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Keywords: Asymmetries, Endogenous growth, R&D, Human capital, FDI, Technology spillovers

JEL Code: C5, C6, E3, E61.

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The study evaluates the role of R&D, human capital, and technology spillovers in influencing India's long-run productivity growth. The primary contributions of the article are: (1) analyzing the applicability of various endogenous growth models in the Indian context, while only R&D driven endogenous growth models have been studied so far, (2) highlighting the role of technology spillovers through FDI and import channels in affecting India's productivity at the aggregate level, as opposed to the existing industry level analysis and, (3) the first study to identify the potential non-linear effects of the variables of interest. The main findings are: (a) FDI and human capital influence India's long-term productivity growth, while R&D based models or technology spillovers via the import channel show mixed evidence of support, (b) the decline in FDI has had a more adverse effect on the economy than the positive effect of increased FDI. Therefore, sustained increase in human capital and FDI is recommended.

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1. Introduction

India was leading in the race of fastest growing economy. The period post-liberalization was a dream run for India, barring the Asian financial crisis (Ahmed & Varshney (2012) and Nagaraj (2013)). However, the latest pre-Covid figure from Ministry of Statistics and Programme Implementation showed that India's annual GDP growth dropped by nearly 40 percent from 7.7 percent in January 2018 to 4.7 percent in January 2020. The Covid-19 pandemic reduced the annual GDP growth rate by (-)23.9 percent in the first quarter of fiscal year 2020-21 and by another (-)7.5 percent in the second quarter, leading India into a recessionary phase. A natural concern, therefore, is whether and how India will regain its strong growth momentum, which it has achieved in the recent past.

To answer that, we must first understand what has made India one of world's fastest-growing economies. Ahluwalia (2008), Ahmed and Varshney (2012), Basu and Maertens (2007), Banerjee and Roy (2014), Ghate and Wright (2012), Madsen et. al (2010), Nell (2013, 2015), Kotwal et. al (2011), Sen (2007) etc. are some of the recent studies analyzing India's growth trajectory. While most of these studies focus on identifying the reforms and policies that have led to India's ever-increasing economic growth, others focus on defining the timing of the growth turnaround. However, Madsen et. al (2010) investigated the role of innovation-driven endogenous growth model in explaining India's large and significant, total factor productivity (TFP) component of economic growth over the period 1950–2005. Following Madsen et. al (2010), in a more updated sample covering the period 1970-2017 and using a new methodology, this paper reassesses the role of R&D with a particular focus on the role of human capital, and technology spillovers via FDI channels and via import channels in explaining India's TFP growth. Moreover, our paper examines the presence of asymmetric effects of these variables on TFP growth.

The two main drivers of long-run productivity growth as predicted by endogenous growth theory (Romer (1990), Grossman and Helpman (1991a), Uzawa (1965) and Lucas (1988) etc.) are R&D and human capital. According to the World Bank data, India has been quite successful in increasing its human capital base and R&D[1]. Moreover, India undertook series of economic reforms starting from the early 1990s by deregulating the markets, reducing the import tariffs and other trade barriers and allowing greater foreign investment etc. This contributed to an explosion of investment flowing to the Indian economy. The FDI inflows in India have increased from $45.5 million in 1970 to around $40 billion in 2017. The sustained increase in human capital, R&D and FDI also coincided with India's catapulted growth in the last few decades and is therefore believed to play an important role in India's growth miracle[2]. In addition to FDI, technology spillover in a country also occurs through imports of technology-intensive products that have been shown to have significant effects on a country's productivity growth[3] (Coe and Helpman (1995), Madsen et. al (2010) etc.). With economic reforms, trade and financial liberalization, India has also seen a substantial increase in the volume of its trade, particularly imports of technology-intensive products (Sen (2002)). We also analyze its impact on India's productivity growth.

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[1] Gross enrollment ratio of secondary students has increased from 13.92 percent in 1970 to 73.5 percent in 2017. India increased its R&D expenditure in absolute terms (from 1.40 billion Indian rupees in 1970 to 1138.25 billion Indian rupees in 2017) and R&D expenditure as a percentage of GDP has also increased over time (from 0.33 percent in 1970 to 0.67 percent in 2017).

[2] Human capital, R&D and FDI are shown to have both the scale effects and efficiency effects leading to long-run economic growth. See Section 2 and 3 for details.

[3] Note that increase in exports or imports of technology-intensive products have efficiency effect but no scale effect as explained in Sections 2 and 3.

The first objective of the paper therefore is to test which endogenous growth model[4] is in line with India's growth story. If human capital or R&D is found to be co-integrated with India's TFP growth with significant positive long-run coefficient, the scale effects of the first-generation endogenous growth models (Romer (1990), Uzawa (1965) and Lucas (1988)) holds. The high growth momentum can be preserved by investing more on human capital or R&D or both. However, if only the short-run coefficients are significantly positive while the long-run coefficient being insignificant, the second-generation endogenous growth models (Jones (2002), Aghion and Howitt (1998)) without the scale effect holds. The policy implication of the latter is investing more on R&D, for example, will only have transitory impact with no effect on long-run economic growth. Finally, Schumpeterian growth theory is relevant if research intensity is found to be significantly co-integrated with long-run economic growth.

The second objective of the paper is to assess the role of technology spillover in explaining the productivity growth of India through FDI channels and import channels. Ang and Madsen (2011), Madsen et. al (2010) etc. have focused on R&D driven growth for India, but the

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[4] The first-generation endogenous growth models of Romer (1990), Grossman and Helpman (1991a), Uzawa (1965) and Lucas (1988) display "strong" scale effects due to the assumption that the production has increasing returns to scale associated with new ideas or human capital. This could be due to the fact that knowledge can be used by many people at the same time without loss or due to the positive externality generally associated with human capital. Jones (1995) introduced a model exhibiting "weak" scale effects that is shown to be more consistent with United States data. Such models are often called semi-endogenous growth models (Jones (1995) and Kortum (1997) and Segerstrom (1998)) and are classified as second-generation growth models. Schumpeterian growth models are another class of models belonging to second-generation growth models (Aghion and Howitt (1998), Dinopoulos and Thompson (1998b), Peretto (1998), and Young (1998)), which eliminate the economy wide scale effects through the introduction of scale effects of firms.

desired attention was not given to the role of technology spillover from imports channel and FDI in India's growth story. The R&D based growth models were originally written and tested for mature economies. And for an economy like India that is far from its technological frontier, these models may not be fully applicable or may not capture the full growth story unless the role of technology spillover from foreign sources are considered more seriously.

While there is some consensus based on cross-country studies on the role of FDI in developed economies, no consensus has been reached on its role in developing economies (see Bournakis et. al (2018), Eapen et. al (2019), Li and Tanna (2018), Makiela and Ouattara (2018), Mallick and Moore (2008), Nemlioglu and Mallick (2020) and Osei and Kim (2020)). Nemlioglu and Mallick (2020) found that, institutional quality is one of the reasons why some non-G7 countries, compared to others, experience the beneficial effects of FDI by boosting their capital. Aizenman (2015) also pointed out that developed and developing countries face different structural and institutional realities and hence have different motivations to attract external financing. The success of FDI in benefiting the host economy therefore depends on several country-specific characteristics, such as the current level of innovation, human capital, political stability, intellectual property rights, ease of doing business, absorptive capacity, etc.

A significant driver of domestic productivity growth (Bournakis et. al (2018), Coe and Helpman (1995)), particularly for developing countries doing less domestic R&D, is the technology spillover through specialized imports. Similar to FDI, the effects of technology spillover from imports also depends on country specific features. More specifically, the extent of the gain depends on how well the technology is absorbed and whether it is used efficiently (Henry et. al (2009)). Therefore, a country-specific analysis assessing the role of FDI and foreign spill-overs through imports channel is imperative for an emerging economy such as India which may not satisfy all preconditions required for their success.

Although studies focusing on the role of technology spill-over via FDI vis-à-vis imports exist for India, most of them are carried out at the industry or sectoral level. For example, Behera et. al (2012) and Saxena (2015) have found significant effects of FDI and foreign spill-overs through imports channel across Indian manufacturing industries. The aggregate level studies mostly focus on either the role of FDI or the role of spill-over through imports and not both of them together. For example, Banerjee and Roy (2014) emphasized the role of foreign spillover through technology-intensive imports in affecting India's aggregate productivity growth, completely ignoring the effect of spillover through the FDI channel. In contrast, Chakroborty and Basu (2002), Choi and Baek (2017), Dash and Parida (2013), Sahoo and Mathiyazhagan (2003), etc., focused mainly on the role of FDI in explaining India's aggregate growth. Therefore, it is particularly important to assess and compare the role of these two variables within the endogenous growth framework at an aggregate level.

Finally, the fact that these variables can have non-linear or asymmetric effects is another significant concern that the literature has totally missed. Such asymmetries can be identified from the fact that the relationships between the underlying variables are complex and can have significant implications for policy. For instance, as it is not necessarily considered a populist strategy[5], the government may choose to reduce the level of FDI, or be under pressure to do that,

[5] Walmart, Amazon, and Uber are some recent examples of businesses which had to face huge opposition from certain sections of Indian society.

because it may potentially take away local jobs. There is, however, a possibility that the gains from any action in favor of one policy (say, R&D) may be lower than the losses from sacrificing other policies (such as FDI) that the government should not ignore. Hence, the third objective is to identify the asymmetric effects of the variables of interest on India's productivity growth.

The paper finds strong support for Lucasian growth theory, where human capital boosts economic growth. Though the linear models provide evidence in support of the Romerian theory with significant positive long-run influence of R&D variables on productivity growth; the theory is rejected in the non-linear version. The non-linear version instead establishes the second-generation Schumpeterian growth theory with a significant long-run influence of R&D intensity variables on productivity growth in line with Madsen et. al (2010). Moreover, our results do not find any evidence supporting the semi-endogenous growth models. Such mixed set of results for R&D is not surprising as, compared to the developed nations; India's innovations have been concentrated in few specific sectors with low density of scientists and engineers; have low-quality scientists and engineers and have further reduced investment per researcher (see Mani (2018)).

