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Information and communication technology and economic growth in India

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ABSTRACT

This paper examines the sources of economic growth in Indian economy since the 1980s, with particular focus on the role of information and communication technology (ICT). The impact of ICT on economic growth is analyzed via two main channels. The direct contribution of ICT investment to aggregate economy and manufacturing growth, and the indirect impact of ICT on Total Factor Productivity Growth (TFPG) in ICT using and ICT producing sectors. The results suggest an increasing role of ICT investment in driving aggregate economic growth in India, though largely limited to the service sector. Moreover, the economy has not been successful in spreading the ICT spillover effect across the board, thus limiting the productivity gain from ICT use. Whereas we see an improving productivity growth in ICT using market services and their contribution to aggregate productivity growth, the manufacturing sectors lags quite behind. Indeed, India's export oriented ICT sector has helped gain efficiency improvement in its fast growing service economy, while there is still large potential for ICT use in the manufacturing sector. The paper opens further avenues for improving the data on ICT investment, and also stresses the need for more detailed sectoral analysis of the impact of ICT on economic growth, treating computer related and software services separately.

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1. Introduction

The role of Information and Communication Technology (ICT) in speeding up economic growth has been empirically established in the context of several mature economies (see for instance Inklaar, Timmer, & van Ark, 2008; Jorgenson, Ho, & Samuels, 2011; Jorgenson & Vu, 2011, 2013; Jorgenson, Ho, & Stiroh, 2005; Jorgenson, 2001; van Ark, Inklaar, & McGuckin, 2003).¹ Investment in ICT has helped firms reduce the cost of communication and coordination substantially and also to increase their efficiency and productivity by facilitating better organization of production. ICT investment, which consists of physical capital (hardware and communication equipment) and intangible capital (software), contributes to economic growth directly via improved productivity and growth of industries that produce ICT goods and services, and indirectly via improved quality of investment and productivity of industries that use ICT assets in their production (van Ark, Gupta, &

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¹ It is often argued that the productivity differences between the United States and the European countries observed during the mid-1990s is largely driven by the faster accumulation of ICT capital in the United States, particularly in the market services sector (van Ark et al., 2003).

Erumban, 2011).² This supply-side productivity gain also nurtures increased welfare, in addition to any direct welfare effect that could be achieved by increased production of ICT. However, the role of ICT in improving productivity and growth, and thereby the standard of living in emerging economies is hardly explored. This paper is an attempt to quantify the impact of ICT use on productivity and economic growth in India.

Economic growth in India during the last decade³ has bypassed any other country of the similar economic situation, except China.⁴ The role of productivity in this growth surge has been examined by many studies in the past, primarily in the (formal) manufacturing sector (see Kathuria, Rajesh Raj, & Sen, 2014; Das & Kalita, 2011 for recent evidence). However, analysis of productivity dynamics in ICT sectors, and in particular the contribution of ICT investment to economic growth and productivity in India in general is hard to find.⁵ Liberalization of the Indian economy in the early 1990s, to some extent conceded with the widespread ICT revolution, and the country has benefitted from this revolution, given its large English speaking pool, low unit labor cost and the availability of qualified engineers and programmers. Ever since the opening up of the economy in the 1990s, India has been a major player in ICT industry, in particular in the software segment. In addition to creating high value jobs for programmers, managers and analysts, software revolution in India has indeed helped introduce innovative entrepreneurship and governance models within the software industry (Arora & Athreye, 2002). Obviously, the improved governance and organization will be reflected in the efficiency of software sector, but is also expected to have impact on other sectors of the economy. In this paper, we examine the contribution of ICT to economic growth in India – both direct and indirect – using a growth accounting approach. The paper differs from previous research on productivity in India in that we use detailed industry level data to understand the growth process in India, with a focus on the role of ICT. More importantly, we use better measures of capital and labor inputs that take account of heterogeneity among different types of capital assets and different types of labor (also see Erumban, Das, & Aggarwal, 2012).

As mentioned before, the impact of ICT on economic growth can accrue via various channels – both direct and indirect (see van Ark et al., 2011). For instance, rapid technological change in the ICT producing sector has helped improve the productivity in the ICT producing sector. This phenomenon, particularly in the United States, has led to significant drop in the price of ICT goods.⁶ This price decline, leading to the substitution of other forms of capital by ICT⁷, has helped firms gain better efficiency in organizing their production (see Jorgenson, 2001). The benefit of this price decline obviously has also reached most emerging economies including India, helping them accelerate the speed of ICT adoption.⁸ The benefit accrued to ICT using industries emanates from increased labor productivity due to increased contribution of ICT capital deepening, but also via spillover effect that ICT capital brings on improving total factor productivity (TFP). This spillover could happen in various forms, such as network externalities, organizational changes and lower transaction costs (van Ark et al., 2011). In this paper, the effect of ICT use in India's aggregate economy is examined via two channels. An investment effect, where the more intensive use of ICT is expected to improve the contribution of capital to output growth in ICT using sectors (and thereby reflect in the aggregate economic growth); and a spillover effect where the use of ICT is expected to enhance total factor productivity in ICT using sectors. However, at the sectoral level, we examine only the latter (productivity effect), due to lack of ICT investment data at industry level. ICT producing sectors, in addition to the rapid technological change, further benefit from the increasing demand for ICT goods, as it helps them expand production, thus resulting in an increase in their direct contribution to aggregate economic growth. We also examine this direct effect of ICT, or the production effect, by analyzing the productivity in ICT producing sectors and their contribution to aggregate productivity and output growth.

