D intensive firms. Similar results are found in the case of capital intensive as well as labour-intensive industries. Nonetheless, 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 R&D spillovers on the output of Indian manufacturing firms during the period 1974–75 to 1981–82. Although the study finds negligible and largely insignificant returns from the firm's own R&D expenditure, the R&D spillovers are found to be significantly positive. Raut (1995) conducted a similar study on Indian private firms during 1975–1986 using an extended production function approach. The industry level spillovers from R&D are found to be significant in most of the industries. Effect of the firm's own R&D stock is also significant in the overall industry, however, in different sub-industries it is found to be insignificant.

On the other hand, Feinberg and Majumdar (2001) analysed the knowledge spillovers generated through local R&D activities of Multinational Corporations (MNCs) in the Indian pharmaceutical industry during 1980–1994. The study argues that technology spillovers emanating from MNCs are present in the 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. Such findings are despite the observation that Indian Pharmaceutical firms are relatively more R&D intensive than multinational corporations. The study argues that MNCs spend on R&D largely to increase process efficiency which results in cost reduction, and 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.

Though a large number of studies have preferred using the production function approach to ascertain the impact of R&D spillovers on the firms' output, a few have resorted to using other related variables of interest. For instance, Hanel (2000) finds the impact of R&D spillovers on the Total Factor Productivity (TFP) of the firms. The study finds significant domestic inter-industry R&D spillovers in Canada's

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)

manufacturing industries and empirically shows that firms' own R&D has a lesser impact on TFP than spillovers generated from aggregated R&D of industries. Consistent with other production function based studies (e.g. Wieser 2005), the findings suggest that R&D's social returns may even be greater than private returns. Various other studies suggest that technological spillovers enhance the productivity of the firms and thereby raise the level of output (see Coe et al. 2009; Higón, 2007).

The literature suggests that only those firms gain from knowledge spillovers that 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. The results show that positive spillovers have benefitted only those firms which invested significantly in R&D activities to cross the threshold level. Hence, it may be argued that investment in human capital or capacity expansion may be required for the absorption of knowledge spillovers.

As suggested invariably in the literature, spillovers may play a significant role in increasing the 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, hence reducing the incentive for the firms to invest in R&D.

The results from various Indian studies suggest that strong R&D spillovers are present in the manufacturing industry and the benefit from firms' own R&D are limited/negligible. The lower absolute investment in R&D and largely stagnant R&D intensity may perhaps be the consequence of higher social returns than private returns in India.

R&D Spillovers and Market Structure

As mentioned earlier, externalities generated from R&D have been discussed in the context of different market structures at the local level. Lucio et al. (2002) review Porter (1990), Jacobs (1969), 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.

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 that may facilitate knowledge spillovers. For instance, Porter (1990) and Jacobs (1969) suggest that high competition is conducive to spillovers. Whereas, Glaeser et al. (1992) argue based on the MAR approach that if spillovers come from the same industry (intra-industry), concentration should facilitate knowledge transmission in the industry at the local level. 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). As mentioned earlier, the focus of some of these studies is to study local markets and the underlying arguments may or may not hold in the context of macro studies and is subject to empirical testing.

Concerning how market structure can affect the level of innovative activities, important arguments have been put forward in the literature. One of the classical works in this regard is by Joseph Schumpeter. Schumpeter argues that markets with a 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 the neoclassical school of thought (Schumpeter 1942). The underlying argument is that a monopolistic market structure is capable of generating profits enough for financing research and development (R&D) activities whereas a 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 a 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 the incentive to innovate is more in the competitive market than in a monopoly market. As pointed out earlier, if the market competition is associated with the innovativeness of the firms, spillovers from the innovation activities may also vary under different market structures. If there is a larger aggregate stock of R&D in the industry at a particular level of competition, this would mean that there is a larger stock of knowledge available that can be utilized partially by others. Hence, it can be argued that more R&D as a result of the conducive level of competition in an industry may result in more intra-industry spillovers.