Furthermore, in both linear and non-linear models, FDI has a positive and significant influence on TFP growth, in the short as well as long run. In addition, these results are asymmetrical in both the short and long term. For example, the negative effect of FDI on TFP growth is greater in the short-run due to the negative FDI shocks than the positive effect of the positive FDI shocks on TFP growth. The argument of technological diffusion playing an important role in influencing a nation's productivity growth through the channels of technology-intensive imports, does not hold true in our study. Although the linear models show significant and positive influence of foreign spill-overs on productivity growth, these beneficial effects are completely rejected by the non-linear model. For US, Keller and Yeaple (2009) also found much weaker evidence on productivity effects of technology spillovers via imports, while FDI had significant effects on productivity.

The 1990s economic reforms of liberalization, privatization and globalization were instrumental in leading India to attain its fast growth momentum. The paper finds that along with human capital investments, FDI plays a major role in shaping the productivity growth of India. In addition to directly affecting India's capital accumulation, FDI can boost its economic growth in two ways: by bringing new technologies through technology transfer, diffusion and spillover effects; and, by enhancing the stock of knowledge through knowledge transfer using training and skill acquisition and using alternative management and organizational practices. In a country like India, where the government still owns a large portion of many sectors and corruption prevails, FDI can promote competition and investment diversification and encourage funds to pursue more viable projects than those favored by the government.

In addition to higher investment in human capital, we therefore recommend a sustained increase in targeted foreign investment, so that the technology gap is reduced in such a way that the country can start benefiting more from its own R&D. The rest of the paper continues as follows. Section 2 presents brief review of endogenous growth models and FDI models of economic growth. Section 3 presents a theoretical framework to outline our hypotheses. Section 4 describes the data and methodology. Section 5 uses the linear and non-linear ARDL models to test those propositions, while Section 6 concludes with policy implications and suggestions.

2. The First-Generation and the Second-Generation Endogenous Growth Models and the FDI Model of Economic Growth

Economic growth was considered exogenous (Solow (1956)). The path breaking work of Paul Romer and Robert Lucas resulted in endogenous growth models. In fact Paul Romer was awarded the Nobel Prize in Economics in 2018 for his contribution to the theory of endogenous growth. Romer proposed that growth is driven by technological change resulting from the R&D of profit maximizing agents. It is expected that the new ideas will enable the firms to produce new intermediate goods and new consumer products with lower cost making the firms more efficient and profitable. In addition, ideas are non-rival in nature (Romer (1990)) which makes it possible for anyone to use them simultaneously. Hence, the production process is associated with increasing returns to scale with respect to new ideas or knowledge. Lucas (1988), on the other hand, suggests that it is the human capital formation itself that could create endogenous growth. Human capital is described as the skills, training, and knowledge acquired through on the job training and formal education. The underlying assumption of the model is that human capital has non-decreasing marginal returns due to the belief that a person with higher level of education can more easily obtain additional knowledge. Moreover, Lucas (1988) assumes that there is a positive externality associated with average level of human capital of the society. Hence, the production process is also associated with increasing returns to scale with respect to human capital or the stock of knowledge.

Acquiring human capital is the most fundamental condition in the process of economic growth. It is a precondition for creation of more knowledge and new innovations, directly affecting nation's production by increasing labor productivity and indirectly contributing to nation's competitive advantage by enabling new innovations. It is also an important precondition for a late comer of industrialization like India for imitation of the more advanced world technologies and its diffusion. It is definitely important to innovate new technologies but it is as important to adopt new already existing technologies from the developed world for a catching up country like India for two reasons: first, it is easier and much faster to imitate and transfer the modern technologies at a lower cost than to innovate a new one and second, the effects of new technology have already been witnessed by the developed world and can therefore be put into practice with greater confidence in the host country. FDI is one of the most popular ways to implement new international technologies. For example, India enjoys the most efficient and cheap Internet and telecommunications facilities, most of which are the product of FDI rather than Indian innovations.

According to Yao and Wei (2007), FDI can act as catalyst in the growth process as compared to domestic investment. It is easier to adopt general purpose technologies that have a broad economy wide user base (eg. computer, Internet, mobile phone etc.) by FDI. New technology, knowledge and skills unknown to the host nations are embedded in FDI. The technology spillovers that take place with the FDI enables the host nation to generate more output using the same amount of resources as before. In short, FDI shifts up the host economy's production frontier (Yao and Wei (2007)). The motivation for multinational corporations to invest in the host nation is to maximize profits by earning relatively higher potential returns on capital (because of the low capital/labor ratio in these countries). In view of their expertise, experience, superior technological know-how, enhanced management and operational processes, the performance of global firms exceeds that of domestic firms. Increased competition requires domestic companies to learn from the best practices of international firms to survive. FDI promotes a more efficient use of resources in the domestic economy through increased competition. FDI therefore increases the production efficiency of a country (Yao and Wei (2007)).

Exports and technology-intensive imports (similar to FDI) raise the production efficiency of a nation. The country's efficiency increases by producing more and exporting the good in which it has comparative advantage or through the technological and knowledge diffusion that occurs through technology-intensive imports. However, these cannot shift the production frontier of a nation like FDI can. We can see this from the following examples. Due to the closed door, self-reliant policies pursued by the Government of India, only two brands, Hindustan Motors (Ambassador) and Premier Automobile (Fiat), produced and supplied passenger cars for decades prior to India's liberalization. The cars were large, expensive and had very poor mileage and were mostly used by the government officials and the rich. There was therefore a very low demand for such cars in India, which discouraged other entrepreneurs from entering the market. The Indian automobile industry stagnated. Realizing this, by 1982, the Government of India founded Maruti Udyog Limited (MUL) as a public sector company with Suzuki Motors as a foreign collaborator. Suzuki Motors vowed to provide locally produced low-cost fuel-efficient car engines and to include local equity participation. The biggest hurdle at that time faced by Suzuki Motors was India's extremely poor automotive infrastructure. As a result, Suzuki motors invested extensively and heavily in the Indian component manufacturers to improve the quality of the components and to reduce the cost of its component procurement (Nayak (2015)). Not only did they invest capital in the Indian auto industry, they even deputized their own workforce. In addition, MUL employees were sent to Japan every year to learn about the Suzuki Motors' method of production, quality assurance and other Japanese management methods, which were an effective means of transferring skills and techniques. The entry of the Suzuki Motors completely changed the landscape of India's automotive industry by making it possible for an average Indian to own a car and by inspiring large number of other international car companies to invest in India. Such a level of transformation in any domestic industry is rarely possible through policies like imports of high-technology products.

A more recent example is the aviation industry for which India was projected to have the fastest growing market. It is clear that the mere imports of most aerospace products and services from US-based Boeing and European-based Airbus will not change the technology and know-how of India's civil aviation industry. By investing in India under the Government's 'Make in India' initiative, Airbus is seeking to increase India's contribution to its international product portfolio by manufacturing various aircraft parts and materials locally and by promoting domestic technology and innovation services. Airbus engaged in intensive training and mentoring of its workforce and fostering research collaborations by supporting and helping many Indian start-ups and entrepreneurs with new ideas to turn into successful businesses. In addition, Airbus is working with Indian companies Tata and Mahindra and is partnering with the Indian Defense Research and Development Organization (DRDO) to develop new defense aircrafts, helicopters and other technological upgrades. Such FDI would generate thousands of local jobs and can be instrumental in making India a strategic resource hub for emerging aerospace technology, talent and R&D.

3. The Theoretical Framework

The production function is given by

$$Y = A^{\sigma} K^{\alpha} (h\mathrm{L_Y})^{1-\alpha} e^{\,h_a},\ 0 < \alpha < 1, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where Y is output, A is technology level, K is physical capital, α is the share of physical capital, L_Y is the labor employed in producing output, and h is human capital per person. e^{h_a} measures the externality associated with average human capital of the work force, h_a. The output is associated with constant returns to scale with respect to the physical capital and labor (rivalrous inputs). The output is associated with increasing returns to capital, labor and ideas together, where $\sigma > 0$ captures the degree of increasing returns associated with ideas. Similarly, the output is associated with increasing returns with respect to capital, labor and human capital together (Lucas (1988)). Note that the time subscripts for all the variables are suppressed for simplicity.

The production function for ideas is given by

$$\dot{A} = \gamma\left(\frac{hL_A}{B}\right)A^{\phi}, \qquad \phi > 0, \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

According to equation (2), new ideas produced at any point in time depend on the effective research effort (hL_A) per variety of consumption goods B. h is human capital per person and L_A is the total number of researchers; and existing stock of ideas (A). ϕ represents the externalities associated with R&D. For simplicity, we assume that $B = L^{\beta}$, where $L = L_A + L_Y$. In our model, human capital directly affects production by making output-producing workers more productive (shift in the production frontier) and indirectly influencing output by increasing the competitiveness of researchers (efficiency effects). Similarly, R&D is shown to have scale effects (captured through ϕ in equation (2)) and efficiency effects (captured by A in equation (1)).

According to the first generation fully endogenous growth models (Romer (1990) and Grossman and Helpman (1991b)), every unit of research effort produces a proportionate increase in the stock of knowledge, that is, $\phi = 1$. It implies that if we keep increasing the stock of knowledge increasing the resources devoted to R&D (increasing the number of researchers or increasing the R&D expenditure), we can achieve an exponential increase in per capita output. To eliminate this scale effects associated with first generation endogenous growth models, the semi-endogenous growth models of Jones (1995) and Kortum (1997) and Segerstrom (1998) assume, $\phi < 1$. Increasing knowledge stock say by increasing resources devoted to say R&D workers only has sustained short-term impact on per capita output, while long-term effects are unsustainable. Note that both endogenous growth models of the first generation and semi-endogenous growth models assume $\beta = 0$.