While in the early phases, the declining prices of ICT goods have resulted increased use of ICT primarily in the United States and several European countries (Van Ark et al., 2003; van Ark, O'Mahony, & Timmer, 2008), the adoption and diffusion rates were quite low in many emerging economies. However, this trend has been changing since the mid-2000s, during which many emerging economies also started going digitally. Yet, in general our understanding of the impact of ICT on aggregate economic performance in emerging economies is very limited, primarily due to lack of appropriate data. Exceptions to this are De Vries, Mulder, Dal Borgo, and Hofman (2010) in the case of Latin America and Jorgenson and Vu (2005, 2011, 2013) in a more global context. This lack of data poses an additional challenge of constructing a consistent series of ICT investment for Indian economy. This study also takes a careful approach to construct a consistent database on ICT investment in India, while still leaving substantial room for further improvement.

² While much of the focus in the literature is on ICT's effect on bringing economic growth, there have been some efforts to look into the employment effects of ICT use. For instance evidence suggests that the increased use of ICT in production has increased demand for skilled workers (Michaels, Natraj, & van Reenen, 2014; Autor, Katz, & Krueger, 1998).

³ See Verma (2012), Kochhar, Kumar, Rajan, Subramanian, and Tokatlidis (2006), Panagariya (2008), and Rodrik and Subramanian (2005) among others, for analysis of economic growth in India in the context of market reforms.

⁴ Though India has witnessed a drop in economic growth since 2010, it had an impressive growth record during the preceding decade. A number of factors have been blamed for the recent slowdown including inflation, decline in currency, large fiscal and current deficit, and lack of labor and product market reforms. A recent study establishes a strong negative relationship between inflation and growth in India (Mohaddes & Raissi, 2015).

⁵ An exception is a series of global studies by Jorgenson and Vu (2005, 2011, 2013).

⁶ Feenstra, Mandel, Reinsdorf, and Slaughter (2013) argues that approximately 20 percent of US productivity growth was due to gains in the terms of trade, particularly in the ICT sector.

⁷ Erumban and Timmer (2012) provides evidence on how innovation can lead to faster replacement of capital, by accelerated scrapping of existing assets resulting in creative destruction.

⁸ Adoption is a term usually referred to the choice to acquire and use a new technology; in this case, information and communication technology.

Fig. 1. Share of software exports in GDP.

Source: Reserve Bank of India Survey on Computer Software & Information Technology Enabled Services Exports: 2012–2013.

Our results suggest an increasing role of ICT investment in driving aggregate economic growth in India, though largely limited to the service sector. Moreover, the economy has not been successful in spreading the ICT spillover effect across the board, thus limiting the productivity gain from ICT use. Whereas the contribution of ICT using services has increased over years, ICT manufacturing sector lagged behind in terms of its contribution to aggregate productivity and economic growth. Moreover, the contribution of ICT investment in the manufacturing sector has not increased significantly over the period of 1985–2011.

The remaining of the paper is presented in seven sections. The second section provides a brief discussion on the evolution of ICT in India under various policy regimes. Section 3 presents the methodology used to delineate the contribution of ICT to economic growth in India, and in Section 4 we present the construction of data and variables. In Sections 5 and 6 we analyze the direct effect of ICT on economic growth respectively in the aggregate economy and in the aggregate manufacturing sector. Section 7 presents the industry origins of aggregate productivity growth, with a special focus on ICT using and producing industries and Section 8 concludes the paper.

2. ICT sector in India: the policy and evolution

The pace of ICT adoption, in general, is argued to be influenced by a host of factors including cultural and economic factors (see for instance Erumban & de Jong, 2006). In the case of India, in addition to its linguistic, mathematical and programming advantages, government initiatives by investing in technical education and export enabling infrastructure (such as export processing zones and IT parks, particularly in the post 1990 period) also played an important role in nurturing ICT industry (Balakrishnan, 2006; Balasubramanyam & Balasubramanyan, 1997). Though these initiatives provided the appropriate infrastructure for flourishing the information technology sector, it is to be noted that as in the case of India's post-independence industrialization strategy in general, the early phase of India's IT industry strategy was also a reflection of its autarky ideology with domestic orientation. Restrictions on import of electronics were at the core of the policy strategy, as the objective was to achieve self-sufficiency in electronics production and modern technology. This extreme domestic focus and hostility to imports resulted in the emergence of some public enterprises. Nevertheless, it often necessitated the use of domestically refurbished systems, which were inferior to what could be imported, and its impact on helping the IT sector to flourish was hardly positive.

Even though in the mid-1970s some incentives were provided to foreign investors, unhealthy competition from public sector enterprises, which were given incentives to produce electronics and small computers, made it less attractive for private firms to operate. Only a handful of private firms operated in the Indian market, and foreign companies stayed away due to continuing regulations. Moreover, the firms in the Indian ICT sector could not get up to date with the technological change in the frontier countries as they could not import most recent versions of the technology due to high import tariffs. Obviously, their ability to excel in software exports was limited, as they could not cope-up with the global demands. However, by the early 1980s, despite all the challenges, Indian firms managed to achieve a reasonable share of software exports, which was nurtured both by India's lower unit labor cost and its large English speaking human capital. Yet, the stringent control over hardware imports along with other supply side bottlenecks limited their ability to expand further.