Methodology and Model Specifications

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, where

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

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

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

where, S is the technological stock of i-th firm in j industry at t time and is a function of RD (R&D stock), RP (technical fees and royalty paid), RPM (recent purchase of machinery and 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 the log transformation of equation (1) after incorporating relevant variables that determine the state of technology as discussed above. The equation is used to estimate the dynamic panel data technique (GMM estimator) in the following form:

$$\begin{aligned} logY_{ijt} = \alpha_i + \beta_0 \log \mathrm{Y}_{\mathrm{ijt}-1} + \beta_1 logK_{ijt} + \beta_2 logL_{ijt} + \beta_3 logM_{ijt} \\ + \beta_4 logRD_{ijt} + \beta_5 logRP_{ijt} + \beta_6 logRPM_{ijt} \\ + \beta_7 logRDSPILL_{ijt} + \lambda_{ij} + \mu_{it} + \varepsilon_{it} \end{aligned} \quad (3)$$

here, the subscripts i, j, and t denote the firm, industry, and time respectively. The variables λ and μ are assumed to capture industry and time fixed effects.

We believe that dynamic panel data approach is more suitable in this case. First, in our model, Y_{ijt} depends on its own past realizations and GMM estimators are predominantly useful in this case (Bond 2002; Chakraborty 2018). Secondly, this technique assists in dealing with the problem of endogeneity that may occur due to various reasons such as measurement errors, omitted variables, or the presence of simultaneity.

It has been suggested that if the dependent variable in an equation is persistent and close to being a random walk, the application of the difference GMM estimator yields both a biased and inefficient estimate of the coefficient of lagged dependent variable. Blundell and Bond (1998) attributes the poor performance of the difference GMM estimator in such cases to the use of poor instruments. Therefore, to address this problem, System-GMM is preferred.

The System-GMM technique uses the instrumental variable approach to deal with the problem of endogeneity (see Arellano and Bond 1991; Blundell and Bond 1998). Lagged values of the dependent variable for three periods have been used as instruments as suggested by Anderson and Hsiao (1982). Similarly, following Reed (2015) and Kahouli (2019), one-period lagged values of the possible endogenous variable RDSPILL and non-lagged values of other control variables have been used as instruments along with the system instruments.

To test the validity and robustness of the empirical results derived from the system-GMM estimator, certain diagnostic tests are used. The Sargan-Hansen test of overidentifying restrictions rejects the null hypothesis suggesting that our models are correctly specified and instruments used are valid. Additionally, the absence of second-order serial correlation in the error term has also been confirmed in all the models. Overall results point out that instruments are valid and the model is correctly specified.

Apart from the aggregate sample, equation (3) has been estimated separately for the firms operating under high and low competition situations. We segregate the sample based on competition faced by the firms to observe the role of spillovers in a high and low competition environment. The median value has been chosen as a benchmark for the segregation of the sample.[4] This exercise allows us to investigate our objective of finding out the effect of competition on the spillovers-output relationship.

Data and Variable Construction

Firm-level data for this study has been extracted from the online database provided by the Centre for Monitoring Indian Economy (CMIE) for the years 2001–02 to 2018–2019. The data of firms registered under the National Stock Exchange (NSE) and Bombay Stock Exchange (BSE) is used to make a balanced panel of 390 firms. The variables described in equation (3) have been introduced as suggested in earlier studies and are calculated as follows:

Output (Y): the dependent variable, output, is the dependent variable in our model and 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.

Capital (K): capital has been captured by converting book values of gross fixed capital into capital stock as suggested by Srivastava (1996). First, 2001–02 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 the WPI series on machinery and machine tools.

[4] Another approach could be to introduce interaction term between spillover and competition variables in our model. However, the present methodology allows us to set a benchmark for low and high competition that otherwise may not have been possible. Moreover, larger number of firms, especially when we use HHI as measure of competition, are operating under very low competition. The segregation on the basis of median allows us to take care of the subjectivity arising because of this reason.

For calculating capital stock for the rest of the years, Perpetual Inventory Method (PIM) is used. Detailed procedures and calculations have been reported in Parameswaran (2002).

Labour (L): in prowess, data on the number of employees contain a large number of missing values. Therefore, labour units have been calculated 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. The 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 the number of employees in the industry at the 2-digit level is obtained from various issues published by the Annual Survey of Industries which can be accessed electronically from the website of the ministry of statistics and programme implementation (http://www.mospi.gov.in). Data on wages have been deflated using the consumer price index (CPI) for Industrial Workers (IW).

