Does innovation matter for total factor productivity growth in India? Evidence from ARDL bound testing approach

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Received 29 August 2017
Revised 23 January 2018
22 March 2018
Accepted 23 April 2018

Abstract

Purpose – The purpose of this paper is to examine whether innovation plays a significant role in the total factor productivity (TFP) growth in India at an aggregate level.

Design/methodology/approach – This study first estimates the TFP growth using a growth accounting framework. In the second stage, the authors examine the long-run and short-run impact of innovation on TFP growth using the ARDL bound testing approach.

Findings – The results indicate a cointegrating relationship between innovation and TFP growth. Further, coefficients of long-run elasticity show that the increase in overall innovation activities improves the TFP growth. Other factors such as human capital, financial development and FDI do not affect the TFP growth in the long run; however, these variables significantly affect the productivity growth in the short run.

Practical implications – Findings of the study suggest that the innovation-friendly policies such as the strengthening of intellectual property rights, R&D subsidies and innovation rebates may spur the productivity growth, and hence, good growth and prosperity as well.

Originality/value – Having devoted a large volume of literature to address the sources of economic growth, the present study focuses on the determinants of TFP growth in India which may fall in similar category but differ in several angles: First, the authors construct a TFP index using a growth accounting framework. Second, the authors construct an innovation index using principal component analysis which is new to the literature and also an innovation index. Third, given the scanty innovation activities in low developed countries like India and its widening role in the contemporary literature, special emphasis will be given to this aspect. Finally, the effect of the examined relationship on TFP growth in the long run and short run provides several implications for policy purpose to the developing nations like India.

Keywords ARDL, Principal component analysis, Total factor productivity, Error-correction mechanism, Innovation index

Paper type Research paper

1. Introduction

A large body of literature emphasizes the key ingredients of growth such as human capital, innovation and technological change which have also become the prerequisite to attain the long-run productivity growth (Solow, 1956; Hasan and Tucci, 2010). The evidence provided by the endogenous growth literature and Schumpeterian's (1934) ideology supports such arguments theoretically and empirically as well and confirmed the critical role of technological progress and innovation towards modern growth (Romer, 1986; Grossman and Helpman, 1991; Aghion and Howitt, 1992). Indeed the significance of innovation and its interaction with several other areas of documentation is growing rapidly as per recent studies[1]. In Indian case, ample number of studies discussed about the prospects of economic growth (Panagariya, 2004; Rodrik and Subramanian, 2005; Kohli, 2006; Ghate *et al.*, 2013), but these studies did not focus on the total factor productivity (TFP) growth at the macroeconomic level, particulary ignored on the grounds of innovation- and

International Journal of Emerging Markets
Vol. 13 No. 5, 2018
pp. 1311-1329
© Emerald Publishing Limited
1746-8809
DOI 10.1108/IJoEM-08-2017-0314

technology-related activities. And some argued that, by and large, India's growth story is driven by the factor accumulation than that of the TFP growth (Bosworth and Collins, 2008), who examined the sources of economic growth without giving any emphasis to the innovation and TFP nexus.

It is evidenced in the economic history over the time and clearly observed that in aggregate production function, innovation and human skills have become more vibrant and active, which led to greater spurt in production possibility frontier. For instance, this linkage – innovation-growth nexus – in the context of OECD nations was observed by Pradhan *et al.* (2017); similarly Andergassen *et al.* (2017) also elaborated the diffusion channels of innovation and emphasized, the role of general purpose of technologies enhancing economic activity and growth in general. However, such studies widely and increasingly are focusing on emerging nations (Yip and Mckern, 2014; Pathak *et al.*, 2016). Some studies such as Grossman and Helpman (1994) argue that despite the key role of technological progress, the accumulation of other types of growth ingredients (such as physical capital) plays a vital role in the process of long-run economic growth. A detailed survey of literature and diverse arguments pertaining to these studies are provided in the literature section; however, studies on linkage between innovation and productivity growth in India are scanty and hence it is demanding.

However, in this context, it is imperative to examine whether innovation activities explain the success stories of India's growth in the recent past through TFP, in which the present study is aimed at. The novelty of the present study can be explained in three ways: First, given the greater recognition of innovation at global scale, the national innovation council of India declared "2010–2020" as a roadmap to the "Decade of Innovations" and caused to encourage such research. Second, this study fills the research gap by examining the linkage at an aggregate level using data of macro indicators, rather than focusing only on R&D expenditure as the proxy of innovation[2]. Third, the study constructs an innovation index which is new for Indian context using patent counts, scientific journal articles, trademark applications and high-tech exports that examine its impact on TFP growth in the long run as well as short run. Fourth, using advanced cointegrating estimation procedures, the present study finds greater linkage from innovation to productivity growth along with human capital. The study also provides a mixed relationship with trade variables; in this line, the correlations between trade and productivity growth in terms of exports and imports are not evidenced, although studies have suggested that trade has a positive impact that generates from both export and import channels, but in our study the ambiguity is left as it is as propounded by Rodriguez and Rodrik (2001). We also consider other control variables which affect the TFP growth. However, from the innovation linkage by its several composites, the study draws several policy implications for the developing nations like India.

The remainder of the paper is organized as follows: Section 2 provides a glimpse of India's innovation activities. Section 3 discusses the theoretical empirical literature that provides the grounds for study under the investigation and follows the review section. We present the data and methodology in Section 4. Section 5 discusses the empirical results, while the final section concludes and offers policy implications out of its findings.