Following the personal computer revolution, software sector gained further momentum in exports in the mid-1980s, and it continued further in the 1990s. The liberalization of external sector in the 1990s further helped gain a boost in software service industry dominated by outsourcing from foreign companies.⁹ This domination of software service industry in the overall IT sector still continues.¹⁰ Software service exports, excluding on-site exports, constituted about 45 percent of total services

⁹ It is also often argued that the brain drain from India in the 1960s and 1970s also paid back by being a source of finance for a booming software industry in India (Balasubramanyam & Balasubramanyan, 1997).

¹⁰ It has been emphasized by earlier studies that India's ICT sector is dominated by the export-oriented service sector, rather than product oriented (e.g. Arora, Arunachalam, Asundi, & Ronald, 2001), and the global computer and information services leadership, measured in terms of export shares, has moved to countries like India (Mani, 2014).

Fig. 2. Share of ICT producing sectors in total GDP.

Source: Central Statistical Organization.

exports and 3.5 percent of GDP in 2012¹¹ (Fig. 1). This industry has grown substantially over time, particularly in the 2000s. Total export of software services, measured in US\$ terms, grew at an annual average rate of 30 percent during the period 2001–2008, though it fell to an average of 16 percent during the years of global financial crisis, i.e. 2009–2012 period (Reserve Bank of India, 2014). It is, however, hard to get data on all relevant variables for this industry consistently, to use in our growth accounting exercise, and therefore, in this paper we stick to the conventional definition of ICT sectors, which are the ICT producing manufacturing sectors – electronics and computer industry – and ICT producing services – the telecommunication industry. This approach, however, may significantly underestimate the true impact of ICT on Indian economy, in terms of its impact on ICT producing sectors and therefore opens up further avenue for future research.

Even though India's ICT sector is still small in size (Fig. 2),¹² it has been one of the fast growing sectors of the economy since the mid-1990s. The share of ICT producing sector has increased from 3.4 percent in 2000 to 5.9 percent in 2007, with the largest increase being in computer and related services (from 1.4 percent to 3.4 percent). In addition, Indian firms in other sectors, predominantly services sectors such as financial services, also started using the technology heavily to enhance efficiency, and reduce communication and coordination costs, which will have an impact on their overall productivity. For instance, a microstudy by Jensen (2007) shows that, the use of mobile phones by fishermen in the Indian state of Kerala has helped improve both consumer and producer welfare, by reducing price dispersion. Similarly, comparing firms in India and Brazil, Commander, Harrison, and Menezes-Filho (2011) find robust positive productivity effects of ICT. In particular their findings suggest the importance of better infrastructure and labor market policy for higher rates of ICT adoption.

However, there is hardly any attempt to quantify the impact of ICT use on India's economic growth from a broader perspective. Going by the standard definition of ICT sectors, we define the total market economy into ICT using sector, ICT producing sector and non-ICT sectors (see Table A1). ICT using sectors according to this definition (which includes printing & publishing, machinery, transport equipment, trade and financial services), constituted about 17.4 (7.4) percent of total GDP (employment) in 1980, which increased to 25 (13) percent in 2010. ICT producing industries, (which includes electrical and optical equipment manufacturing and telecommunication services), increased their share in GDP (employment) from 1.3 (0.3) in 1980 to 2.1 (0.7) percent in 2010. It may be noted that some sectors such as electrical machinery & apparatus, which are included in the ICT producing category in our industry classification, may not be necessarily ICT producing, and therefore might lead to an overestimation of the size of this sector. However, it was hard to split inputs and output in these sectors in the India KLEMS database for growth accounting analysis. Moreover, this sector is still part of the ICT sector, even though it is hard to attribute it strictly to ICT producing or ICT using category. Therefore, in our productivity analysis, we consider both possibilities – attributing it to ICT using and ICT producing – to see what impact it makes (see a detailed discussion on this in Sections 5 and 7). Clearly, the ICT sector, though the size of ICT producing sector is small, show a remarkable increase both in employment generation and GDP over time, substantiating the importance of this sector for Indian economy.

India's ICT sector also excels in terms of its relative productivity performance, for instance, compared to the neighboring China. Fig. 3 depicts the labor productivity (output per worker) levels in India compared to China. Productivity levels are expressed as percentage of the United States. While India lags much behind China in terms of aggregate economy productivity, which includes all non-ICT sectors including informal sector, India clearly have a productivity advantage in ICT sector. Whereas it is in par with China in ICT services,¹³ it has gained over China over years in ICT manufacturing, leading to

¹¹ Most Indian data are presented for the financial year, which span from April 1st to March 31st. Therefore, throughout this paper, the reference to a calendar year refers to the major part of the financial year. For instance, 1990 refers to 1990 April 1st to 1991 March 31, as the larger part of the data belongs to 1990.

¹² As per NSSO 63rd round of survey, ICT producing services provides 3.15 million jobs, approximately 0.7 percent of total employment in 2006 (Central Statistical Organization, 2010).

¹³ Despite having large software services exports compared to China, India's ICT services productivity levels, at aggregate, is not higher than that of China's. It should be noted that this aggregate picture of ICT services, which includes software services, call centers, other computer related services and telecom services might mask many underlying dynamics at detailed industry and firm level. If software services alone are considered separately, the productivity levels in India could be quite higher. For instance McKinsey Global Institute (2001) suggests that Indian software companies are 44 percent as productive as their U.S. counter parts, with some individual companies even being in par with the U.S. companies.

Fig. 3. Labor productivity in ICT sectors and total economy, India and China. *Notes:* ICT sector is defined as the operational ICT industries, which includes electronic components and boards, computers and peripheral equipment, communication equipment and consumer electronics (manufacturing) and telecom services and computer and related services (services). Labor productivity is measured as output per worker. .