The Schumpeterian growth models (Aghion and Howitt (1998), Dinopoulos and Thompson (1998), Peretto (1998), and Young (1998)) proposed an alternative way to eliminate the scale effects. They retained the assumption of $\phi = 1$ from the first generation fully endogenous growth models. But they incorporated the assumption of $\beta = 1$, that is, the variety of consumption goods is proportional to the total labor force. Simply increasing the number of R&D workers is not enough to generate long run growth effects. Sustained increase in output per capita requires an increase in R&D intensity, i.e. an increase in the number of researchers per product/sector or, aggregate R&D expenditures per product/sector etc.

As discussed before, FDI shifts up the host economy's production frontier as well as increases country's production efficiency (Yao and Wei (2007)). So the shift in the production frontier due to the presence of FDI is now captured by the 'FDI' term in equation (3). And the increase in production efficiency due to FDI is captured by equation (4) where the rate of arrival of new ideas, $\delta,$ is an increasing function of FDI, $\delta = \gamma(\text{FDI}),\ \gamma'(FDI) > 0$. FDI is the most direct and efficient way of acquiring new technologies and fastens the arrival of new ideas captured by $\tilde{A} > A$ for the host nation.

$$Y = \tilde{A}^{\sigma} K^{\alpha} (h\mathrm{L_Y})^{1-\alpha} e^{(h_a + FDI)},\ 0 < \alpha < 1, \qquad \text{………………… (3)}$$

$$\dot{\tilde{A}} = \delta \left(\frac{\mathrm{hL_A}}{B}\right) A^{\phi}, \qquad \phi > 0, \qquad \text{………………… (4)}$$

Furthermore, the technological diffusion through the channels of technology-intensive imports from R&D-intensive countries (captured by R_t^f in our analysis) can play an important role in influencing Indian productivity growth (Coe and Helpman (1995) and Madsen et. al (2010) etc.). However, the spillover variable will only appear in equation (4) and not equation in (3) as it will only exhibit efficiency effect. In equation (4), in addition to FDI, the rate of arrival of new ideas, $\delta,$ is an increasing function of spillover variable as well, $\delta = \gamma(\mathrm{FDI}, R_t^f),\ \ \gamma_1, \gamma_2 > 0.$

4. Data and Methodology:

The empirical analysis in this study examines the determinants of TFP for India. The variables considered for the analysis are explained in details in the Appendix along with their sources. Annual data is used from 1970 to 2017. Madsen and Ang (2009) showed that more than half of per capita output growth in India during the period 1950–2006, and particularly post 1990-91 reforms, is explained using TFP. Hence, we use the logarithm of TFP obtained from Penn World Tables database. Following Madsen et al (2010), the R&D stock is captured by four measures: total expenditure on R&D (R), number of researchers engaged in R&D (N), patents applied by the domestic residents (PA) and patents granted to the domestic residents (PG). R&D intensity is captured using the productivity-adjusted research inputs given by: ratio of R&D expenditure to GDP (R/Y), ratio of total researchers to the total labor force (N/L), patents applied by domestic residents to total labor force (PA/L) and patents granted to domestic residents by the labor force (PG/L). All these measures are taken in logarithms for estimation purposes. We use logarithms of gross enrollment ratio of secondary education obtained from World Bank database, as a proxy for human capital similar to studies like Tsai et. al (2010), Azizi (2018) etc. We estimate a stock measure of FDI as it captures already established foreign firms instead of the only newly arriving ones (Baltabaev (2014)). Hence, the ratio of real FDI stock to real GDP (FDI/Y) is used to capture the effects of foreign firms established in India. FDI stock data is obtained from the updated version of the External Wealth of Nations Mark II database by Lane and Milesi-Ferretti (2007). The logarithms of FDI/Y are used for analysis. Coe and Helpman (1995) found a significant role of technological diffusion from the foreign countries in influencing the domestic factor productivity in developing economies. Hence, we estimate a variable in lines of Coe and Helpman (1995) and Madsen et al. (2010) to capture the foreign spillover effect, using import-ratio weighting scheme.[6]

$$R_t^f = \sum_{i=1}^{n} \frac{m_i}{M} \bar{R}_{i,t}^d \qquad \text{…………………. (5)}$$

where R_t^f is the total spillover effect, n is the number of import partners of India, m_i is the import of high-technology products from country 'i', M signifies total imports of high-technology products from all the countries and $\bar{R}_{i,t}^d$ is the real domestic R&D for country 'i'.[7] The data for

[6] We use average of weights of high-technology imports to India over all the years.

[7] Following Madsen et. al (2010), we use three SITC classifications for high-technology goods: chemical and related goods (SITC Section 5), machinery and transport equipment (SITC Section 7) and professional and scientific equipment (SITC Section 8.7). We include all the countries with share larger than 0.1%.

imports based on product categories are obtained from UN Comtrade and various publications of the IMF and the UN. We use a financial development variable in the form of percentage of private credit to GDP (FinDev) as a fixed regressor.[8]

Fig. 1(a) compares TFP growth with the four measures of R&D stock used in our analysis: total expenditure on R&D, number of researchers engaged in R&D, patents applied by the domestic residents and patents granted to the domestic residents. The trend in the TFP growth rate has been increasing since the late 1970s. Except for patents granted all the other three measures show similar increasing trend early 1980 onwards. Patents granted in fact show zero correlation with TFP growth. Even though the three series show similar positive trend, only patents applied show good correlation with TFP growth followed by the number of researchers.

Fig. 1(b) compares TFP growth with the four measures of research intensity. Number of researcher intensity followed TFP growth very closely until 1997 but showed a decrease until 2000 while TFP growth continued to increase in that period, finally showing an increasing trend after 2000 onwards in tandem with TFP growth. Patents applied intensity followed a smooth curvilinear model intersecting the TFP growth trajectory twice. Slope of this variable too changed at the turn of the century. Patents granted intensity, on the other hand, did not follow a growth trajectory like the patents applied. They peaked around global financial crisis and dipped sharply after that. In fact the poor correlation of patent granted and its intensity with TFP growth is

[8]Arizala et. al (2013) used this measure for a cross-country analysis (which includes India). Madsen et. al (2010) used a composite index of financial repression while Banerjee and Roy (2014) used the ratio of M3 to GDP. Private sector credit to GDP is a commonly used measure of financial deepening in the literature (Beck et. al (2000)). Hence, we incorporate the same as a control variable in our analysis.

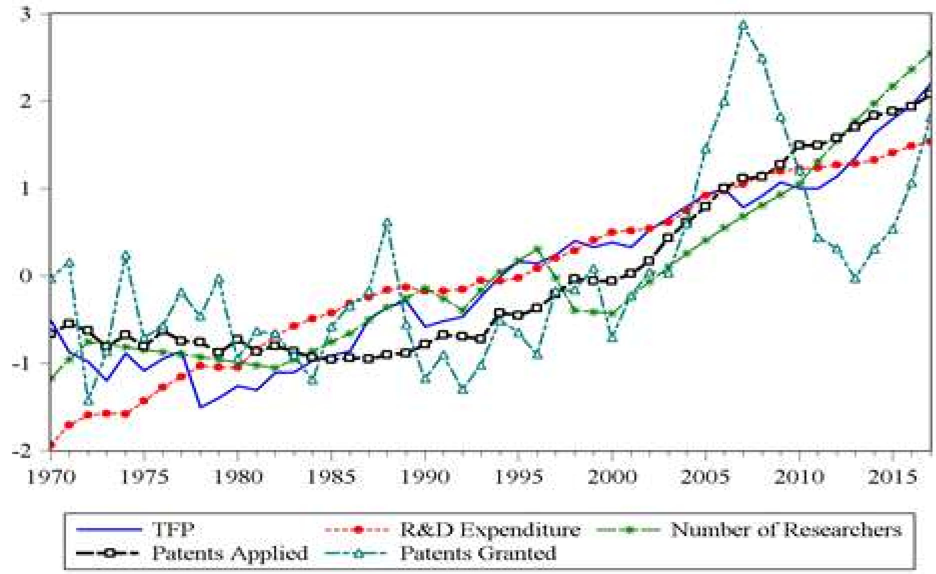
reflected in the absence of long-run co-integration in our non-linear model. R&D expenditure intensity showed a good correlation with TFP growth, except for the beginning and towards the end of our sample.

Fig. 1(c) compares TFP growth with human capital, FDI/Y, and spillover through technology-intensive imports. The trend in human capital has been increasing similar to TFP growth and also showed good correlation with TFP growth from 1973. FDI/Y dipped from 1970 to 1990 but followed an upward trajectory post-liberalization. Note that TFP growth declined till 1978, before following the upward trajectory. Foreign spillovers too fell until 1995, and subsequently showed an increasing trend. However, any substantive correlation between the spillover variable and the growth of TFP is hard to find.

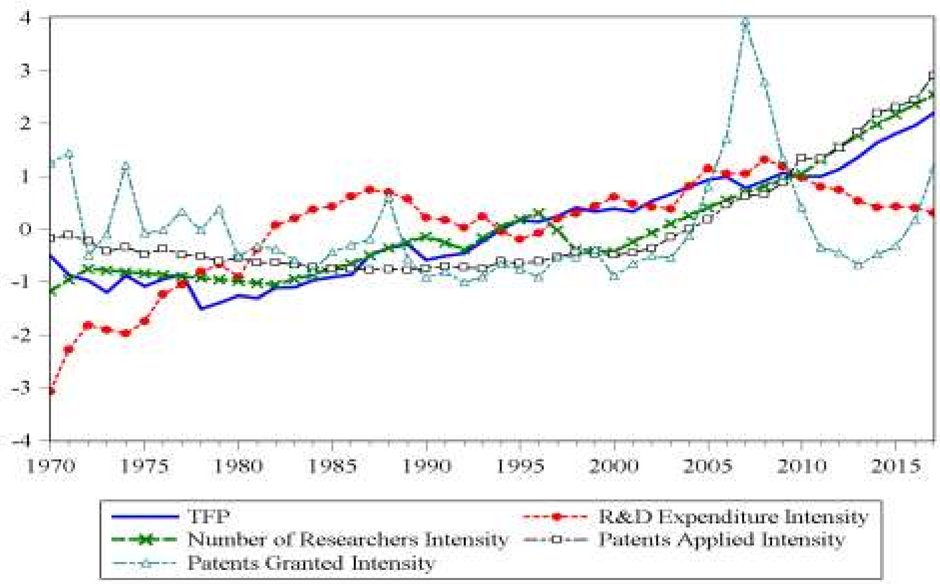
Overall, the graphical evidence provides some indications of the potential relationship between human capital, FDI/Y and certain R&D intensity measurements with TFP growth. However there remains weak evidence of an association between R&D and TFP growth.