2. A Glimpse of Indian innovation activities

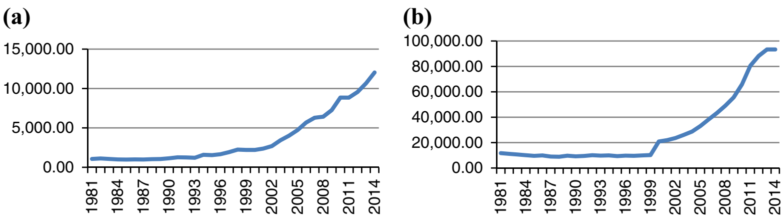
Since the beginning of early 80s and then with the effect of big reforms of 1991, Indian economy has been experiencing a remarkable growth and is able to serve as a better laboratory for conducting research in several aspects. These new developments connect economic activity through a variety of sectors ranging from industry to trade and business to finance. Along with trade and global connectivity in areas such as technology adoption and flow of knowledge, assimilation from the overseas rapidly went up.

The indigenous capabilities flourished to absorb these new developments and slowly evolved to penetrate into basic sciences, research and production lines of Indian economic system. This is depicted in Figure 1, which highlights the gradual developments as can be seen from the science, innovation and technological episodes in the recent past. This trend in scientific temper from the Figure 1 reveals that the composition of innovation activities in India is increasingly growing over the years, particularly after the reforms of 1991. The innovation activities which we use in this study not only are patents and scientific journal articles but also include trademark applications and high technology exports. Overall innovation activities show an upward trend with an average of 3,500 patent files, and around 30,000 scientific journal articles in each year show the strength of Indian innovation capabilities. Similar to these two, other indications of innovations such as trade mark applications shot up by an average of 68,000 per year, but the share of high technology exports was relatively slow but averaged at 6 to 10 percentage growth as a share in the total exports of manufacturing sector. These fascinating figures provide greater avenues to the conceptual background for the present study. Along with these activities, which were treated as technological tools (innovation and scientific journals), we also consider the technology supported activities (human capital and trade openness) trending upward since the reform initiatives. Along with these — new ideas, skills, knowledge, trade and other traditional factors such as labor force, physical investment, FDIs and financial development, particularly banking sector might boost up India's growth (Delong, 2003; Rodrik and Subramanian, 2005). These traditional growth factors caused to improve and perform relatively better due to the newly emerged factors such as spending in R&D, creating new technologies and innovations by collective interactions among and impel the growth channels.

Given this institutional set up, the present research study focuses on the potential explanations of the TFP growth from the new perspectives, i.e. innovations, knowledge creation, assimilation and absorption. Apart from the greater emphasis observed from Indian subcontinent, the next section provides motivations and research needs from the ongoing research in the field, and given the connectivity between innovation to productivity, it shows the needs and necessity for the present research in the Indian context.

3. Theoretical linkage, literature and hypothesis

Innovation and growth is an extensive area and evidence was plenty in growth literature both at the micro and macro level[3]. The strong linkage has been emerging between innovation and productivity growth in recent times, and is receiving greater attention across the research community and academia. However, innovation is not new to the literature in the field of economics. In modern times, in association with growth was systematically analyzed by Solow (1956), who found a long-run relationship between innovation and economic growth. Prior to this, Schumpeter (1911, 1934) made the distinction between economic development and innovation and showed how innovation stimulates growth via



Notes: (a) Patent statistics; (b) scientific journal articles
Source: World Development Indicators

Figure 1. Innovation and scientific progress in India

creative destruction[4]. According to him, economic growth is a slow process, and a progressive system generated by external factors and system of discontinuous actions where growth originates through Dynamic changes, interactions and creative ideas of new economic agents, i.e. entrepreneurs.

Theoretically, Schumpeterian model of economic growth, as mentioned already, upholds the system through viable innovative economic actions which enable the creation of newer technologies disrupting the older ones. Later, this was proved by the seminal contributions of Romer (1986) and Aghion and Howitt (1992), who empirically evidenced these channels of innovation that connected to the modern growth story. Numerous empirical studies produced such evidence of "innovation leads to productivity upsurge" and well documented (e.g. see Griliches, 1979; Nadiri and Kim, 1996; Aghion and Howitt, 1990; Geroski, 1989; Geroski, 1991; Crespi and Zuniga, 2012; Raymond *et al.*, 2015). These studies found similarities by investing for innovation in the form of increasing R&D expenditure or creation of new products, and production methods and other non-technological related innovations[5] have significantly promoted the TFP growth particularly in OECD context. There are studies at a micro level with similar objectives around innovation and technological developments which examine linkage between R&D and productivity, determinants of R&D, spillover effects of FDI and productivity, and relationship between trade, R&D and productivity by focusing on Indian manufacturing sector (see, for instance, Siddharthan, 1992; Raut, 1995; Basant and Fikkert, 1996; Kumar and Saqib, 1996; Ray and Bhaduri, 2001; Hasan, 2002; Kathuria, 2002; Kumar and Aggarwal, 2005; Franco and Sasidharan, 2010; Sasidharan and Kathuria, 2011; Sharma and Mishra, 2011; Sharma, 2012; Mitra *et al.*, 2016). Similar to this, studies also are available at the macro level such as Pathak *et al.* (2016) that empirically studied 18 emerging nations, interlinked various socio-economic activities and found to have a positive impact on the latest technologies used by entrepreneurs during the 2002–2008 but, at the same time, ethnic-polarization has showed a negative impact on these technologies. Yip and Mckern (2014) observed the impressive expression from Chinese firms which are stimulating innovations through R&D laboratories which develop new products for emerging markets like China. Chinese markets are analyzed via the role of MNCs by upgrading from imitation to innovation and found the greater role of innovation in Chinese transformation; this was due to the large volume of R&D reflected in high scientific research undertakings.