Source: ICT sectors from [PREDICT ICT sector database \(2013\)](#) and Total Economy from The Conference Board Total Economy Database™.

an overall edge in ICT sector productivity. This is an important observation, given that aggregate productivity levels in India are still far below that of China. India's aggregate productivity relative to the United States is approximately 4 percent lower than that of China, while her ICT productivity is higher by the same magnitude in 2009. ICT sector productivity levels both in India and China are quite low compared to the US, which may be due to a number of additional factors, apart from country specific factors that drive productivity down in general. For instance, it could perhaps be due to the presence of a handful of highly productive firms in the US, while that is not the case in most other economies. The interesting feature of China's and India's productivity levels, however, is that the ICT productivity is higher than aggregate productivity.

3. ICT and economic growth in India – the methodology¹⁴

In this section, we discuss the methodology used to construct aggregate estimates of productivity growth and the sources of aggregate value added and labor productivity growth –in terms of industries (ICT and non-ICT), inputs (ICT capital, non-ICT capital and Labor) and Total Factor Productivity Growth (TFPG). To decompose the contributions of ICT and non-ICT capital, we use the aggregate production function approach discussed. To measure the contribution of ICT and non-ICT sectors to aggregate TFPG, we use the direct aggregation method suggested by [Jorgenson et al. \(2007\)](#). In the latter case, estimates of productivity and output growth are constructed for 26 industries that cover the entire Indian economy during the time period 1980–2011. These industries are further classified into ICT producing, ICT using and non-ICT industries, to delineate the direct and indirect effects of ICT on economic growth. These approaches are explained in detail below.

3.1. ICT and aggregate economic growth – aggregate production function approach

The most common approach to measure aggregate economic growth and its sources is to assume an aggregate production function. In this setting inputs and value added are aggregated across industries to obtain aggregate volume indices under strict assumptions on the nature of production function and industry detail ([Jorgenson et al., 2007](#)).¹⁵ Despite its limitations, which we address partly in our industry analysis where we examine the contribution of ICT industries to aggregate productivity growth, we opt to do the aggregate production function to evaluate the impact of ICT investment on aggregate GDP and labor productivity growth, due to non-availability of reliable sectoral ICT data.

Using an aggregate production function approach, aggregate value added (V^{PF}), obtained by summing value added across industries (i.e. $V^{PF} = \sum V_i$, with V_i being real value added in industry i), can be decomposed into contribution from aggregate capital input (K), aggregate labor input (L) and aggregate total factor productivity (A) growth as

$$\Delta \ln V^{PF} = s_K \Delta \ln K + s_L \Delta \ln L + \Delta \ln A^{PF} \quad (1)$$

where s_K is the share of aggregate capital compensation in aggregate nominal value added, and s_L is the share of aggregate labor compensation in aggregate nominal value added, both averaged over the current and previous periods. Aggregate capital and labor compensation are derived from the identity that total nominal value added is the sum of aggregate labor and capital compensation. $\Delta \ln K$ is the aggregate capital services growth rate and $\Delta \ln L$ is the aggregate labor input growth rate. Aggregate capital and labor inputs are also the sum of industry labor and capital inputs. $\Delta \ln A^{PF}$ is the growth of aggregate total factor productivity assuming an aggregate production function.

¹⁴ This section draws largely upon [Jorgenson, Ho, Samuels, and Stiroh \(2007\)](#).

¹⁵ The underlying assumptions include separability of gross output production function in value added for each industry and same value added function across all industries. We do not intend to discuss the different aggregation approaches available in the literature. Interested readers may refer to [Jorgenson et al. \(2007\)](#), who provide an in-depth and detailed discussion on the same.

As mentioned before, the above approach is built on restrictive assumptions on the existence of an aggregate production function, which requires identical industry value added functions. Jorgenson et al. (2005) use a less restrictive production possibility frontier approach, which relaxes the restrictions on industry value-added function. In this approach, the measurement of output differs from the aggregate production function, but the measurement of input remains the same (see Jorgenson et al., 2007). Defining aggregate value added growth as a translog index of industry value added growth, and keeping capital and labor unchanged as in (1), Eq. (1) can be re-written as

$$\Delta \ln V = \sum_i \bar{s}_i \Delta \ln V_i = \bar{s}_K \Delta \ln K + \bar{s}_L \Delta \ln L + \Delta \ln A \quad (2)$$

where V_i is the real value added in industry i . Note that $\Delta \ln V$ in Eq. (2) is different from $\Delta \ln V^{PF}$ in Eq. (1), as Eq. (2) uses a translog aggregation of industry value added growth while Eq. (1) is the growth rate of simply aggregated value added across industries. The difference between the two is the reallocation of value added across industries.