Figure 1 – Variables used for analysis

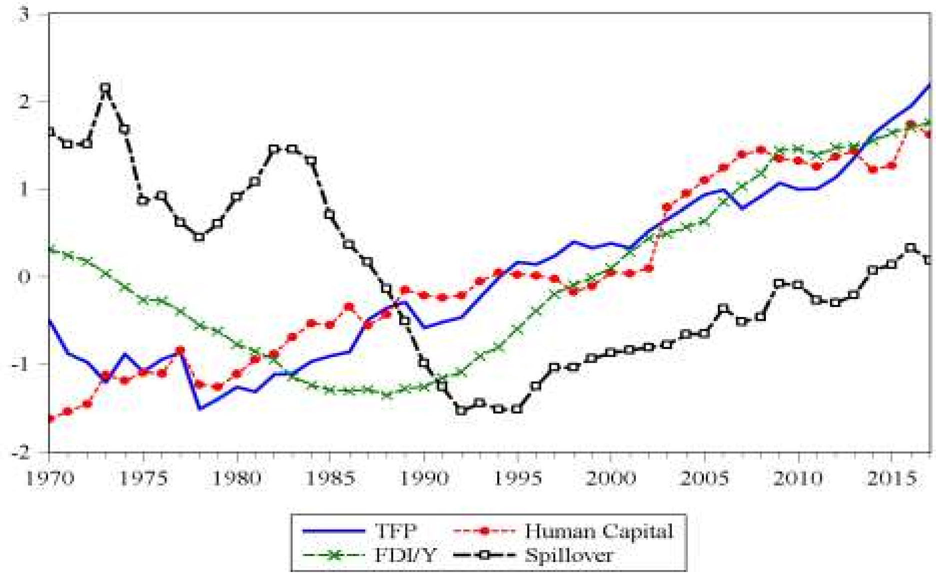
(a) TFP and all R&D stock measures



(b) TFP and all R&D Intensity measures



(c) TFP, Human Capital, FDI/Y and Spillover



Source: Authors' Estimates, various sources (Details provided in the appendix)

We perform three types of stationarity tests, namely, Augmented Dickey Fuller (ADF) test, Dickey Fuller t-test (DF-GLS) and Zivot-Andrews structural break unit root test (ZA). The tests provide mixed results regarding the order of integration of the variables. The presence of structural breaks in the time series data gives an early indication of a time series asymmetric behavior over time supporting the presence of possible asymmetric short- and long-run relationships (Shahzad et. al (2017)).

We then use the ARDL model by Pesaran et. al (2001). Using ARDL models gives flexibility with regards to the stationarity of explanatory variables as they can either be I(1) or I(0) or even fractionally integrated. Further, the co-integration framework allows for the estimation of short-run and long-run effects of the control variables as each of the underlying variables stands as a single long-run relationship equation[9]. Unlike Madsen et. al (2010) who focus predominantly on the long-run influence of the variables, we emphasize the usefulness of both short-run and long-run effects. Another important advantage of the model is that unlike traditional vector auto regression models and vector error correction models, different explanatory variables can have different lagged values. It also provides best estimates for a small sample size. It can provide significant results even if some explanatory variables are endogenous. However, any variable of the order I(2) can lead to unreliable estimates of the model.

The model used is given as:

$$\Delta TFP_t = \theta_0 + \sum_{j=1}^{L_1} \theta_{1j} \Delta TFP_{t-j} + \sum_{j=0}^{L_2} \theta_{2j} \Delta HK_{t-j} + \sum_{j=0}^{L_3} \theta_{3j} \Delta R\&D_{t-j} + \sum_{j=0}^{L_4} \theta_{4j} \Delta R\&DINT_{t-j} + \sum_{j=0}^{L_5} \theta_{5j} \Delta (FDI/Y)_{t-j} + \sum_{j=0}^{L_6} \theta_{6j} \Delta R^f_{t-j} + \theta_7 \Delta FinDev_t + \phi_1 TFP_{t-1} + \phi_2 HK_{t-1} + \phi_3 R\&D_{t-1} + \phi_4 R\&DINT_{t-1} + \phi_5 (FDI/Y)_{t-1} + \phi_6 R^f_{t-1} + \phi_7 FinDev_t + \varepsilon_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where $\theta'_{ij}s$ and $\phi'_i s$ are short run and long run coefficients of the model respectively. TFP represents total factor productivity, HK represents Human Capital, the variable R&D and R&DINT represent four different measures of R&D stock and their respective productivity adjusted intensities: R, N, PA, and PG; R/Y, N/L, PA/L, and PG/L. The variable FDI/Y captures real FDI stock as a ratio of real GDP. We control for foreign spillovers using the variable R^f_t as estimated by equation (5).

[9]Once the co-integrating vector is identified, the ARDL model of the co-integrating vector is re-parameterized into an error correction model which gives the short-run dynamics and the long-run relationship of the variables of the model (Nkoro and Uko (2016)). Notice, however, that when several co-integrating vectors exist, the ARDL approach to co-integration cannot be applied. The Johansen and Juselius (1990) co-integration approach thus become the way out.

We test for long run co-integration using bounds test. The F-statistic for long run co-integration is analyzed for the null of $H_0: \phi_1 = \phi_2 = \phi_3 = \phi_4 = \phi_5 = \phi_6 = \phi_7 = 0$ against the alternative hypothesis of H_1: At least one of the $\phi_i' s \neq 0$. It gives two values of F-statistics, one where it assumes all the explanatory variables to be I(0) and another when all the variables are assumed I(1). The optimal lag lengths are chosen using Akaike Information Criterion (AIC). We test for short run error correction if the variables are found co-integrated in the long run. The following equation is used for error correction mechanism analysis:

$$\Delta TFP_t = \theta_0 + \sum_{j=1}^{L_1} \theta_{1j} \Delta TFP_{t-j} + \sum_{j=0}^{L_2} \theta_{2j} \Delta HK_{t-j} + \sum_{j=0}^{L_3} \theta_{3j} \Delta R\&D_{t-j} + \sum_{j=0}^{L_4} \theta_{4j} \Delta R\&DINT_{t-j} + \sum_{j=0}^{L_5} \theta_{5j} \Delta (FDI/Y)_{t-j} + \sum_{j=0}^{L_6} \theta_{6j} \Delta R_{t-j}^{f} + \theta_7 \Delta FinDev_t + \delta ECM_{t-1} + \varepsilon_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where δ is the coefficient of the short term error correction. It shows the speed of reversion of the deviations in the dependent variable on the equilibrium path. A range of post estimation diagnostics are conducted namely Ljung-Box Q test for autocorrelation, Ramsey RESET test for stability of parameters, Breush-Pagan-Godfrey test for heteroscedasticity and Jarque-Berra test for normality of residuals.

The ARDL model however gives linear relationships between TFP and its determinants. But, over the years, influence of certain variables on TFP would have been non-linear in nature. Some techniques developed in literature to tackle non-linear error correction mechanism are Balke and Fomby (1997), Psaradakis et. al (2004), Kapetanios et. al (2006) and Shin et. al (2014). According to Lahiani et. al (2016), NARDL has three advantages over its linear counterparts: (1) It distinguishes between short- and long-run asymmetries. (2) It captures the response of the dependent variable to positive and negative changes in each explanatory variable. (3) It is flexible to the co-integration dynamics between variables and it can accommodate multiple data series of different integration orders. This study uses the NARDL model developed by Shin et. al (2014). This model captures non-linear short- and long-run asymmetries. It also enables to detect hidden co-integration, a concept introduced by Granger and Yoon (2002). Hidden co-integration states that the variables may not be linearly correlated but their positive and negative components could be co-integrated to their respective counterparts. The NARDL approach is not applicable for the variables with integration of order I(2). Following NARDL specification is used for the current analysis:

$$\Delta TFP_t = \theta_0 + \sum_{j=1}^{L_1} \theta_{1j} \Delta TFP_{t-j} + \sum_{j=0}^{L_2} \theta_{2j}^{+} \Delta HK_{t-j}^{+} + \sum_{j=0}^{L_2'} \theta_{2j}^{-} \Delta HK_{t-j}^{-} + \sum_{j=0}^{L_3} \theta_{3j}^{+} \Delta R\&D_{t-j}^{+} + \sum_{j=0}^{L_3'} \theta_{3j}^{-} \Delta R\&D_{t-j}^{-} + \sum_{j=0}^{L_4} \theta_{4j}^{+} \Delta R\&DINT_{t-j}^{+} + \sum_{j=0}^{L_4'} \theta_{4j}^{-} \Delta R\&DINT_{t-j}^{-} + \sum_{j=0}^{L_5} \theta_{5j}^{+} \Delta (FDI/Y)_{t-j}^{+} + \sum_{j=0}^{L_5'} \theta_{5j}^{-} \Delta (FDI/Y)_{t-j}^{-} + \sum_{j=0}^{L_6} \theta_{6j}^{+} \Delta {R_{t-j}^{f}}^{+} + \sum_{j=0}^{L_6'} \theta_{6j}^{-} \Delta {R_{t-j}^{f}}^{-} + \theta_7 \Delta FinDev_t + \phi_1 TFP_{t-1} + \phi_2^{+} HK_{t-1}^{+} + \phi_2^{-} HK_{t-1}^{-} + \phi_3^{+} R\&D_{t-1}^{+} + \phi_3^{-} R\&D_{t-1}^{-} + \phi_4^{+} R\&DINT_{t-1}^{+} + \phi_4^{-} R\&DINT_{t-1}^{-} + \phi_5^{+} (FDI/Y)_{t-1}^{+} + \phi_5^{-} (FDI/Y)_{t-1}^{-} + \phi_6^{+} {R_{t-1}^{f}}^{+} + \phi_6^{-} {R_{t-1}^{f}}^{-} + \phi_7 FinDev_t + \varepsilon_t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

where

$$TFP_t = \alpha_1 + \alpha_2^{+} HK_t^{+} + \alpha_2^{-} HK_t^{-} + \alpha_3^{+} R\&D_t^{+} + \alpha_3^{-} R\&D_t^{-} + \alpha_4^{+} R\&DINT_t^{+} + \alpha_4^{-} R\&DINT_t^{-} + \alpha_5^{+} (FDI/Y)_t^{+} + \alpha_5^{-} (FDI/Y)_t^{-} + \alpha_6^{+} {R_t^{f}}^{+} + \alpha_6^{-} {R_t^{f}}^{-} + \alpha_7 FinDev_t + \eta_t \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