Similarly, Abdih and Joutz (2006) using US data found a positive link from patent counts (knowledge creation) to TFP growth in the long run but the effects are extremely small. However, it was claimed that their results are similar to the new growth models, where innovation was a key to the growth. Similarly, another study by Ulku (2004) found that innovations (through patent statistics) are important for GDP per capita and TFP as well. However, some pre-conditions are to be met such as high R&D intensive nations would only be able to draw the positive outcomes (innovations are transforming into high growth rates) but smaller OECD nations learn from the high R&D intensive nations. Exploring further, they also found that the innovations only lead to high growth rates in the short run which contradict with Romer evidence, confirming that there is no such perpetual growth via innovations. Furman and Hayes (2004) also studied the issue of national innovative productivity among the 23 OECD nations (1978–1999) by splitting as innovators and narrowed innovators categorized by the intensity of innovations that are new to the world, i.e. which developed radical and second grade innovations. The analysis explains why some of the countries could generate the innovations that are of high degree of innovativeness, products that are new to the world and corresponding reasons associated with national industrial competitive advantage (Porter, 1990) and national innovation systems (Nelson, 1993). Chen and Dahlman (2004) showed the importance of knowledge creation for productivity growth covering most of the developing countries (1960–2000), in which they have measured the domestic innovation variable using proxies such as number of patents, utility patents, published scientific journal articles and the amount of royalty payments and receipts; obtained results are positive and statistically significant. In another study by Pessoa (2007), the role of R&D expenditure in relation between innovation and growth for the Sweden and Ireland was examined. The findings are not so strong from R&D to innovation. But the study suggested that a better innovation policy might explain the complexities involved in the growth process. Some of the other studies in the literature such as Petrariu *et al.* (2013) and Czarnitzki and Toivanen (2013) have explored similar issues and found positive relationships between innovation and economic growth in several cases. In this line, studies with cross-country evidence, for instance Hasan and Tucci (2010), used the global patent data on economic growth and found an empirical relationship from the sample of 58 countries for the period of 20 years. More recently, such interrelationships among the innovation and growth along with other macroeconomic variable have been found in studies such as Pradhan *et al.* (2017), particularly non-R&D type variables (see Lopez-Rodriguez and Martinez-Lopez, 2017). Such strong observations from innovation to growth via R&D were consistent; here again the data were used against the advanced nations, for instance the Netherlands (Donselaar *et al.*, 2004).

This confirms the quality and quantity of innovation that affect the growth in these countries and clarifies how the patent counts really turn into the output growth. It is well known from these studies that the literature on innovation and productivity growth nexus is lesser known particularly at the macro level, though literature is somewhat familiar to the link between innovation and economic growth. The above studies found greater avenues for the ongoing importance of innovation in shaping better and efficient systems, and prompted economic growth channeling innovation capabilities. But, to the best of our knowledge, there is no such study that suggests innovative activity leading to a higher level of TFP growth in the Indian context at an aggregate level. To fill this gap, our study makes an attempt to examine this research question framing the following testable hypothesis:

H1. Higher level of innovative activity leads to the higher level of TFP growth in India.

4. Data and methodology

4.1 Measurement of total factor productivity growth

There are many approaches in the literature to calculate the productivity growth viz. growth accounting framework using Cobb–Douglas production function, translog production function through least square approach, and others such as Kendrick Index, Divisia, Fisher Index, stochastic frontier approach and data envelopment analysis. This study measures the TFP growth using the traditional growth accounting framework using the Cobb–Douglas production function.

This core growth-accounting framework was propounded by Solow (1957), who used the aggregate neoclassical production function to decompose the growth rate of aggregate output into the contributions of growth measured by various inputs and improvements in TFP. However, this exercise depends on the specification of the production function. This is a widely used method to estimate TFP at an aggregate or economy level translog production function. And this Cobb–Douglas production function through ordinary least squares (OLS) estimation is very restrictive because it depends on several assumptions such as constant returns to scale, perfect competition, and autonomous Hicks-neutral technological progress. The most commonly used Cobb–Douglas production function can be written as:

$$Y = AK^{\alpha}L^{1-\alpha}, \tag{1}$$

where *Y, L* and *K* refer to real GDP, labor force and physical capital stock, respectively. *A* is the technological progress, α and $(1-\alpha)$ are the elasticities of GDP on capital and labor, respectively. A logarithmic transformation of C–D production function yields an equation that is linear in the logarithms of output and inputs and in time, and can be written in the following form:

$$\ln Y_t = \delta + \alpha \ln K_t + (1-\alpha)\ln L_t. \tag{2}$$

The OLS estimation of this equation yields estimate values of $\delta = \log A$, α, and $(1-\alpha) = \beta$. The sum of the estimates α and β is a measure of the degree of homogeneity in the production function. It is assumed to be the disembodied and Hicksian framework, so that the involved inputs such as labor and capital remain to be constant relatively following the shift in the technology or knowledge in the function. Hence, the elasticity of substitution among the variables is assumed to be 1, which shows the constant returns to scale. Under the assumption of constant returns to scale and autonomous Hicks-neutral technological progress, the Solow Index of TFP can be obtained this way:

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \left[(1-\alpha)\frac{\dot{L}}{L} + \alpha\frac{\dot{K}}{K}\right], \tag{3}$$

where Y, L and K refer to the gross sales, labor and capital, respectively. Technical change is assumed to be taking place in the constant returns form. The estimated Equation (3) fulfills the formal OLS conditions which allow the error term that is identically independently distributed (i.i.d.) with zero mean and constant variance. Using the parameter estimates of α and β, TFP levels can be calculated and its differences in the level lead to TFP growth. After calculating TFP growth, in the next step, the study moves to discuss the methodology for examining the impact of innovation on productivity growth at an aggregate level for India using the ARDL version of cointegration technique.

4.2 Unit root tests

We use the traditional Augmented Dickey Fuller (1979) and Phillips and Perron (1988) tests, which have been commonly considered to test the stationary properties of time series data in the literature. The empirical analysis starts with the conventional unit root tests to find the order of integration of the variables; such tests are used to find whether the series contains a unit root (non-stationary) or is a stationary process. Most of the macroeconomic time series data are sensitive to the shocks or said to be non-stationary in nature which leads to the spurious results of the estimation. In this regard, it is essential to apply these tests for all the time series variables to know the data properties, whether variable integrated at same order or not. Therefore, it is essential to check the existence of non-stationary properties, or to test the null hypothesis of the non-stationary (unit root) against the alternative hypothesis i.e. stationarity. Based on the integration properties of the data, we further proceed to study the long-run relationship among the variables under the investigation.