In (1) and (2), aggregate capital and labor inputs are measured as the flow of services from these inputs to the production process. Aggregate capital and aggregate labor inputs consists of different types of capital assets (e.g. machinery, computers, buildings etc.) and labor types (low-skilled, high-skilled etc.), with differing marginal productivities. Therefore, following Jorgenson (1963), we define aggregate capital services and labor input as translog aggregates of heterogeneous types of capital and labor.

$$\Delta \ln K = \sum_k \bar{v}_k \Delta \ln K_k; \quad \text{and} \quad \Delta \ln L = \sum_l \bar{v}_l \Delta \ln L_l \quad (3)$$

where v_k is the share of each type of capital k in aggregate capital compensation, and v_l is the share of each type of labor l in total labor compensation, defined as

$$v_k = \frac{P_{K,k} K_k}{\sum_k P_{K,k} K_k} \quad \text{and} \quad v_l = \frac{P_{L,l} L_l}{\sum_l P_{L,l} L_l} \quad (4)$$

where $P_{K,k}$ is the rental price of capital type k , and $P_{L,l}$ is the price (wage rate) of labor type l . As before $\bar{v}$ in (3) is the two-period averages of these shares. In our analysis, we distinguish between five types of labor, and six types of capital assets (see section on data). They are respectively employees with education (1) up to primary; (2) primary school; (3) middle school; (4) secondary and higher secondary school; and above (5) higher secondary school and capital assets (1) transport equipment; (2) non-ICT machinery; (3) construction, (4) hardware, (5) communication equipment and (6) software. Assets 1–3 are considered as non-ICT assets, and 4–6 are ICT assets.

Note that aggregate capital and labor input can also be measured as the growth rate of simple aggregated capital and labor across different types, which is the standard approach followed in earlier studies in the Indian context. This will provide us

$$\Delta \ln K^* = \Delta \ln \sum_k K_k; \quad \text{and} \quad \Delta \ln L^* = \Delta \ln \sum_l L_l \quad (5)$$

where K^* and L^* are respectively the aggregate capital stock and aggregate employment obtained by summing across investment in different types of assets and different types of labor. Such an approach undermines the importance of heterogeneity among different types of capital and labor, as it assumes that the marginal productivities of these different types of assets and labor are the same. The difference between capital and labor input growth rates aggregated using Eq. (3) and the standard aggregation across assets or worker types in Eq. (5) is, therefore, often called respectively as capital quality (or capital composition effect) and labor quality (or labor composition effect), as they capture the heterogeneity within these inputs (see Jorgenson, 2001). Our empirical analysis presents the contribution of labor split into the contribution of pure employment quantity (L^*) and labor quality (LQ) and the contribution of capital services split into ICT capital services (it) and non-ICT capital services (nit). Then, Eq. (2) can be re-written as

$$\Delta \ln V = \sum_i \bar{s}_i \Delta \ln V_i = \bar{s}_{K,it} \Delta \ln K_{it} + \bar{s}_{K,nit} \Delta \ln K_{nit} + \bar{s}_L \Delta \ln L^* + \bar{s}_L \Delta \ln LQ + \Delta \ln A \quad (6)$$

where $\bar{s}_{K,it} = \bar{s}_K \bar{v}_{it}$ and $\bar{s}_{K,nit} = \bar{s}_K \bar{v}_{nit}$, with $\bar{v}_{it}$ and $\bar{v}_{nit}$ being the share of ICT capital and non-ICT capital in total capital compensation

By subtracting the growth rate of employment, Eq. (6) can be used to understand the sources of aggregate labor productivity growth as:

$$\Delta \ln v = \bar{s}_{K,it} \Delta \ln k_{it} + \bar{s}_{K,nit} \Delta \ln k_{nit} + \bar{s}_L \Delta \ln LQ + \Delta \ln A \quad (7)$$

where v is the aggregate labor productivity growth, measured as the difference between aggregate value added growth, as measured in Eq. (2), and aggregate employment growth, as measured in Eq. (5) and k is aggregate capital deepening, measured as the difference between aggregate capital service growth (Eq. (3)) and aggregate employment growth (Eq. (5)).

The above decomposition is used for the aggregate economy and also for the total manufacturing, as in both cases we had data on investment in ICT assets.

3.2. Contribution of ICT and non-ICT sectors to aggregate TFPG

In order to trace the industry origins of aggregate productivity, and to quantify the relative importance of ICT producing and ICT using sectors vis-à-vis non-ICT sectors in driving aggregate productivity growth, we use the direct aggregation

method suggested by Jorgenson et al. (2007). This approach relaxes many assumptions on input and output measurement that exist in the aggregate production function approach. In this approach, aggregate production function is a value added function and the aggregate value added growth is measured as a translog index of industry value added, with weights being the industry share in aggregate nominal value added (as in Eq. (6)). The production function at the industry level, however, is a gross output (Y) function, and therefore, industry output growth can be decomposed into contributions from capital (K), labor (L) and intermediate input (X) as¹⁶

$$\Delta \ln Y_i = \bar{s}_{K,i} \Delta \ln K_i + \bar{s}_{L,i} \Delta \ln L_i + \bar{s}_{X,i} \Delta \ln X_i + \Delta \ln A_i \quad (8)$$

where s_K , s_L , and s_X are respectively the share of capital, labor and intermediate input in total nominal output in industry i . Since nominal value of gross output is the sum of nominal value of industry value added and nominal value of total intermediate inputs, the industry output growth can be obtained as a weighted sum of industry value added growth and industry intermediate growth with the weights being respectively the nominal share of value added in output and nominal share of intermediate inputs in output. Assuming that aggregate value added is a translog sum of industry value added, we can decompose the aggregate value added growth as (see Jorgenson et al., 2007):

$$\Delta \ln V = \sum_i \bar{s}_i \Delta \ln V_i = \sum_i \bar{s}_i \frac{\bar{s}_{K,i}}{\bar{s}_{V,i}} \Delta \ln K_i + \sum_i \bar{s}_i \frac{\bar{s}_{L,i}}{\bar{s}_{V,i}} \Delta \ln L_i + \sum_i \bar{s}_i \frac{1}{\bar{s}_{V,i}} \Delta \ln A_i \quad (9)$$

In Eq. (9), aggregate value added growth is sum of the weighted contribution of industry capital input, industry labor input and industry TFPG. The weights on capital and labor consists of s_i , the share of industry value added in aggregate value added, $s_{K,i}$ and $s_{L,i}$, the share of industry capital and labor compensation in industry gross output and s_{vi} , the share of industry value added in industry gross output.¹⁷ The first and last components of the input weights (s_i and s_{vi}) also reflect in the TFPG weights.