η_t is a zero mean stationary error term for the long run asymmetric relationship between total factor productivity and its determinants. We do not consider asymmetric components of the distance of technology frontier as it is used as control variable for long and short run. Here, $\alpha_i^{+'}s,\ \alpha_i^{-'}s$ are long run asymmetric coefficients of the explanatory variables. For instance, if x_t is an explanatory variable, then its long run asymmetric components are given by

$x_t = x_0 + x_t^+ + x_t^-$. x_0 is an arbitrary initial value and x_t^+ and x_t^- are partial sums of cumulative positive and negative changes, respectively. These partial sum processes are defined as follows:

$x_t^+ = \sum_{n=1}^{N} \Delta x_n^+ = \sum_{n=1}^{N} max(0, \Delta x_n)$ …………………. (10)

$x_t^- = \sum_{n=1}^{N} \Delta x_n^- = \sum_{n=1}^{N} min(0, \Delta x_n)$ …………………. (11)

The values of ϕ_i^+ and ϕ_i^- are given by $\phi_i^+ = -\phi_1 \alpha_i^+$ and $\phi_i^- = -\phi_1 \alpha_i^-$ and i=2, 3 … 6.

The empirical methodology is carried out as follows: First we examine the stationarity of the variables used in analysis. Using linear ARDL and non-linear ARDL methodologies, we check whether the variables are linearly and non-linearly co-integrated. We then analyze the long-run and short-run effects of human capital, R&D, R&D intensity, FDI, and foreign spillover on India's TFP growth, using financial development variable as a control variable. Finally, if non-linear co-integration exists, we also analyze the long-run and the short-run asymmetric effects of the explanatory variables on TFP growth.

5. Empirical Results:

5.1. Unit Root tests:

The results of unit root tests are given in Table 1 below. According to the ADF test, all the variables used for the analysis are integrated of the first order I(1) except for R/Y which is I(0). According to the DF-GLS test, all the variables are stationary at first difference barring the financial development variable which is stationary at levels. The unit root tests performed so far are known to have low power in the presence of structural breaks. Hence, we perform the stationary tests using Zivot-Andrews test which allow for these breaks. The tests show that all the variables are I(1) except human capital and number of researchers which are I(0). This deems them fit for an ARDL type of analysis.

Table 1 – Unit Root Tests

Augmented Dickey Fuller, DF-GLS and Structural Break Tests for Unit Root Null Hypothesis: Variable has a unit root India (Estimation Period 1970-2017)							
	ADF		DF-GLS test statistics		Zivot-Andrews test		
Variables	**Levels**	**First Difference**	**Levels**	**First Difference**	**Levels**	**First Difference**	**Break point**
TFP	1.32	-7.11***	0.93	-3.95***	-4.62	-9.00***	1978
HK	-0.85	-7.06***	-2.62	-5.54***	-5.29**		2002
R	-1.54	-5.58***	1.21	-2.67***	-4.23	-6.52***	1994
R/Y	-4.42**		-0.38	-2.40**	-3.56	-6.37***	1996
N	2.75	-3.30**	-1.76	-3.54**	-5.99***		1996
N/L	1.86	-3.95**	-1.15	-3.21**	-4.29	-7.53***	1996
PA	-1.42	-8.94***	-0.54	-4.43***	-3.95	-10.56***	2002
PA/L	1.89	-7.95***	0.26	-4.57***	-2.62	-9.50***	2010
PG	-2.60	-6.88***	-2.38	-4.89***	-3.44	-8.32***	2007
PG/L	-2.51	-6.17***	-2.51	-4.67***	-4.26	-9.75***	2007
FDI/Y	-2.63	-3.34*	-1.63	-3.41**	-3.83	-5.69**	1992
R^f	-1.69	-4.82***	-1.30	-4.96***	-4.23	-5.68**	1992
FinDev	-2.00	-4.08**	-3.59***		-2.70	-5.32**	1999

Test statistics are given for all the unit root tests.

*, **, *** represent 10%, 5% and 1% levels of significance respectively.

Source: Authors' Estimates

5.2. Linear ARDL Model:

The analysis begins with tests for the presence of co-integrating relationships between the dependent variables and the explanatory variables using Bounds test approach in the ARDL framework (see Table 2). We estimate Models 1-4 for four different measures of R&D stock and their respective productivity adjusted intensities. The optimal lag lengths are obtained using the AIC criterion.

A significant value of the Bounds test F-statistic signifies the presence of long-run co-integration between TFP and the explanatory variables.[10] The Bounds test F-statistic suggests that symmetric long-run relationship exists between TFP and its explanatory variables at 5 percent level of significance for Model 2 and Model 3 and at 1 percent level of significance for Model 4. The Bounds test F-statistic lies in the uncertainty interval for Model 1 at 5 percent level of significance. In such a situation, we draw conclusions about the presence of long-run co-integration in lines of Kremers et. al (1992), Banerjee et. al (1998) and Boutabba (2014) based on the error correction term (ECM). A negative and significant ECM (-0.89) indicates the presence of long-run co-integrating relationship for Model 1. The ECM term is significant for the other models as well. The adjusted R-squared is in the range of 0.44 to 0.73 suggesting higher explanatory power of the variables.

All the estimations of ARDL model are stable as the long-run coefficients of lagged TFP are negative and significant (Shahzad et. al (2017)). Human capital has a positive and significant

[10] Bounds test results display the presence of only 1 co-integrating relationship. Using Johansen co-integration maximum Eigen-value test, we show that there exists at most one co-integrating vector for all the models at 1 percent and 5 percent levels of significance. The results are given in Table A1 in the appendix.

long-run influence on TFP for Models 1, 3 and 4. The R&D stock variables display significant positive long-run effects for Models 1, 2 and 4. Banerjee and Roy (2014) use only R&D expenditure as an explanatory variable and find significant and positive long-run effects of the same on TFP growth. R&D intensity, on the other hand, shows negative and significant effects for most of the models, not supporting the Schumpeterian growth theory. The results of our linear model contrast markedly with Madsen et. al (2010)), who find significant positive effect of R&D intensity variables. FDI/Y displays significant and positive long-run effects for Models 2, 3 and 4. The financial development variable, which is used as a fixed regressor, displays negative and significant long-run influence in all the models.[11] The spillover variable shows positive and significant effect.

In the short-run, human capital has significant and positive influence for Models 1 and 4. The R&D variables display positive and significant effects for most of the models. Similarly, R&D intensity variables display negative effects, mimicking their long-run counterparts. FDI/Y and foreign spillovers display significant and positive short-run influence for most of the models. Financial development has negative and significant short-run effects for all the models.

The diagnostic tests reveal that error terms are normally distributed. Heteroscedasticity is observed in Models 1 and 2. Autocorrelation is absent for all the models. Barring Model 4, all the models have stable parameters as can be seen from the Ramsey RESET test.

[11] Madsen et. al (2010) discover a 1.5 percentage point decline in TFP growth due to financial repression. Banerjee and Roy (2014) find a negative but insignificant influence of financial deepening variable for India. Both these studies attribute such results to the improvement in financial sector, albeit slow, post 1990-91 reforms. Given the longer span of the data (1970-2017), we too find a negative influence of financial development.

Table 2 – ARDL model for TFP

	Model 1	Model 2	Model 3	Model 4
	R&D Expenditure	**Number of Researchers**	**Patents Applied**	**Patents Granted**
ECM	-0.89***	-0.56***	-0.63***	-0.85***
		LONG RUN COEFFICIENTS		
TFP (t-1)	-0.84***	-0.56***	-0.62***	-0.34**
HK	0.28***	-0.79***	0.39*	0.21*
R&D	0.29***	1.24***	-0.26***	0.05***
R&D Intensity	-0.38***	-0.20***	0.02***	-0.02*
FDI/Y	-0.01	0.02*	0.06***	0.01*
R^f	0.01**	0.03**	0.01**	0.01***
FinDev	-0.16***	-0.28***	-0.10***	-0.27***
		SHORT RUN COEFFICIENTS		
ΔTFP(t-1)	0.41	-0.16	-0.06	-0.24
ΔHK	0.25*	0.22	0.25	0.18*
ΔHK(t-1)		0.04		
ΔHK(t-2)		0.32		
ΔR&D	0.26***	-0.31	0.07	0.04***
ΔR&D(t-1)		2.25***	0.11***	
ΔR&D(t-2)		-0.92**		
ΔR&D Intensity	-0.24**	0.13	-0.00	-0.02***
ΔR&D Intensity (t-1)	0.16**	-0.61***		0.01***
ΔR&D Intensity (t-2)		0.21*		
ΔFDI/Y	0.08**	0.07**	0.10***	0.04
ΔFDI/Y(t-1)	-0.10*			-0.05
ΔFDI/Y(t-2)	0.05			
ΔR^f	-0.004	0.01*	0.01**	0.01**
ΔR^f **(t-1)**	0.02***	0.01		0.03***
ΔR^f **(t-2)**	-0.02***	-0.02***		-0.03***
ΔFinDev	-0.14**	-0.16***	-0.07***	-0.23***
Constant	-4.12***	-9.74***	-0.22	-1.05*
		DIAGNOSTIC TESTS		
Bounds	3.77*	5.04**	5.29**	9.29***
Adj R-Sq	0.59	0.63	0.44	0.73
LB-Q test	2.13	4.19	2.34	4.53
BPG	1.88*	2.24**	0.94	1.51
JB	0.53	0.65	0.40	0.34
RESET	0.91	1.29	0.25	2.45*

*, **, *** represent 10%, 5% and 1% levels of significance respectively. Bounds test F-statistics are compared to the table values given by Narayan (2004). Dependent variable is ΔTFP (year-on-year change in total factor productivity).