4.3 Structural breaks

Although the traditional unit root tests indicate the stationary property of a series, it failed to capture the presence of structural breaks in the data. To overcome this problem, we employ the Zivot-Andrews's (1992) unit root test written in the form of Equation (4). Our proceeding depends on the data behavior whether it has trend or no trend in the data:

$$\Delta y_t = k + \alpha y_{t-1} + \beta t + \theta \mathrm{DU}_t + \gamma \mathrm{DT}_t + \sum_{j-1}^{k} d_j \Delta y_{t-j} u_t, \tag{4}$$

where Δ is the first difference of the variable, DU_t is an indicator of dummy variable for a mean shift occurring at time trend break, DT_t is the corresponding trend shift variable, ε_t is the white noise disturbance term and $t = 1, 2, \ldots, T$, are the breaks in the series, adjustment procedure and estimated results are provided in the empirical section.

4.4 ARDL bound testing approach

After checking the stationary properties and taking care of the breaks in the variables under the study, in the next stage, we proceed further to examine the impact of innovation on TFP growth using the ARDL bound testing approach (Pesaran and Shin, 1998; Pesaran *et al.*, 2001). The ARDL bound testing has several attractive advantages: first, this test allows the series for both stationary i(0) or non-stationary i(1) or mixed order of condition i(0) and i(1). Second, relatively superior to the previous models such as Engle and Granger (1987), Phillips and Hansen (1990), Johansen (1988) and Johansen and Juselius (1990) which all require the variables to be of equal degree of integration i.e. i(1) and also this approach ensures more consistent estimates, even though sample size is small (Pesaran and Shin, 1998). Third, by using this application, we obtain both the long-run and short-run parameters without losing any information of the model and can be estimated at once. Fourth, given the free of residual correlation, the ARDL model handle the eventual phenomena of endogeneity among the explanatory variables (Pesaran *et al.*, 2001), which indicates that the existence of endogeneity among the explanatory variables and the validity of ARDL approach estimations will not be compromised.

The ARDL procedure involves two steps. The first step is to examine the existence of long-run relationship between the variables in the model. If cointegration exists, the second step is to estimate the long-run and short-run coefficients using associated ARDL and Error Correction Models (ECMs). Based on theoretical underpinnings and related literature, we frame Equation (5) to be estimated further; instead of estimating the formal OLS model, we choose to apply ARDL approach, given the advantages of the model over other empirical strategies:

$$\mathrm{TFP}_t = \alpha_0 + \beta_1 \mathrm{INV}_t + \beta_2 \mathrm{HC}_t + \beta_3 \mathrm{FD}_t + \beta_4 \mathrm{FDI}_t + \beta_5 \mathrm{OP}_t + v_t. \tag{5}$$

To empirically examine the long-run associations and dynamic interactions among the variables of interest, the model has been estimated by the ARDL bound testing framework under cointegration. Another feature of this technique is that when the sample size is small, it is a more statistically significant approach for determining the cointegrating relationships. Hence, we have constructed the error correction representation of the ARDL models implemented in the following form:

$$\begin{aligned}\Delta\mathrm{TFP}_t = {} & \alpha_0 + \beta_1 \mathrm{INV}i_{t-1} + \beta_2 \mathrm{HC}_{t-1} + \beta_2 \mathrm{OP}_{t-1} + \beta_2 \mathrm{FD}_{t-1} + \beta_2 \mathrm{FDI}_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta\mathrm{TFP}_{t-i} \\ & + \sum_{i=1}^{p} \gamma_i \Delta\mathrm{INV}i_{t-i} + \sum_{j=0}^{q} \delta_j \Delta\mathrm{HC}_{t-j} + \sum_{i=1}^{p} \gamma_i \Delta\mathrm{FD}_{t-i} + \sum_{i=1}^{p} \gamma_i \Delta\mathrm{FDI}_{t-i} + \sum_{j=0}^{q} \theta_j \Delta\mathrm{OP}_{t-j} + \varepsilon_t. \end{aligned} \tag{6}$$

In Equation (6), Δ symbol denotes the first difference operator of the corresponding variable and α_0 is the deterministic drift parameter. After estimation of the hypothesis constructed by the theory, the Wald test (F-statistics) can be computed by imposing linear restrictions on the estimated long-run coefficients of one period lagged level of variables. The existence of long-run relationship among the variables can be found by testing the null hypothesis of no cointegration against its alternative hypothesis of the existence of relationship. In order to find out the cointegration relationship among the variables TFP, INV, HC, FD, FDI and OPEN (EXP and IMP)[6], we test null hypothesis that is: $H_0: \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 = 0$ (no long-run relationship) and alternative hypothesis $H1$: $\varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi 5 \neq \varphi_6 \neq 0$ (there is a long-run relationship) by conducting non-standard F-test developed by Pesaran *et al.* (2001) and further it was extended by Narayan (2005) for small samples. The computed F-statistic value will be evaluated with the critical values followed by Pesaran *et al.* (2001). According to these authors, the lower bound critical values assumed that the explanatory variables are integrated i(0), while the upper bound critical values assumed that are integrated of order i(1). Therefore, if the computed F-statistics is smaller than the lower bound value, then the null hypothesis of no cointegration cannot be rejected. Conversely, if the computed F-statistic is greater than the upper bound value i(1), then the null hypothesis of no cointegration is rejected. On the other hand, F-statistic falls between the lower and upper bound values, and then the results are inconclusive.