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 the variable have been deflated to 2004–05 prices using the 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): the literature suggests us to treat R&D as stock, rather than a flow variable (see Griliches 1979; Raut 1995; Basant and Fikkert 1996; Cincera 2005; Chen and Yang 2005). It is argued that investment in R&D continues to have an impact on the output even after a period in which it is done. The PIM method is used to convert expenditure on R&D into a stock variable. As suggested in earlier 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 5 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 represents the rate of depreciation of R&D stock. The real value of R&D stock is obtained by deflating the values using the deflator, which is a weighted average of the capital and wage deflators in the manufacturing industry. The weights are the average shares of current and capital expenditure in the reported R&D expenditure. Now, for subsequent years, PIM is used to calculate R&D stock:

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

Royalty, licenses, and technical know-how (RP): Hu et al. (2005) argues that purchased technology may be an important factor that may influence sales of the firms. Similar to R&D, the stock values of the amount spent on royalty, licenses, and technical know-how have been taken as a proxy for technology purchased from other firms.

Recent stock of plant and machinery (RPM): The embodied technology may be instrumental in raising the output of the firms' (see Saxena 2011). In the paper, the stock value of recently purchased plant and machinery is used 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 the real expenditure on plant and machinery. It is calculated as the difference between book values and stock value of newly purchased 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 the ratio of RPM to total fixed capital.

R&D spillovers (RDSPILL): the dependent variable R&D spillover is measured using differences in the values of R&D stock of a firm and its corresponding industry as suggested in Saxena (2011). R&D stock of industry is calculated similarly to that of a firm's R&D stock. Symbolically, R&D spillovers can be depicted as follows:

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

here $RDSPILL_{it}$ is the aggregate stock of R&D spillovers available to the i'th firm operating in j'th industry at a particular time t. It can be expressed as the aggregate R&D stock of an industry net of a firm's own R&D stock. The R&D stock of the industry has been calculated at the 3-digit level as per NIC-2008.

Competition: competition has been used as a benchmark for segregated analysis and is measured with the help of Price-Cost Margin (PCM) as well as the Herfindahl-Hirschman Index (HHI). Following formulas are used to calculate HHI and PCM:

(1) Price Cost Margin (PCM) $= \frac{\text{totaloutput}-\text{totalinputs}-\text{payroll}}{totaloutput}$

(2) Herfindahl–Hirschman Index (HHI) is calculated as a 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:

$$HHI_{mt} = \sum_{i=1}^{N} S_{it}^{2} where, S_{it} = \frac{sales_{it}}{\sum_{i=1}^{N} sales_{it}}$$

Table 2 GMM Estimation of Production function (aggregate sample)

Variables	Coefficients (Standard error) Model-1.1	Coefficients (Standard error) Model-1.2
K	0.031*** (0.006)	0.061** (0.026)
L	0.131*** (0.028)	0.136*** (0.012)
M	0.798*** (0.041)	0.756*** (0.051)
RD	0.08*** (0.011)	0.084*** (0.016)
RP	0.029** (0.011)	0.028** (0.013)
RPM	0.001 (0.012)	0.001 (0.002)
RDSPILL	NA	0.076*** (0.020)
C	0.031***	0.042***
Wald chi-sq	5241.63	5396.13
Hansen Test	20.09	21.42
AR (1)	− 3.71***	− 3.50***
AR (2)	− 0.57	− 0.31

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

It should be noted here, that HHI has been calculated using sales data belonging to all the firms present in manufacturing firms (not only sampled firms). This is important because firms not reporting any R&D expenditure may be influencing the distribution of market shares of the firms.

The values of PCM and HHI lie between 0 and 1. If the value is 0, perfect competition is considered to be prevailing, whereas, if it is 1, it signifies a monopoly in the market. By definition, HHI measures competition from domestic firms in terms of their relative shares in the market. It does not take into consideration competition from foreign firms. However, PCM, as the difference between price and marginal cost, reflects the overall price competition that a firm faces. To convert PCM and HHI from explicit measures of market concentration into measures of competition, we subtract them from one.

Empirical Results

The following sub-sections will describe the production function estimates using the system-GMM technique as described in the previous section. We have shown the estimated results of our model in a step-wise manner to exhibit how inclusion or exclusion of the R&D spillover variable affects the econometric results of the model.

R&D Spillovers in the Manufacturing Industry

Table 2 shows the estimated results of the production function described in the third section. Model-1.1 includes all the variables in equation (3) except RDSPILL (R&D spillovers). The results show that capital, labour, raw material, R&D investments, and purchased disembodied technology are the significant variables that are positively related to the output of a firm. The embodied technology, however, is found to be an insignificant variable.