Subtracting Eq. (2) from (9), and rearranging, we obtain

$$\begin{aligned} \Delta \ln A &= \sum_i \frac{\bar{s}_i}{\bar{s}_{V,i}} \Delta \ln A_i + \left(\sum_i \bar{s}_i \frac{\bar{s}_{K,i}}{\bar{s}_{V,i}} \Delta \ln K_i - \bar{s}_K \Delta \ln K \right) + \left(\sum_i \bar{s}_i \frac{\bar{s}_{L,i}}{\bar{s}_{V,i}} \Delta \ln L_i - \bar{s}_L \Delta \ln L \right) \\ &= \sum_i \frac{\bar{s}_i}{\bar{s}_{V,i}} \Delta \ln A_i + REAL_K + REAL_L \end{aligned} \quad (10)$$

Eq. (10) suggests that aggregate TFPG can be decomposed into weighted average of industry TFPG and the capital and labor reallocation across industries. Note that the weights attributed to industry TFPG in this setting is equivalent to the well-known Domar weight (Domar, 1961). The weight in Eq. (10) is the ratio of s_i , or industry share in aggregate value added and s_{vi} or the industry value added share in aggregate output, which approximates to the Domar weight, which is the ratio of industry gross output to aggregate value added. These weights will be greater than one, as industry TFP improvement can have a direct effect through industry output, but also an indirect effect through output in other industries, by means of intermediate input sold to other industries (Jorgenson et al., 2007). The difference between Domar weighted TFPG and the aggregate TFPG is the sum of labor and capital reallocation effects, which reflects the movement of these resources across industries. For instance, a positive reallocation term would indicate a movement of resources from less productive to more productive industries. In the subsequent sections of the paper, we present results based on Eq. (10), along with Eqs. (6) and (7). In the latter two cases, capital is distinguished between ICT equipment and non-ICT capital and labor between labor quantity and labor quality.

4. Data and variables

The primary source of all the data used in this paper is the India KLEMS database,¹⁸ which is consistent with official National Accounts Statistics (NAS), published annually by the Central Statistical Organization (CSO). However, in order to construct detailed industry data, consistent employment series, and intermediate inputs, National Accounts data is supplemented by Input–Output tables, Annual Survey of Industries (ASI) on organized (formal) manufacturing and various rounds of National Sample Survey Organizations (NSSO) surveys on employment & unemployment and unorganized sector. Whereas Eqs. (1) and (6) requires only aggregate economy and total manufacturing data on value added, employment by worker categories and investment by assets, Eq. (10) requires detailed industry level data on all the above mentioned indicators along with intermediate inputs – material, energy and services.

Aggregate value added, and aggregate investment by asset types (except ICT assets, which are discussed separately) are obtained from National Accounts, and aggregate employment are constructed from NSSO surveys on employment and unemployment (EUS) using a broader usual principal and subsidiary status (UPSS) definition. The labor composition index

¹⁶ For simplicity, we suppress the asset subscript and labor quality term.

¹⁷ These input weights are industry share of capital and labor compensation in aggregate value added, and the TFPG weight is the industry output share in aggregate value added.

¹⁸ A first version of the India-KLEMS database is now available at the Reserve Bank of India website http://www.rbi.org.in/scripts/BS_PressReleaseDisplay.aspx?prid=31390

has been constructed using five education categories namely- up to primary school, primary school, middle school, secondary & higher secondary school, and above higher secondary school, using data taken from the EUS.

Current price value added at industry level is taken from National Accounts whenever available. For sectors for which NAS data was not available, sectoral value added data are constructed using industry distribution from Annual Survey of Industries (ASI) for splitting the formal sector and distribution from NSSO Surveys on unorganized manufacturing for informal manufacturing sector. Gross output estimates for sectors agriculture, hunting, forestry and fishing, mining and quarrying, construction and manufacturing sectors are obtained from National Accounts. For splitting some sectors within the manufacturing, as in the case of value added, additional information is used from ASI and NSSO. For non-manufacturing sectors, mainly service sectors, where there was no output information available from NAS, we use input–output transaction tables, which provides output and value added. The ratio of these two is applied to value added in NAS to obtain consistent estimates of gross output. We use the benchmark input output tables for the years 1978, 1983, 1989, 1993, 1998, 2003, and 2007 and for the intermediate years they are interpolated. Intermediate inputs in current prices are basically the difference between nominal output and value added. The commodity inputs going into the production process of output industries are aggregated into energy, material and service inputs. In this way, for each benchmark year, estimates are obtained for material, energy and service inputs used to produce output in different industries. The time series of input proportions for industries are compiled for the benchmark years and then linear interpolation is used to obtain the series for 1980–2011 at current prices. To generate a weighted price deflator for intermediate inputs –materials, energy and service inputs– for each industry, we use wholesale price indices with commodity weights from input–output tables. Real value added growth rates are obtained using a double deflation approach, exploiting data on real gross output and real intermediate inputs. Since the focus of this paper is on evaluating the impact of ICT on economic growth, we discuss the measurement of capital services in general with a focus on measurement of ICT for Indian economy in the next section.