The results of F-test reveal that if we reject the null hypothesis of cointegration relationship Equation (6) statistically following the Pesaran *et al.* (2001), we further estimate the model for short-run analysis through the error correction mechanism (ECT). Assuming that a long-run relationship is ascertained in stage one, then in stage two, we obtain the long-run relationship and the associated short-run dynamic error correction models (ECM) using Equation (7). The following equation is used for the estimation of ECT in the system of a short-run framework:

$$\Delta \mathrm{TFP}_t = \alpha_0 + \sum_{i=1}^{n-1} \gamma_i \Delta \mathrm{TFP}_{t-i} + \sum_{i=1}^{n-1} \gamma_i \Delta \mathrm{PA}_{t-i} + \sum_{j=0}^{n-1} \delta_j \Delta \mathrm{HC}_{t-j} + \sum_{j=0}^{n-1} \theta_j \Delta \mathrm{FD}_{t-j}$$

$$+ \sum_{j=0}^{n-1} \theta_j \Delta \mathrm{FDI}_{t-j} + \sum_{j=0}^{n-1} \theta_j \Delta \mathrm{OP}_{t-j} + \lambda\, \mathrm{ECT}-1 + \varepsilon_t. \quad (7)$$

In Equation (7), λ is the speed of adjustment parameter and ECT is the residual from the estimated model. The error correction representation defines the effectiveness of the feedback or correction mechanism in reaching back to the equilibrium position, the magnitude of the ECT term shows the speed of adjustment in the system (Sbia *et al.*, 2014; Alkhathlan, 2013; Jalil *et al.*, 2013); and ε is as usual error term in the model.

4.5 Data

We use annual time series data over the period from 1980 to 2014. To capture the innovation activities, we extracted various forms of innovation measures such as patent counts, scientific journal articles, trade mark applications and the share of high technology exports. Along with innovation, other control variables that are expected to influence the TFP growth including human capital, financial development, foreign direct investment and trade openness are included in the model. Time series data used in the study have been gathered from the World Development Indicators (WDI) published by the World Bank. The TFPTFP growth calculated using the Cobb–Douglas production function and the detailed methodology of the TFP calculations are outlined in Section 4.1. To estimate the TFP growth, we use real GDP, labor force and capital stock data also extracted from the WDI[7].

To understand the nature of the variables, we present the descriptive statistics in Table I, where all the variables except TFP growth are in logarithmic form. Despite running

Acronym	Description	Mean	SD	Min.	Max.
TFP	TFP growth, estimated through Cobb–Douglass production function	1.00	0.06	0.92	1.13
INV	Innovation index constructed through PCA	9.45	0.86	8.52	11.00
HC	Gross enrollment ratio, secondary, both sexes (%)	46.50	11.00	28.95	69.16
FD	Credit to private sector (as % of GDP)	30.97	10.77	20.19	52.20
FDI	Inflow of Foreign Direct investment (as % of GDP	0.76	0.88	0.00	3.55
OPEN	Total trade (exports + imports, as % of GDP)	27.33	14.67	12.01	55.75
EXP	Exports of goods and services (as % of GDP)	12.57	6.70	5.11	25.32
IMP	Imports of goods and services (as % of GDP)	14.76	8.01	6.86	31.24

Source: Authors calculation

Table I.
Descriptive statistics

different models for each measurement of innovation and to avoid multicollinearity, we construct an innovation index through principal component analysis (PCA) using various forms of innovation measures. The study uses four types of innovation variables; it is useful to construct such index because the availability of data on each segment reveals the different ways of innovation intensity in the economy. The constructed index would explain the behavior of innovation plausibly in a better way than that of each segment, or cover all desirable properties of innovation depth and breadth. The principal components (PCs) are computed through the linear combination of the four standard measures of innovation indicators by obtaining the factor scores and eigenvalues.

The detailed procedure for the construction of innovation index is explained in the following section. And formal definitions of various innovations provide further clarity about the dependent variable.

The much debated variable pertaining to innovation and growth literature is R&D expenditure and R&D personnel involved in production function, more particularly at the macro level it is the "ratio of R&D expenditure to GDP." Basically in studies like this, R&D expenditure has been considered as a growth driver; numerous studies in the context of OECD have been undertaken and found to have a strong linkage between R&D and economic growth, and in some instances, bi-directional causation was found from growth to R&D or vice versa (Stokey, 1995; Hu *et al.*, 2007) and a few others considered linking growth credit flows and R&D investment and back to growth connectivity (Pessoa, 2010; Guney *et al.*, 2017). However, the much relevant, influential and debated variable has not been included in the present study due to the following reason. This research considered innovation as an output of R&D [INV $= (f)$ R&D], but in the present paper, given the objective, it treats innovation as an input for the TFP [i.e., TFP $(f) =$ INV]. However, our aim is not to see the impact of R&D on TFP growth because R&D is not true indicator or a true proxy for innovation, but R&D is nothing but an innovation effort, such efforts may fail, thus R&D may not lead to the innovation, given this uncertain attitude of R&D, we dropped R&D variable from the analysis. Higher R&D may lead to higher TFP and economic output but not certainly, though there is large a pool of literature addressing this at the micro and macro levels in a variety of contexts (for instance, see Chun *et al.*, 2014; Bilbao-Osorio and Rodríguez-Pose, 2004; Siliverstovs, 2016; Di Cintio *et al.*, 2017). However, R&D variable can be added if the study tries inquiring about the determinants of innovation, but in the case of the factors that influence the TFP growth, it would pay attention to innovation (rather than R&D) that make interpretations cluttered and inconclusive; therefore, R&D variable is dropped from the analysis.

4.6 Independent variables

As suggested by the literature, we have used the variables that are likely to affect the productivity growth. This paper considers the traditional indicators such as trade openness, FDI, financial development, human capital along with innovation as major determinants of the productivity growth of India. This sub-section explains the data used as explanatory variables for analyzing the impact of innovation on TFP growth. Innovation is usually measured by the patents statistics and scientific journal articles at the macro level (see Madsen *et al.*, 2010). However, given the considerable debate and controversies in the literature, this study measures the innovation by considering four variables such as number of patents, scientific journal articles, trademark applications and high technology exports of manufacturing goods. These four variables altogether constructed an innovation index that provides the better information rather than creating separate models on each category of innovation. As this paper has discussed, innovation is a process that involves the implementation of new ideas and generated knowledge into the application of producing a new product or a new process or a kind of business which is substantially expected to improve the system/model/business or growth of something where it involves. Innovation could be in any form and to capture them altogether, it is important to construct an innovation index. This study has constructed an innovation index by considering those four broader indicators with the help of PCA.