In Model-1.2, we include the R&D spillover variable along with other control variables. The increased value of the wald-statistic indicates that Model-1.2 explains the results better than Model-1.1. The empirical results suggest that R&D spillover is a highly significant variable and its benefits seem to be largely comparable to firms' own R&D investments. Overall, after incorporating RDSPILL, the results suggest 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 having a positive relationship with firms' output. Embodied technology proxied by expenditure on the stock of recently purchased machinery is found to be insignificant in Model 1.2 as well.

The findings are consistent with the erstwhile studies and suggest the presence of a strong spillover effect from R&D in the Indian manufacturing industry.

R&D Spillovers and Product Market Competition

As mentioned earlier, the market competition has been measured by two inherently distinctive measures of competition, i.e., Price-cost Margin, and Herfindahl-Hirschman Index, to see the impact of competition on intra-industry R&D spillovers. For the purpose of analysis, the sample has been segregated using medians as a benchmark to separately observe the firms operating under high and low competition.

Table 3 (competition measured by 1-PCM) and Table 4 (competition measured by 1-HHI) depict the estimation results of the model respectively under the highly competitive and less competitive market structure. The results have been reported in a step-wise manner as previously done in the case of estimation of the aggregate sample.

Model 2.1 in Table 3 shows that capital, labour input, raw material, and firms' own R&D are the significant variables affecting the firms' output under high competition. Disembodied as well as embodied technology are found to be insignificant. Whereas, when the competition is low (Model 2.2), RP emerges as a significant variable at a 10 percent confidence interval.

With the inclusion of RDSPILL in Model-2.3 and Model-2.4, it has been observed that R&D spillovers are also significantly associated with firms' output. However, the coefficient of the R&D spillover variable is relatively much lower in a highly competitive market than in a less competitive market. The R&D spillovers from domestic firms in the low competition situation are found to be roughly three times stronger than spillovers in high competition. The results indicate that firms'

Table 3 GMM Estimates of the Production function in the high and low competition (measured as 1-PCM)

Variables	High competition (1-PCM) Model-2.1	Low competition (1-PCM) Model-2.2	High competition (1-PCM) Model-2.3	Low competition (1-PCM) Model-2.4
K	0.079***	0.123***	0.091**	0.101***
	(0.016)	(0.029)	(0.015)	(0.019)
L	0.051***	0.123***	0.09***	0.129***
	(0.015)	(0.031)	(0.011)	(0.021)
M	0.967***	0.627***	0.929***	0.724***
	(0.016)	(0.069)	(0.055)	(0.081)
RD	0.069***	0.124***	0.023*	0.080***
	(0.014)	(0.021)	(0.013)	(0.028)
RP	− 0.002	0.025*	− 0.005	0.030**
	(0.008)	(0.014)	(0.007)	(0.014)
RPM	0.004	− 0.01	0.006***	− 0.006
	(0.002)	(0.007)	(0.002)	(0.007)
RDSPILL	NA	NA	0.044***	0.126***
			(0.009)	(0.028)
C	0.09**	0.29***	0.12**	0.15***
Wald chi-sq	2007.7	1207.5	2028.4	1221.1
Hansen Test	21.34	21.74	25.67	30.43
AR (1)	− 3.79***	− 2.99***	− 3.10***	− 3.20***
AR (2)	− 0.19	− 0.21	− 0.15	− 0.25

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

own R&D is relatively less effective than benefits from spillovers in high competition conditions, which corroborates the findings of several earlier studies suggesting higher social return than private returns from R&D.

Among the control variables, capital, labour, raw material, and firms' R&D stock have a significantly positive effect on output in less competitive market situations. The positive impact of embodied technology is observed only in Model 2.3. The disembodied technology variable (technology purchased) is significantly positive in the less competitive market and insignificant when the competition is high.

Table 4 indicates that domestic market competition also affects our variables of interest significantly. The variables such as labour, raw material, and R&D stock are consistently found to be significantly positive in all the models. The disembodied technology is significant only when the competition is high, whereas embodied technology is an insignificant variable. A high R&D spillover effect is noticed under a high competition market situation (Model 3.3), whereas, it is insignificant when the market is less competitive (Model 3.4). The estimation results indicate that in the highly competitive market, the effect of spillovers on output is approximately double that of firms' own R&D (see Model 3.3).