4.1. Measuring ICT capital for Indian economy

All data on investment in non-ICT assets and software and their prices are based on the underlying data for the published series on Gross Fixed Capital Formation in the National Accounts Statistics. We measure capital services for the aggregate economy and by industries using Eq. (3) using investment data on 6 different asset types – construction, transport equipment, and non-ICT machinery, software, hardware and communication equipment. We obtained current and constant series of investment data for assets construction, transport equipment, machinery and software from CSO for a number of industries. As in the case of output and value added, for splitting industries within manufacturing sector we exploit industry and asset distribution of gross fixed capital formation from Annual Survey of Industries (ASI) covering the formal manufacturing sector, and the NSSO surveys on unorganized manufacturing. Even though we use multiple sources of data, our final estimates are fully consistent with the aggregate data obtained from the NAS. Sectoral and aggregate investment data are used to construct capital stock using perpetual inventory method, i.e.

$$K_{K,t} = K_{K,t-1} (1 - \delta_K) + I_{K,t-1} \quad (11)$$

where K_K is the capital stock in asset K , δ_K and I_K are respectively depreciation rate for and real investment in asset K , and the subscript t stands for year t . We assume depreciation rates of 8 percent for machinery, 2.5 percent for construction and 10 percent for transport equipment, which are derived assuming a double declining balance to the assumed life times of these assets in National Accounts. The rental price of capital $P_{K,k}$ in (4) is measured assuming an external rate of return (r)¹⁹, as

$$P_{K,k,t} = P_{I,k,t-1} r + P_{I,k,t} \delta_K \quad (12)$$

where the external rate of return, r , is represented by a long-run average of real bond rate and market interest rate, obtained from Reserve Bank of India.

While information on non-ICT assets was easily available from NAS, there is no official data on complete ICT investment series, covering hardware, software and communication equipment in India yet. Therefore, we had to estimate a series of ICT investment for Indian economy compiling various sources of information, and it may be noted that these estimates still leave substantial room for improvement. Moreover, for the purpose of the present paper, we estimate ICT series only for the aggregate economy and aggregate manufacturing sector, as the data at detailed sectoral level requires further refinement.

The available information on ICT investment in India include software investment from NAS since 1999–00,²⁰ ASI's ICT investment series in organized manufacturing sectors since 1998, NSSO 62nd round data on ICT investment in unorganized manufacturing, CMIE's PROWESS firm level data on gross fixed assets in hardware, software and communication equipment (1989 onwards) and World Information Technology and Services Alliance's (WITSA)²¹ estimates on ICT spending by broad sectors of the economy since 2000. We make use of all these information in our ICT investment estimates along with investment data available by commodities in input–output tables.

¹⁹ See Erumban (2008) for a discussion on the empirical implications of using internal and external rates of return in rental price calculations.

²⁰ Adopting the suggestions of 1993 System of National Accounts (SNA), NAS has included software in its capital formation data. However, it does not include own-account software.

²¹ WITSA provides ICT spending data in a cross section of countries through their Digital Planet Report. See <http://www.witsa.org/>.

It may be noted that there have been attempts in the past to estimate ICT investment in Indian economy. For instance [Jorgenson and Vu \(2005\)](#) have estimated ICT investment for aggregate economy in a cross-section of countries, including India. They apply United States' ICT investment to ICT spending ratio to WITSA ICT spending data for India, to obtain aggregate economy ICT investment. However, this approach may produce a severe bias in the estimated investment. For instance, as argued by [De Vries et al. \(2010\)](#) it might overestimate the actual ICT investment in developing countries, as the investment/spending ratio in developing countries might be lower than that of the United States. On the other hand, it is also possible that most of the ICT spending in developing countries is in the form of investment, as consumption spending on ICT in low income countries would be relatively low compared to the US. Therefore, this approach might underestimate the volume of ICT investment in developing countries. In any case, the use of US investment to spending ratio to impute investment in India does not seem to be appropriate. Our approach to estimate ICT investment by asset type is detailed below.

4.1.1. Software investment

National Accounts Statistics provides software investment by different undertakings covering administrative departments, autonomous bodies, cooperatives, departmental enterprises, household sector, non-departmental enterprises, private corporate sector and public administration, since 1999. We have obtained this data by industries from CSO, and this has been the basic series we consider as the sacred set of software series for India. A comparison of CSO's software series with that of ICT spending data from WITSA suggests a substantial downward bias in WITSA software spending data. For instance, in 2008 WITSA software spending to GDP ratio is 0.12 percent, excluding consumer spending and 0.17 percent including consumer spending, whereas NAS software investment/GDP ratio from National Accounts is 1.2 percent.

For years before 1999, we extrapolate software series by applying software/hardware ratio to measured series of hardware investment (measurement of hardware series is discussed below). Here, we use three alternative approaches to derive time series of software/hardware ratio. The first is to keep software/hardware ratio from WITSA in 1999 as constant; the second is to use a linearly forecasted software/hardware ratio from WITSA; and the last and preferred series is to generate a series of software/hardware ratio using the trend in software/hardware ratio in the United States. The U.S data has been obtained from EU KLEMS ([O'Mahony and Timmer, 2009](#)). While this is still a rough assumption, it is better than assuming a constant or linearly growing software/hardware ratio for two reasons. The first is that the U.S, being the ICT leader, may provide a realistic picture of the required hardware/software ratio, particularly in the early years. And the second is that the trend in software/hardware ratio for the U.S during 2000–2007 moves in the same direction as that of the Indian data (the simple correlation between the two is 0.8).²²