4.6.1 Innovation index. PCA is a multivariate procedure that uses to transform a number of highly correlated variables into a smaller number of uncorrelated variables called PCs. Since there are a number of ways by which innovation can be captured from different domains, it represents the overall innovation in the country at the aggregate level.

4.6.1.1 Patents. Patents are considered as the world-wide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention - a product or process that provides a new way of doing something or offers a new technical solution to a problem. A patent provides protection for the invention to the owner of the patent for a limited period, generally 20 years.

4.6.1.2 Scientific journal articles. Scientific and technical journal articles refer to the number of scientific and engineering articles published in the following fields: Physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, earth and space sciences.

4.6.1.3 Trademark applications. Trademark applications filed are applications to register a trademark with a national or regional Intellectual Property (IP) office. A trademark is a distinctive sign which identifies certain goods or services as those produced or provided by a specific person or enterprise. A trademark provides protection to the owner of the mark by ensuring the exclusive right to use it to identify goods or services or to authorize another to use it in return for payment. The period of protection varies, but a trademark can be renewed indefinitely beyond the time limit on the payment of additional fees.

4.6.1.4 High-technology exports (% of manufactured exports). High-technology exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery. Data are in current US dollars.

To capture the innovation activities, this paper employed the PCA to construct an index which offers us a comprehensive measure that represents the aggregate innovation in India. The construction of innovation index (INVi) can be written in the following terms:

$$\mathrm{INV}_i = q1\,\mathrm{pANTENT}_t + q2\,\mathrm{SCIN}_t + q3\,\mathrm{TRADM}_t + q4\,\mathrm{HITECH}_t. \quad (8)$$

In the above equation, q_1, q_2, q_3 and q_4 are weights of the components given by the respective eigenvector of the selected PCs. The eigenvalues and eigenvectors of the component matrix of all innovation variables are given in Table II.

Components	Eigenvalue	Proportion
P1	3.70224	0.9256
P2	0.240477	0.0601
P3	0.043487	0.0109
P4	0.013796	0.0034
	P1	Factor loadings
PA	0.512396	0.256271
STJA	0.491514	0.245827
TMA	0.510649	255397
THE	0.484873	0.242505

Source: Author's computation

Table II.
Principal component analysis (PCA): innovation index

The first PC, i.e. PC_1, captures the 93 percent of the total variance[8]. The respective factor loadings from first PC of all the four variables are mentioned in the following equation and an innovation index is obtained:

$$\mathrm{INV}_i = (0.26)\mathrm{PATENT}_i + (0.25)\mathrm{SCIE}_t + (0.25)\mathrm{TRADM}_t + (0.24)\mathrm{HITECH}_t \quad (9)$$

5. Results and discussion

Our empirical analysis starts looking at the time series properties of the data used in the study. Unit root tests have been conducted and found mixed order of condition. To check the order of condition, we use the ADF and the Philips–Perron unit root tests. As mentioned, this is an *a priori* condition to perform any time series exercise to come up with the idea that variables are integrated in same order or not. Applying this mechanism, we found the mixed order of condition in the variables, suggesting going in for the ADRL bound testing approach; the unit root results are presented in Table III. In addition to the traditional unit root tests, we also check whether there exists any structural break in the data by applying Zivot and Andrews's (1992) unit root test.

The results are presented in Table IV, and since we did not get the common break points in all the variables, we adjusted the variables accordingly using the following equation:

$$\mathrm{TFP}_t = \alpha + \beta \times \mathrm{dummy} + e(t). \quad (10)$$

Variables	Augment Dickey Fuller test		Philips–Perron test	
	With trend	Trend and intercept	With trend	Trend and intercept
TFP				
Level	−3.509**	−3.448**	−3.509**	−3.448**
First difference	−6.871***	−6.750***	−7.082***	−6.946***
INV				
Level	2.539	−2.911	2.331	−4.056
First difference	−4.314***	−5.441***	−4.331***	−5.441***
EDU				
Level	−0.687	−1.630	−1.166	−1.420
First difference	−6.173***	−8.040***	−7.843***	−8.155***
FD				
Level	0.415	−1.871	1.250	−1.884
First difference	−7.958***	−5.573***	−5.569***	−5.569***
FDI				
Level	−1.282	−3.403*	−0.956	−3.392
First difference	−6.290***	−6.185***	−7.980***	−8.047***
OPENS				
Level	0.607	−3.250*	0.580	−3.287*
First difference	−5.651***	−5.765***	−5.768***	−5.768***
EXP				
Level	0.373	−3.153	0.427	−3.153
First difference	−6.176***	−7.001***	−6.857***	−6.882***
IMP				
Level	−0.590	−3.203	0.492	−3.203
First difference	−5.118***	−5.232***	−5.102***	−5.205***

Notes: *,**,***Indicates the level of significance rejecting null hypothesis at 10, 5 and 1 percent levels, respectively

Table III. Unit roots test (ADF and PP) results

Variable	Intercept Break year	Intercept Lag (AIC, HQ)	Trend and intercept Break year	Trend and intercept Lag (AIC, HQ)
TFP	−4.875 (1990)	2	−4.450 (1990)	2
INV	No		No	
FD	−3.202 (1996)	2	−3.272 (1997)	2
FDI	−4.314 (1994)	2	−3.975 (1999)	2
EDU	−4.854 (2000)	1	−3.361 (2004)	2
OPENS	No		No	
EXP	No		No	
IMP	No		No	
Critical values				
1%	−5.34		−5.57	
5%	−4.93		−5.08	
10%	−4.58		−4.82	

Source: Authors calculation

Table IV. Structural breaks: Zivot and Andrew unit root test

From Equation (10), the dummy variable takes value 1 for the break year and zero otherwise. Then break adjusted for TFP, say TFPb(t) = $a + e(t)$, following this we have constructed for other variables. To evaluate the existence of cointegrating relationship among the variables, we estimated Equation 6 and the results are presented in Table V.