Source: Authors' Estimates

5.3. Non-Linear ARDL Model:

The results of NARDL model are given in Table 3. Here models 1, 2 and 3 represents models which use R&D expenditure, number of researchers and patent applied, respectively.[12] The optimal lag lengths are obtained using the AIC criterion. Significant values of the Bounds test F-statistics point to the existence of asymmetric long-run relationship for all the models. Co-integration exists at 10 percent level of significance for Model 1. But based on the tests by Kremers et. al (1992), Banerjee et. al (1998) and Boutabba (2014), long-run relationships exist at 5 percent level of significance as the F-statistic lies within the uncertainty bounds and the ECM term is negative and significant. The Bounds test show the presence of long-run relationships for Models 2 and 3 at 1 percent level of significance. The adjusted R-squared values in the range of 0.66 to 0.80 are marginally higher than those of the linear ARDL model, suggesting a greater explanatory power of the variables once they have been decomposed into positive and negative components. The ECM terms are negative and significant for all the models.

Table 3 – NARDL model for TFP

	Model 1	**Model 2**	**Model 3**
	R&D Expenditure	**Number of Researchers**	**Patents Applied**
ECM	-0.60***	-1.49***	-0.76***
	LONG RUN COEFFICIENTS		
TFP(t-1)	-0.98***	-1.50***	-0.72***
HK+	2.01**	0.97*	0.45***
HK-	-1.61*	-0.97	-0.07
R&D+	-0.86*	-0.75	-0.19**
R&D-	4.11***	-1.73**	-2.71*
R&D Intensity+	0.74*	0.16	0.01*
R&D Intensity-	-0.07	0.38**	0.35**
FDI/Y+	0.15**	0.10	-0.01

[12] We do not present the results of the model with patents granted as long-run co-integration does not exist based on Bounds test results.

FDI/Y-	-0.06	-0.30	0.33*
R^f+	0.05	-0.02	-0.02
R^f-	-0.004	0.002	0.02***
FinDev	-0.33***	-0.01	-0.09
SHORT RUN COEFFICIENTS			
ΔTFP(t-1)	1.00	0.93*	0.06
ΔHK (t)+	0.69***	0.50	0.34**
ΔHK (t-1)+	-0.50***	-0.40*	
ΔHK (t)-	-0.36	-0.03	-0.08
ΔHK (t-1)-		0.48	-0.47
ΔR&D (t)+	-0.52***	-0.09	-0.16**
ΔR&D (t-1)+		1.81*	-0.15*
ΔR&D (t)-	1.32***	-0.28	-0.65
ΔR&D (t-1)-		2.04*	-0.57
ΔR&D Intensity (t)+	0.45**	0.03	0.01**
ΔR&D Intensity (t-1)+		-0.41*	0.01*
ΔR&D Intensity (t)-	0.11	-0.05	0.23*
ΔR&D Intensity (t-1)-	0.28	-0.57	0.21***
ΔFDI/Y (t)+	0.18***	0.21	0.07
ΔFDI/Y (t-1)+	-0.14**		-0.14***
ΔFDI/Y (t)-	0.33***	-0.06	0.42***
ΔFDI/Y (t-1)-	0.32***	0.33***	
ΔR^f **(t)+**	-0.03**	-0.03	-0.04**
ΔR^f **(t-1)+**	-0.01	-0.01	-0.02*
ΔR^f **(t)-**	0.01	0.04***	0.03***
ΔR^f **(t-1)-**	0.02**	0.03**	0.04***
ΔFinDev	-0.20***	-0.01	-0.07
Constant	0.72**	-0.21	0.65***
LONG RUN ASYMMETRY			
HK	3.12*	2.02	1.01
R&D	7.55***	0.89	5.86**
R&D Intensity	0.21	2.91	8.70***
FDI/Y	3.23*	0.85	9.81***
R^f	0.06	0.001	0.59
SHORT RUN ASYMMETRY			
HK	3.58*	0.91	0.25
R&D	2.98*	0.04	0.76
R&D Intensity	0.003	0.09	8.90**
FDI/Y	6.29**	1.80	28.70***
R^f	1.70	5.81*	16.67***
DIAGNOSTIC TESTS			
Bounds	4.10*	6.41***	6.89***
Adj R-Sq	0.66	0.76	0.80
LB-Q test	2.04	4.29**	3.81
BPG	0.72	1.89	1.19
JB	1.28	1.62	2.42
RESET	3.50*	2.57	0.29

*, **, *** represent 10%, 5% and 1% levels of significance respectively. Bounds test F-statistics are compared to the table values given by Narayan (2004). The dependent variable is ΔTFP (year-on-year change in total factor productivity).

Source: Authors' Estimates

All the estimated NARDL models are stable as the long-run coefficients of lagged TFP are negative and significant (Shahzad et al. (2017)). In order to test the appropriateness and validity of the asymmetric influence of the explanatory variables on TFP growth, we test for the presence of asymmetry in the long and short run using Wald tests. Significant long-run asymmetries are observed for FDI/Y and human capital in Model 1 at 10 percent level of significance and for R&D at 1 percent level of significance. Short-run asymmetries in Model 1 are observed for FDI/Y with 5 percent level of significance and human capital and R&D at 10 percent level of significance. In Model 2, long-run asymmetric effect is insignificant for all the variables while short-run asymmetries are observed only for the spillover variable at 10 percent level of significance. In Model 3, R&D, R&D intensity and FDI/Y have significant long-run asymmetric influence on TFP growth. However, short-run asymmetries are observed for R&D intensity, FDI/Y and spillover variable. While the R&D variable mostly shows having an asymmetric impact on TFP growth in the long run, however, FDI/Y shows consistent significant evidence of both short- and long-run asymmetry. The asymmetric effect of the spillover variable is limited to the short run.

Our analysis confirms that positive and negative changes in the variables under consideration can have dissimilar effects on India's TFP growth. These asymmetries can be identified from the fact that the relationships among the underlying variables are complex. Additionally, resources are limited in any economy and any government action in favor of one policy may take place at the cost of sacrificing other policies. In such a situation, the aggressiveness with which the government pursues a policy (say, human capital investment) should depend on the extent of gains from the policy compared to the losses from cutting out on other policies (say, R&D). Moreover, the explanatory variables can have differential short- and long-run, positive and negative effects on TFP growth which the NARDL model is equipped to capture.

The long-run coefficient estimates indicate that the positive component of human capital (HK+) has statistically significant positive effects on TFP growth for all models. However, the negative component of human capital (HK-) mostly shows insignificant long-run effects. The positive and negative components of R&D, R&D+ and R&D-, respectively, confirm an inverse relationship between R&D and TFP growth captured by the negative coefficients in most of the cases. This implies that increase in R&D is detrimental to India's long-run TFP growth (or, decrease in R&D increases India's TFP growth) rejecting the theory of first-generation R&D based endogenous growth model. R&D intensity, on the other hand, shows direct relationship with TFP growth. The positive component of R&D intensity in Model 1 (R&D Intensity+), negative component in Model 2 (R&D Intensity-) and both the positive and negative components of R&D intensity in Model 3 have significant positive influence on TFP growth. An increase (decrease) in R&D intensity increases (decreases) TFP growth. These results favor the Schumpeterian theory.

The positive and significant long-run effects of FDI/Y stand out for linear as well as the non-linear models. The positive component of FDI/Y (FDI/Y+) in Model 1 and the negative component (FDI/Y-) in Model 3 have statistically significant positive coefficients indicating theory-consistent effects of FDI stock. Only the negative component of the spillover variable

(R^f**-)** has significant long-run influence in Model 3 with the coefficient in other models remaining insignificant. The financial development variable has negative and significant effects in Model 1.

According to the short-run estimates of the coefficients, the contemporaneous effects of most of the variables (ΔHK (t)+, ΔR&D Intensity (t)+, ΔR&D Intensity (t)-, ΔFDI/Y (t)+, ΔFDI/Y (t)-) are positive and significant, barring the positive components of R&D (ΔR&D (t)+) and foreign spillover (ΔR^f(t)+). Both R&D and R&D intensity largely have significant and positive lagged effects in the short run. The negative components of human capital fail to have any significant short-run influence on TFP growth. With an exception of the positive components of FDI/Y at first lag (ΔFDI/Y(t-1)+), coefficients are positive and significant indicating a larger role played by the FDI stock even in the short run. The short-run effect of spillover variable on TFP growth is ambiguous. Financial development has negative and significant effects for Model 1 even in the short run.

The post-estimation diagnostics are satisfied for most of the models. Autocorrelation is present only in Model 2 while it is absent in Model 1 and Model 3. The parameters are unstable at 10 percent level of significance in Model 1 only, with parameters of the other models being stable. Moreover, all the estimates are homoscedastic and normally distributed.

Similar to the prediction of linear models, among the first-generation growth models, India's growth story finds support in the Lucasian model, where human capital affects long-run productivity growth. Although the Romerian model finds support in the linear model, where R&D is the driving force behind long-run productivity growth, it faces complete dismissal in the non-linear version. The non-linear version instead establishes the Schumpeterian theory with the long-run influence of R&D intensity variables on TFP growth, which the linear model fails to capture. Our results, in line with Madsen et. al (2010), do not find any evidence supporting the semi-endogenous growth models.