The conflicting results in Tables 3 and 4, in terms of the effect of R&D spillovers under high and low competition, are probably because of the difference in how PCM and HHI are measured and how various channels are affected by the competition. By

Table 4 GMM Estimates of the Production function in the high and low competition (measured as 1-HHI)

Variables	High competition (1-HHI) Model-3.1	Low competition (1-HHI) Model-3.2	High competition (1-HHI) Model-3.3	Low competition (1-HHI) Model-3.4
K	0.071*** (0.004)	0.045*** (0.009)	0.087** (0.042)	0.031** (0.019)
L	0.158*** (0.031)	0.105*** (0.033)	0.143*** (0.029)	0.137*** (0.031)
M	0.699*** (0.07)	0.881*** (0.033)	0.651*** (0.071)	0.840*** (0.030)
RD	0.12*** (0.017)	0.063*** (0.022)	0.053** (0.026)	0.061*** (0.026)
RP	0.041*** (0.018)	0.011 (0.017)	0.047*** (0.013)	0.005 (0.017)
RPM	− 0.005 (0.006)	0.00007 (0.008)	− 0.0009 (0.001)	0.003 (0.007)
RDSPILL	NA	NA	0.107*** (0.031)	0.017 (0.026)
C	0.13*	0.09***	0.23**	0.08***
Wald chi-sq	2080.9	4038.9	2234.1	4892.6
Hansen Test	23.77	23.54	26.54	23.56
AR (1)	− 2.50***	− 3.91***	− 2.40***	− 3.76***
AR (2)	− 0.30	− 0.29	− 0.36	− 0.32

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

definition, the PCM represents the overall 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. Considering the definition of PCM and HHI, it can be argued that overall price competition contracts spillovers from R&D, whereas spillovers are high when the firms face intense competition from domestic firms.

It may be argued that the firms, which are facing higher price competition (PCM), may not have sufficient funds to spend on capacity building even if they have the incentive to imitate/learn from other domestic rival firms. On the other hand, learning from domestic rivals may not be much useful under such circumstances as this will not help them compete with high technology firms situated abroad. Nonetheless, when the competition is domestic in nature and defined in terms of market shares, firms may have sufficient funds for capacity building as well as a greater incentive to learn from domestic rivals.

Additionally, relative geographical, political, and technological proximity among firms within domestic markets may act as a conducive factor in the absorption of spillovers through various means (like skilled labour mobility, business interactions, and R&D collaborations) which are likely to get triggered more as the competition increases. As discussed earlier, activities such as imitation, interaction among skilled workers, and cooperation are likely to be more effective when the competition is

Table 5 Average R&D-intensity of the firms under different market competition

	All firms	High Competition (1-PCM)	Low Competition (1-PCM)	High Competition (1-HHI)	Low Competition (1-HHI)
R&D-Intensity	0.373	0.496	0.313	1.12	0.273
Spillovers		Weak	Very Strong	Very Strong	Weak/Absent

Source: Authors calculations using Prowess-CMIE data

high among domestic firms. Geographical proximity, the possibility of more frequent labour mobility within a country than abroad, and greater cooperation/interaction among immediate competitors probably provide a more conducive environment for the spillovers. However, these factors may not play an equally significant role if a significant share of competition is with firms situated abroad, specifically due to various possible geographical, political, economic, and social restrictions. Though technological reach may still play an effective role, yet the effectiveness may be limited due to greater physical distance, visa restrictions, language barriers, and the fact that not all the firms engage in international trade leading to the limited influence of activities such as imitation, cooperation, and other business interactions.

Policy Implications

India's Science, Technology, and Innovation Policy (STI) 2013 puts greater emphasis on the need to invest more in innovations for 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 the private sector increases its R&D expenditure. The present share of private R&D investment is less as compared to 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 elements in R&D investments by the government and encouragement to the public-private partnership along with other measures so that investment in R&D can be increased.

The aforementioned objectives of the STI policy mainly focus on increment in R&D expenditure. Nonetheless, the crucial role of technology diffusion, especially in the case of developing countries engaged in catching up, 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. This shortcoming can be witnessed in the STI policy as well. Mani (2013) 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, nevertheless, introduce a range of innovations. If STI policy considers itself to be an innovation policy and not an R&D policy, it should include several other measures for enhancing the non-R&D route to innovation (see Mani 2013). The findings of the present paper are in agreement with the argument and suggest that R&D policy should also focus on technology diffusion by making use of externalities emanating from R&D investments.