Results based on these models (models I and II) confirmed that the null hypothesis of no cointegration is rejected, which implies that there is a cointegrating relationship among those variables. Model I is based on trade openness with (1, 1, 1, 0, 1, 2) lags and we replace trade openness variable by taking export and import separately in model II with (1, 1, 1, 0, 1, 1) ordering of optimum lags.

5.1 Long-run elasticities

After finding the cointegrating relationship, we estimated the long-run coefficients using Equation (6) for both the models. The results are presented in Table VI, which provide the long-run elasticities. The results indicate that innovation index was positive and statistically significant, which implies that innovations do affect the TFP growth positively in India. The coefficient of 0.383 suggests that 1 percent increase in innovation on an average leads to an increase in TFP growth by around 0.4 percent. First, this result could be true that innovation systems in India are helping in long-run growth for enhancing its TFP growth via the establishment of National Innovation Council which tries to coordinate such relevant activities among its stakeholders in the economy. Second, innovation led-productivity growth policy supports our analysis because of the new Science, Technology and Innovation policy in 2013.

Further, based on our proposed hypothesis, results were drawn with meaningful conclusion that innovations boost India's TFP growth rates and it is consistent with

Test statistic	Model I		Model II	
F-statistic	8.067		12.329	
Bound critical values by Narayan (2005)[a] and Pesaran *et al.* (2001)[b]	i(0)[a]	i(1)[a]	i(0)[b]	i(1)[b]
1%	4.483	6.320	3.74	5.05
5%	3.120	4.560	2.45	3.61
10%	2.560	3.828	2.12	3.23

Notes: [a]Naryan (2005); [b]Pesaran *et al.* (2001)
Source: Authors calculation

Table V. Bound test results

Table VI. Results of long-run elasticities

Variable	Model I Coefficient	Model I *t*-statistic	Model II Coefficient	Model II *t*-statistic
INV	0.383***	3.195	0.357***	3.805
HC	0.250	1.072	0.259	1.241
FD	−0.177	−1.343	−0.090	−0.829
FDI	−0.012	−0.396	−0.008	−0.336
OPEN	−0.605**	−2.785		
EXP			−0.023	−0.191
IMP			−0.593***	−4.441
C	−1.108	−1.428	−1.530	−2.032

Notes: **,***Indicates the level of significance (rejecting null hypothesis) at 5 and 1 percent levels, respectively

the previous literature in the context of OECD nations (for instance, Ulku, 2004; Abdih and Joutz, 2006) and even it is true in the context of some developing nations (Chen and Dahlman, 2004). However, the other key indicators such as human capital, FD and FDI are found to be insignificant for both the models, but they show some relationship in the short run. However, trade openness negatively affects the TFP growth. The existing literature also found mixed opinion, in same way it states –"Policies towards foreign trade are among the more important factors promoting productivity growth and convergence in developing countries" (IMF, 1997). Likewise, a large body of literature on historical trade theories argues that trade helps to grow or for growth of TFP level, but in some other arguments in the literature it is noticed that openness has a negative relationship toward promoting economic growth. In a similar vein, the standard literature such as Rodriguez and Rodrik (2001) also argued that restrictive trade policies may not be harmful to the country and conclusions remain controversial in "trade-growth" literature. However, we further extended our model by adding export and imports by replacing trade openness (see model II). The results indicate that export does not affect the TFP growth, but the coefficient on import negatively affects the TFP growth. The impact of import on TFP growth based on the review of literature seems to be mixed. Some studies found that import positively affects the TFP growth, whereas another strand of literature found that import has negatively affected the TFP growth (Herrerias and Orts, 2011). However, the negative trade openness in the long run suggests that the increasing volume of trade with rest of world has hurt India's TFP growth. When the study looks into further studies separately as exports and imports, the negative effect was found only from the import activity. This confirms that the large volume of import activity (exceeding export volumes) is not a healthy indication as observed by Seenaiah and Badri (2015). They noticed that wider gaps between export and imports lead to high current account deficits which consequently worsen the productivity growth in India.

5.2 Short-run adjustment

After analyzing the long-run elasticities, this study examines the short-run relationship among these variables using ECM and the results are presented in Table VII. The result of error correction term is negative and significant (−0.952), which suggest that the speed of adjustment is taking less time to reach the equilibrium. Spending in R&D for scientific research-hubs and academic institutions would turn into positive over the time; however, the lagged variable has a negative impact, significantly affecting the TFP growth. This implies that it may take little longer time spans to bring such agglomeration effects from innovation generating positive TFP growth. In short run, human capital and financial development along with innovation capability have positive effects on TFP growth.

Variable	Model I Coefficient	Model I t-statistic	Model II Coefficient	Model II t-statistic
ΔTFP(−1)	0.179	0.948		
ΔINV	0.566***	3.674	0.545***	4.873
ΔLINV(−1)	−0.540***	−4.595	−0.475***	−5.394
ΔHC	0.038	0.127	−0.001	−0.004
ΔHC(−1)	−0.225	−0.886	−0.399*	−2.012
ΔHC(−2)	0.430	1.593	0.624**	3.555
ΔFD	0.142	1.108	0.250*	2.102
ΔFD(−1)	−0.136	−1.005	−0.060	−0.637
ΔFD(−2)	0.389**	2.538	0.364*	3.330
ΔFDI	0.019	1.494	0.018	1.581
ΔFDI(−1)	−0.019	−1.327	−0.016	−1.331
ΔFDI(−2)	0.031*	1.907	0.026*	2.263
ΔOPEN	−0.298	−1.749		
ΔOPEN(−1)	0.221	1.332		
ΔOPEN(−2)	−0.108	−0.934		
ΔEXP			−0.020	−0.191
ΔIMP			−0.407**	−3.261
ΔIMP(−1)			0.234	1.825
ΔIMP(−2)			−0.278*	−2.841
Coint Eq(−1)	−0.952***		−0.886***	−6.524
Adjusted R^2			0.786	0.871
Breusch–Godfrey Serial Correlation LM test:			3.22 (0.101)	4.239 (0.093)
Heteroskedasticity test: Breusch–Pagan–Godfrey			0.450 (0.936)	0.675 (0.780)
Stability test: Cusum and Cusum square			Stable	Stable