FDI stock, however, plays an important role in enhancing TFP growth in the short as well as long run as shown by both the linear and non-linear models. Our findings support the theory of FDI spillovers pioneered by Findlay (1978). The presence of large FDI stock in a recipient country is welfare-enhancing and improves the efficiency of domestic firms. The international technology spillovers captured using R^f shows significant and positive long-run influence for the linear models indicating that India derives strong benefits from the technological imports from R&D intensive countries in lines of Coe and Helpman (1995) and Madsen et. al (2010). However, the non-linear model completely rejects the beneficial effects of R^f as captured by the linear models. The financial development variable in the non-linear models has insignificant effects in line with Banerjee and Roy (2014).

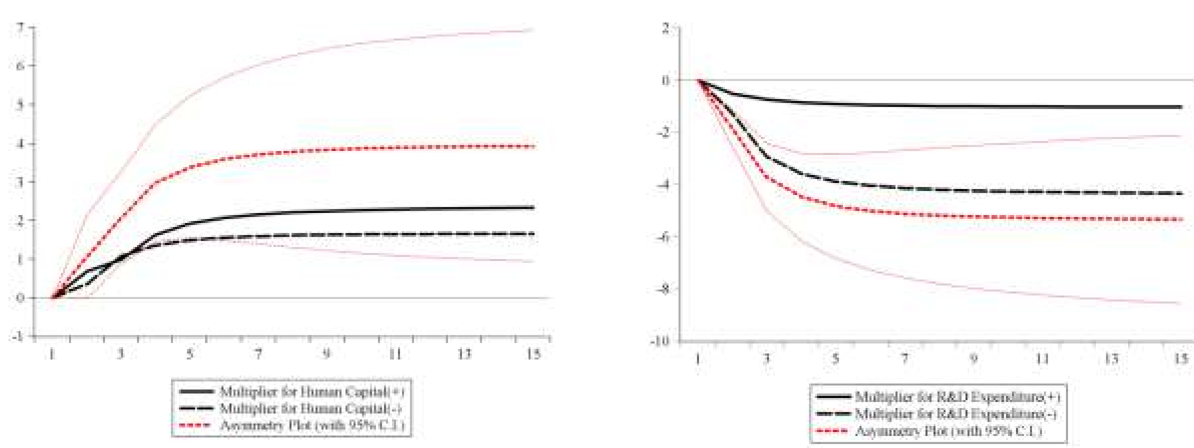
5.3.1. Asymmetric Dynamic Multipliers:

The analysis of dynamic effects of all the explanatory variables on TFP can be complemented using the dynamic multiplier graphs. Figures 2-4 present the graphs of asymmetric effects of all the explanatory variables based on the results in Table 3. Asymmetric dynamic multipliers mimic the Wald test results given in Table 3. They provide a better representation of the magnitude and direction of the effects of all the explanatory variables.

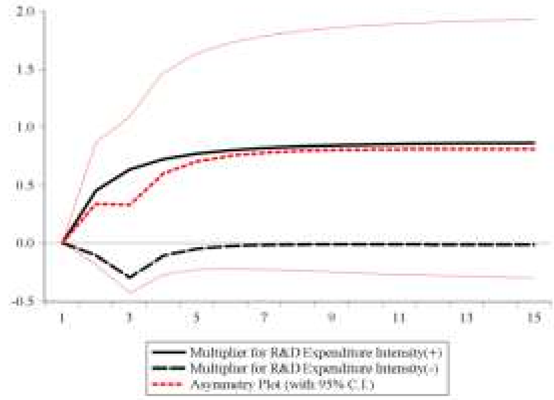
The continuous (dotted) black lines capture the pattern of TFP to its long-run equilibrium after a positive (negative) change in the respective explanatory variables at any given forecast horizon. The asymmetry curve given by the central red line captures the difference between the dynamic multipliers associated with positive and negative shocks of each variable. This curve is given with 95 percent confidence bands on either side. If the zero line falls in between the confidence bands, we consider the asymmetric effects to be insignificant at 5 percent level of significance.

Figure 2 captures the dynamic multipliers for Model 1. Panel (a) shows the significant asymmetry plot of the influence of human capital on TFP growth in the short as well as long run. This asymmetry effect is captured by the Wald test statistics in the first column of Table 3. According to this result, the extent to which TFP growth increases due to a policy aimed at increasing human capital is greater than the reduction in TFP growth due to a policy which lowers human capital. Significant asymmetry exists in case of R&D expenditure both in the short and long run as seen in Panel (b) of Figure 2 and the effect of negative shock dominates the effect positive shock in magnitude. Panel (d) of Figure 2 shows significant long-run and short-run asymmetric influence of FDI/Y with the short-run dominance in the effect of negative shock and long-run dominance of the positive shock. The asymmetric influence of R&D intensity and spillover is insignificant based on the confidence bands.

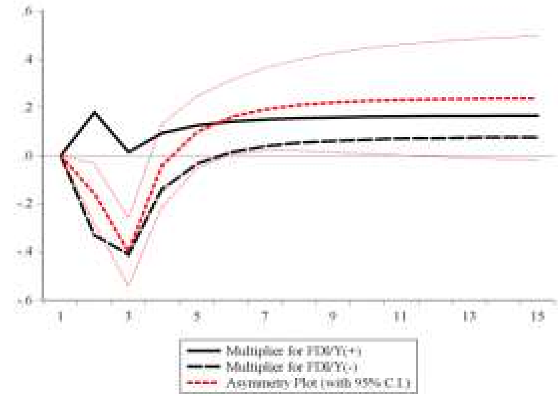
Figure 2 – Dynamic Multipliers of Model 1



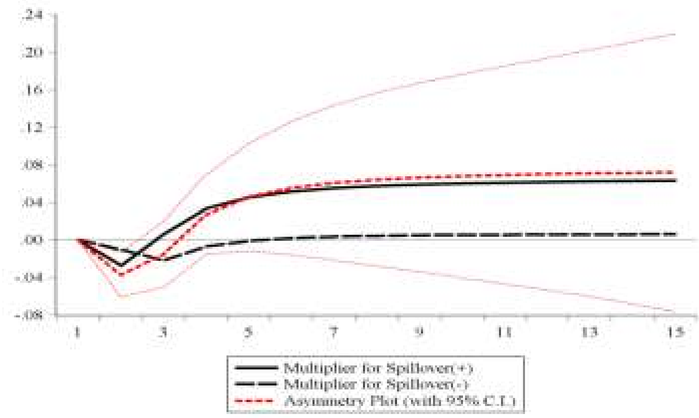
(a) (b)



(c)



(d)

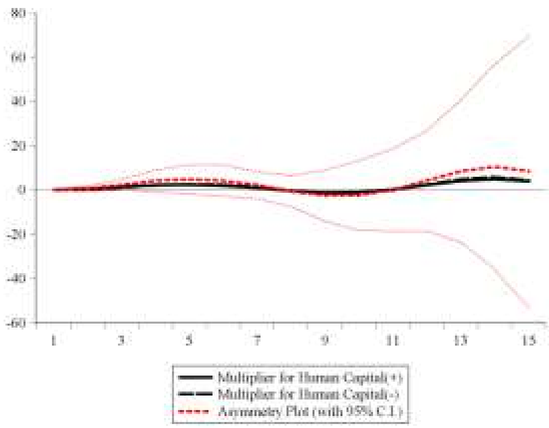


(e)

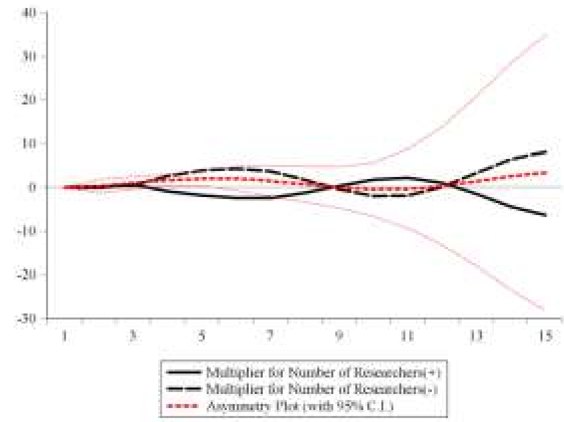
Source: Authors' Estimates

Figure 3 captures the asymmetric dynamic multipliers for Model 2. Almost all the models have insignificant asymmetric effects except for the one with N (Panel (b)). Effects of negative components dominate both in the short-run as well as in the long-run.

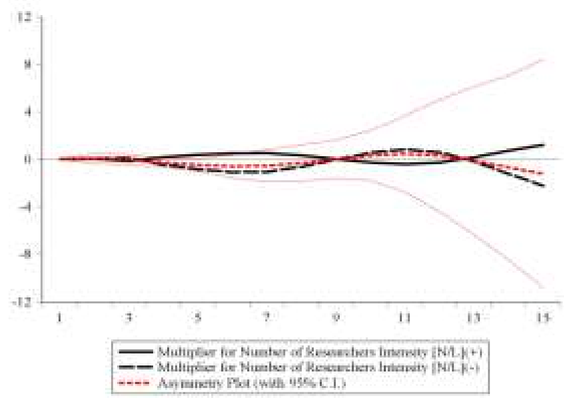
Figure 3 – Dynamic Multipliers of Model 2



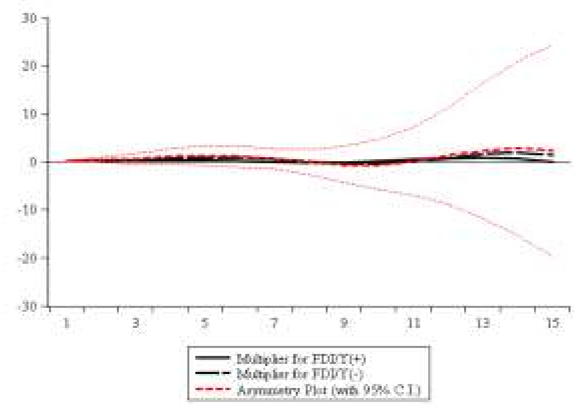
(a)