Moreover, the findings suggest that the role of market competition should also be recognized while formulating innovation policy. Table 5 shows the average R&D-intensity[5] of the firms (during the period under consideration) operating under different market competition levels. The R&D-intensity of the firms seems to be significantly different in low and high competition.

Although the average R&D intensity in the case of firms operating under high price competition (measured as 1-PCM) is more than the firms facing lower competition, the benefits from spillovers are low. Contrary to this, R&D intensity is less in the case of firms facing lower price competition, yet the gains from spillovers are greater. The observation suggests that under high price competition, actual social returns from innovations may be relatively less even when R&D intensity is high. We suggest that encouraging R&D investment more in the case of firms that face lower price competition may stimulate more spillovers in the economy.[6]

On the other hand, high competition, characterized by smaller market share (measured as 1-HHI), is found to be benefiting firms through the spillover effect. The firms operating under high competition are highly R&D-intensive in comparison to the firms facing lower competition. The spillover effect is absent/weak in the case of the firms operating under a low competition situation. The innovation policy incentivizing R&D investments coupled with competition enhancing measures should be introduced to provide the firms operating under low domestic competition with an incentive to learn from rivals. Such policies may help the firms to build up absorptive capacity for reaping the benefits of prevalent spillovers.

Conclusion

Spillovers are considered important for the growth of an economy. The empirical literature finds R&D spillovers as one of the important determinants of growth and technological improvement in various countries. Spillover coefficients are consistently and significantly comparable to the firm's own R&D investments in several 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 2001–2018. Additionally, we observe the presence of spillovers in the context of product market competition. Our results indicate that the magnitude of R&D spillovers depends upon the level of market competition faced by the firms. However, contrasting

[5] R&D intensity is measured as the ratio of R&D expenditure to sales of the firms.

[6] The extent to which social returns from R&D should prevail is a matter of discussion. For detailed discussion see Frischmann & Lemley (2007).

results have been found when different indicators of competition are used (PCM and HHI). We argue that the variation among the results may be because of the varied impact of overall price competition and competition measured by domestic market share.

Finally, the results suggest that the government policies related to science, technology, and innovations should be designed considering the role of technological diffusion and the factors, such as product market competition, which may affect the assimilation of R&D spillovers.

Appendix

Summary Statistics

Variable	Mean	Std. Dev	Min	Max
Y	3.752	0.777	1.802	6.631
K	3.493	0.747	1.734	5.909
L	3.537	0.673	1.681	5.605
M	3.401	0.778	1.374	6.232
RD	1.848	0.825	− 0.089	4.544
RP	0.888	1.193	− 1.925	4.795
RPM	− 1.103	0.962	− 3.590	− 0.043
RDSPILL	3.806	0.632	0.460	5.158

Correlation Matrix

	K	L	M	RD	RP	RPM	RDSPILL	VIF
K	1							7.71
L	0.842	1						4.49
M	0.894	0.783	1					5.8
RD	0.552	0.595	0.608	1				2.26
RP	0.309	0.353	0.357	0.356	1			1.23
RPM	0.147	0.139	0.051	− 0.071	0.011	1		1.17
RDSPILL	− 0.141	− 0.195	− 0.039	0.266	− 0.022	− 0.259	1	1.54

Note: The correlation among some of the variables is strong. However, the Variance Inflation Factor less than 10 (VIF < 10) suggests that a high correlation among various independent variables does not cause the problem of multicollinearity (see Nachane 2006).

Acknowledgements This paper has immensely benefitted from suggestions by Professor

Indrani Chakraborty, Professor & Director Achin Chakraborty and other faculty members of the Institute of Development Studies Kolkata (IDSK). I am also grateful to Professor Lakhwinder Singh (Punjabi University, Patiala) and Dr Indervir Singh (Central University of Himachal Pradesh) for their encouragement. The comments from various anonymous scholars and experts, who were present during a presentation at the International Schumpeter Society Conference, Seoul (2018), were very instrumental and helped to improve the quality of the research work.

Declarations

Conflict of interest The author has no conflicts of interest to declare that are relevant to the content of this article.

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