Notes: *,**,***Indicates the level of significance (rejecting null hypothesis) at 10, 5 and 1 percent levels, respectively

Table VII.
Short-run adjustment

The other variables such as FDI, trade openness and exports show insignificance in the short run. But the import variable continues to have a negative effect on TFP growth. However, the overall short-run error correction term suggests that the speed of adjustment is faster, which indicates that the Indian institutional set-up particularly enhancing innovation through various measures such as patent statistics, scientific journal articles, trademark applications and share of high technology exports will boost the TFP growth. The long-run and short-run results based on the ARDL bound testing approach is reliable subject to several diagnostic check-ups such as Heteroskedasticity Breusch–Pagan–Godfrey test and Breusch–Godfrey Serial Correlation (LM Test). The results of both the diagnostic tests are presented in Table VII.

Finally, Figure 2 shows the parameter stability conditions using cumulative sum (CUSUM) and cumulative sum of squares (CUSUM Square) which confirmed that all the models are stable at 5 percent level of significance (Brown *et al.*, 1975).

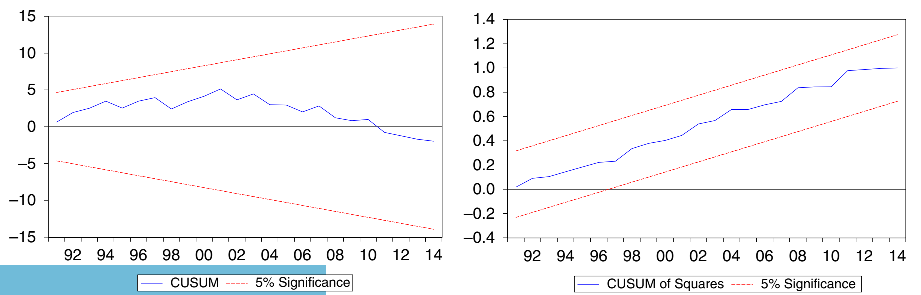


Figure 2.
Stability diagnostics:
TFP = *f* (INV)

6. Conclusions

Although a bulk of previous studies examines the different prospects of economic growth and sources of economic growth, studies related to the determinants of TFP growth in India emphasizing on innovation are scanty. In this regard, the present study explored the relation between innovation and TFP growth of India using annual data from 1980 to 2014. First, the innovation index was constructed using various forms of innovation measures (patent counts, scientific journal articles, trade mark applications and technology exports % manufactured goods). Then we employed an ARDL model to investigate the long-run and short-run impact of innovation on TFP growth. The results showed that innovation activities have positively affected the TFP growth. However, among other variables, trade openness has found the negative relationship and mostly this negative aspect arises from the large import volume. Results from the trade openness in the long run indicate the mounting trade volumes with rest of the world that have an adverse impact on TFP growth. This confirms that higher level of import values (exceeding export volumes) may not be a healthy indication for the productivity growth.

From this analysis, several policy implications can be drawn: First, the positive effects show to aim at fostering innovative activities through shaping innovation driven policies in various sectors across the country. Delving little deeper, having direct and straight productivity enhancing effects from innovation, the study suggests for shaping the quality of human capital through higher and scientific education as a pre-requisite for producing scientific research. Similarly strengthening policies for protecting IP rights may spur the innovative environment for the science, technology and thus business upgradation in India. Other way, the indirect channels of public spending need to focus on social infrastructure which indirectly facilitates the education and innovation, hence the growth chain through backward and forward linkages. Human capital measures through secondary education have an impact on increasing the TFP growth in the short run only.

Notes

1. Detailed discussion on the review of literature is provided in Section 3.
2. Most of the studies in the literature considered R&D as a measure of innovation, but it has several limitations and R&D may not be the true representation for innovation. Sometimes, R&D may tend to fail in reaching intended objectives and would not be able to reflect in high productivity growth; such discussions are available at a micro level. For instance, Lee and Stone (1994) found that R&D expenses just represent the innovations but may fail to become the real innovations.
3. Several studies focused in different context in recent days, for instance Hasan and Tucci (2010), Goedhuys and Veugelers (2012), Petariu *et el.* (2013) and Czarnitzki and Toivanen (2013).
4. This can be more connected to Schumpeter's process of "creative destruction," which departs from the existing growth models by emphasizing obsolescence of old technologies induced by the creativity, knowledge assimilation and creation which leads to develop new products, processes that actually made possible industrial innovation and revolution.
5. Innovations can be categorized into several forms and however literature is in several pieces, such as at micro level product, process, market and organizational innovations based in the nature of technology involvement. Innovations also can be seen in the form of degree of novelty, can be categorized as incremental and radical innovations. And other forms such as level of new technological exports, through a variety of fields that are considered as innovation which adds net revenue through newly developed products, business, actions or whatsoever.
6. We have another model similar to that of (Equation (6)) in which we split the OPEN variable into EXP and IMP. The reason is to delve more about the openness impact on TFP growth, then we study the openness into parts and estimated similar model replacing openness into export and imports ratio to the GDP.

7. The capital stock data are not readily available. Therefore, we estimate the capital stock data series using the standard perpetual inventory method (PIM).
8. $\Sigma E_k = 3.70224 + 0.240477 + 0.043487 + 0.013796 = 4$. $PC_1 = 4/3.70224 = 0.925$.

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