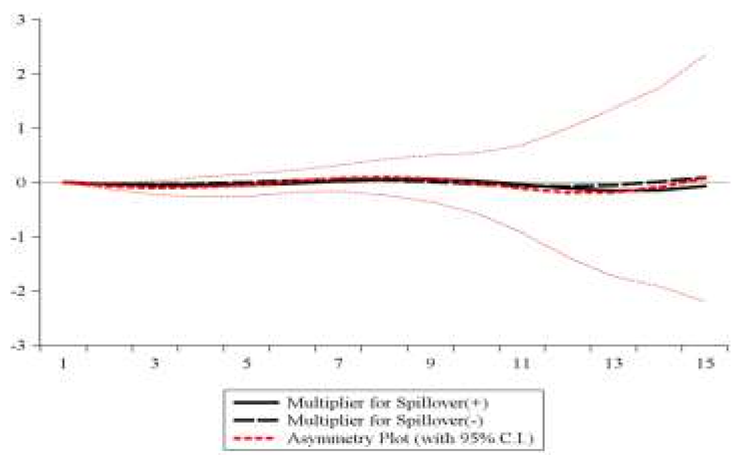
(b)



(c)



(d)

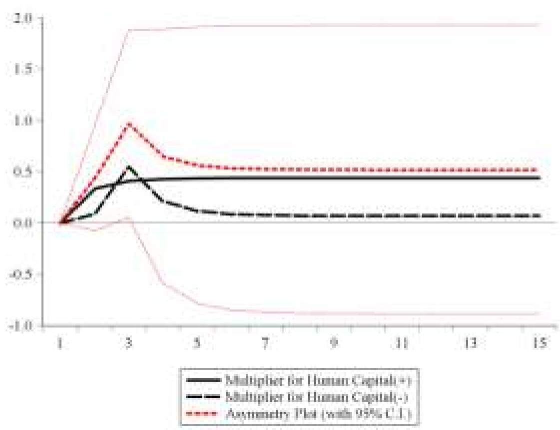


(e)

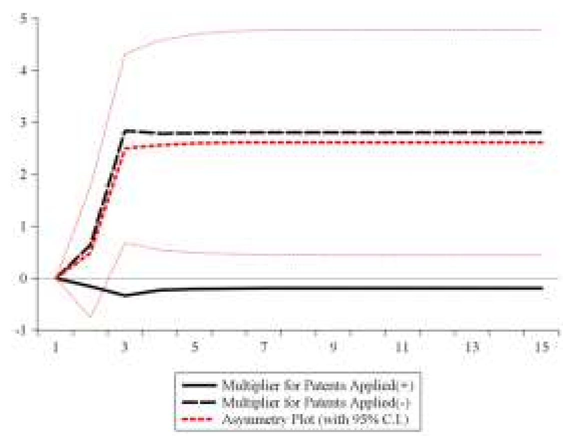
Source: Authors' Estimates

Figure 4 gives the asymmetric dynamic multipliers for Model 3. Human capital displays insignificant asymmetric influence. Significant asymmetry exists in the case of R&D (Figure 4: Panel (b)) with the dominance of positive shocks. Similar results are obtained for the R&D intensity variable but with the dominant effects of negative shocks. Panel (d) of Figure 4 displays presence of significant asymmetric effects of FDI/Y. Negative shocks have an upper hand even in this case. Moreover, the asymmetric effects of the spillover variable are insignificant in the long run for all the models.

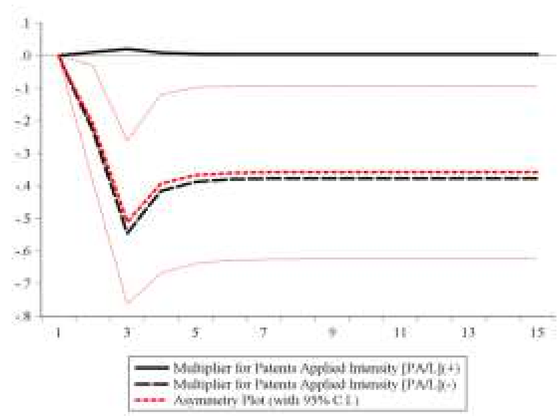
Figure 4 – Dynamic Multipliers of Model 3



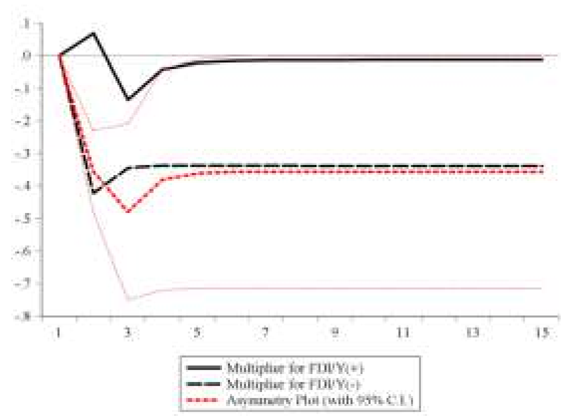
(a)



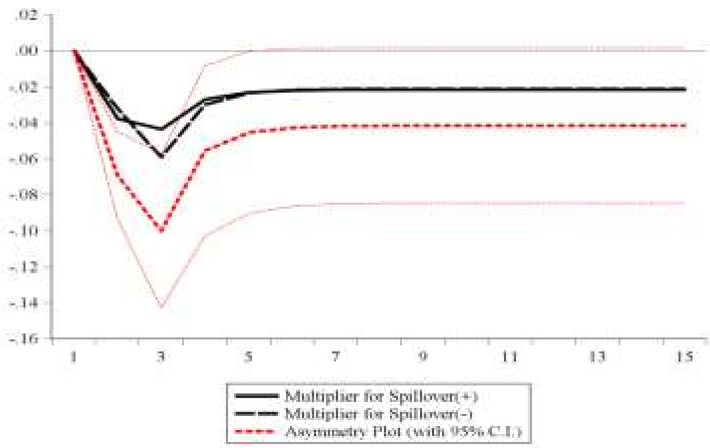
(b)



(c)



(d)



(e)

Source: Authors' Estimates

6. Conclusion

After liberalization, the Indian economy has been on an upward growth trajectory. Investments in human capital formation, R&D and foreign investments grew significantly. In this paper, we model the influence of human capital formation, investments in R&D, FDI stock and foreign technology spillovers on total factor productivity (TFP) growth by testing the applicability of conventional growth models in the Indian context. In particular, we test the applicability of first generation Romerian and Lucasian endogenous growth models; second generation Jonesian and Schumpeterian endogenous growth models; and growth models of FDI. To this end, we use linear and non-linear ARDL models and evaluate the short-run and long-run, symmetric and asymmetric effects of these variables on India's productivity growth.

India's growth story finds support in the Lucasian model, where human capital affects long run productivity growth, and some support of the Romerian model using linear ARDL, where R&D is the driving force behind long-run productivity growth. Using different measures of R&D intensity in the non-linear analysis, we find evidence in favor of Schumpeterian growth models. FDI, consistently and robustly, across both linear and non-linear models, has shown significant contribution in explaining India's TFP growth. In addition, FDI has an asymmetric effect on TFP, with the decline in FDI having a more negative impact on the economy than the positive impact it has had as a result of increased FDI investment. We find limited support for the foreign spillover variable.

We recommend sustained increase in targeted foreign investments alongside investment in human capital, such that the technological gap reduces to the extent from which the country can start to benefit from its own R&D. The implications of the findings are crucial at a time when the Indian Government has embarked on a 'Make in India' campaign to push the economy out of the growth slowdown along with the very recent announcement of the strategy of 'self-reliance' to be adopted for India's post-Covid recovery, whose implications remain unclear for the future of India's FDI.

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Appendix:

Variables used for analysis:

Total Factor Productivity (TFP) – Taken from Penn World Series Database 9.1. They estimate TFP using techniques similar to Madsen et al (2010) where human capital is taken from the extended data set of Barro and Lee (2013) and the constant shares of labor and human capital are 0.7 and 0.3 respectively.

Human Capital (HK) – We use Gross Enrollment Ratios of secondary school - the ratio of total enrollment in secondary, regardless of age, to the population of the secondary age group; taken from UIS.stat.

R&D Expenditure (R) – This expenditure is measured in Rupees. We take data from UIS.stat and various statistical yearbooks of the United Nations.

Gross Domestic Product (Y) – This data is taken from RBI DBIE database and converted to real GDP using GDP deflator taken from FRED stats.

Number of Researchers (N) – This data is taken from UIS.stat and various statistical yearbooks of the United Nations.

Labor Force (L) – This dataset is taken from International Labor Office (ILO). Labor force is considered as the population in the working age group of 15-64 years.

Patents Applied by local residents (PA) – This data is taken from World Intellectual Property Rights (WIPO) Statistics database.

Patents Granted to local residents (PG) – This data is taken from World Intellectual Property Rights (WIPO) Statistics database.

Foreign Direct Investment (FDI) – This data is taken from the updated version of the External Wealth of Nations Mark II database by Lane and Milesi-Ferretti (2007). It gives the total nominal stock of FDI. Real FDI stock is estimated by deflating the nominal FDI stock by the investment deflator, which is obtained from Penn World Tables database.

Foreign Spillovers (R^f) – This data is constructed as given in equation (6) in the write-up. Data for high-technology goods is taken from UN Comtrade database and various publications of the International Monetary Fund and the United Nations. Data for R&D of the partner countries is obtained from OECD statistics database.

Financial Development (FinDev) – This data is taken from Global Financial Development Database of the World Bank. We use percentage of private credit by deposit money banks to GDP as a financial development variable.

Table A1 – Johansen Co-integration test (Maximum Eigen-value)

Null Hypothesis: There exist at most 'r' co-integrating relationships				
	R&D Expenditure	**Number of Researchers**	**Patents Applied**	**Patents Granted**
r=0	0.64***	0.62**	0.63**	0.71***
r=1	0.51*	0.52*	0.54	0.54*
r=2	0.36	0.29	0.39	0.43

*, **, *** represent 10%, 5% and 1% levels of significance respectively.

Source: Authors' Estimates