4.1.2. Hardware investment

National Accounts, however, does not provide investment in hardware and communication separately from total machinery investment. To construct a series of software investment, once hardware data is available, [De Vries et al. \(2010\)](#) suggest using the elasticities of hardware to software investment, estimated using a fixed effect panel regression of software on hardware and a set of control variables. We follow this approach to derive hardware investment, but not using econometric techniques. We use software/hardware ratio from WITSA ICT spending data. While doing this, we exclude consumer spending. This ratio is applied to software series obtained from National Accounts, thus providing us a hardware series for 1999–2011. For years before 1999, hardware series is obtained using the trends in the hardware investment series arrived at using a commodity flow approach²³. In this approach, total economy investment in hardware and communication equipment can be estimated using the information on the total domestic availability of these goods and its investment component. This requires the use of input–output tables, in combination with NAS and trade statistics. We define the investment in ICT asset i as:

$$I_{i,t} = \left(\frac{I_{i,s}^{IO}}{Y_{i,s}^{IO} + IM_{i,s}^{IO} - EX_{i,s}^{IO}} \right) (Y_{i,t} + IM_{i,t} - EX_{i,t}) \quad (13)$$

where $I_{i,t}$ is the current investment, Y is the gross domestic output, IM is imports and EX is exports. Superscript IO refers to input–output tables, i.e. for instance, $I_{i,s}^{IO}$ indicates investment in asset type i (since we consider computer hardware and communication equipment, $i=1,2$, i.e. hardware and communication equipment) in years (where s is the benchmark year for IO table) obtained from input–output table. All other variables without the superscript IO are time-series data obtained from the NAS. Following the previous studies, we define industry 30 according to ISIC 3.1 (office equipment and machinery) as computer hardware and industry 32 (radio, TV and communication equipment) as communication equipment. There is no strict concordance between ISIC 3.1 and India's input–output table classification, and therefore, we consider the Indian IO sector office computing and accounting machinery as hardware, communication equipment and electronic equipment including TV as communication equipment. We obtain investment in hardware and communication equipment, along with total domestic output, imports and exports for 6 benchmark years, 1983, 1989, 1993, 1998, 2003 and 2007 from input–output tables published by the Central Statistical Organization (CSO). This information is used to compute the first part of Eq. (13). Then, using time-series data on gross output obtained from

²² The impact of this choice on our final results was, however, trivial.

²³ See [De Vries et al. \(2010\)](#) and [Timmer and van Ark \(2005\)](#) for a good description of the commodity flow approach.

Fig. 4. Composition of ICT investment in Indian economy (average shares in current ICT investment).
Source: Author's calculation (see text).

National Accounts and exports and imports obtained from UN-Comtrade statistics, we construct a series of hardware investment using Eq. (13).

As mentioned before, to extrapolate hardware investment series backward we apply the trend in the obtained hardware series to hardware investment in 1999 obtained using software/hardware ratio from WITSA applied to software data from NAS. Alternatively, one could directly take the series generated using commodity flow approach for the entire period. However, we opted not to do so, because, the industry concordances are not at the maximum precision, particularly for IO tables after 2003.

4.1.3. Communication equipment

For the communication equipment series, we could directly take the series from IOT table, because the industry description was quite consistent and clear. We use the IOTT based series derived using commodity flow approach (see Eq. 13). This way, we have a complete series of ICT investment for the aggregate economy. This approach allows us to generate investment series only for total economy, as an industry break-down is not possible with input–output table.

The distribution of ICT investment in terms software, hardware and communication equipment during the period of analysis 1986–2011 are depicted in Fig. 4. Even though India's software sector has been dominating in its ICT exports, the share of software in aggregate economy ICT investment stayed at about 1/3rd on average since the 1990s, with very little variation. Software share did show a drastic increase during the early 1990s, whereas the share of communication investment witnessed a decline. In general, hardware investment dominated, though its share has declined over time. During 2006–2011 period, both software and communication equipment contributed each 31 percent of total ICT investment, whereas hardware contributed about 38 percent.

4.1.4. ICT investment in manufacturing

For sub-sectors of the economy the construction of ICT series was even more challenging, and therefore, we attempted this only for the aggregate manufacturing sector. For the registered manufacturing, we obtained a series on gross additions to fixed capital in ICT equipment from the Annual Survey of Industries since 1993. We apply the share of gross additions to fixed capital in ICT equipment in total gross additions to fixed capital from the ASI, to gross fixed capital formation data in registered manufacturing obtained from the National Accounts. For unregistered manufacturing, we obtained a series on ICT equipment in 2005–2006. Both these series, however, do not distinguish between hardware, software and communication. Rather they provide total ICT equipment including software. Moreover, this data is available only since 1993, and for years before 1993, they are extrapolated using forecasted share of manufacturing in total ICT, where the shares are obtained using a linear regression of manufacturing share on total ICT investment during 1993–2011. Therefore, our results for manufacturing in the pre-1990 period are relatively less reliable.

4.1.5. ICT prices and depreciation

Price measurement for ICT assets has been an important research topic in the literature, as the quality of ICT capital goods has been rapidly increasing. The use of a single harmonized deflator across countries was widely advocated and used (Schreyer, 2002; Timmer & van Ark, 2005). We use the harmonization procedure suggested by Schreyer (2002), where the US hedonic deflators are adjusted for India's domestic inflation rates. The estimated investment series are deflated using ICT price deflators obtained using this harmonization procedure.

Following Jorgenson and Vu (2005), we assume 31.5 percent depreciation rate for hardware and software and 11.5 percent for communication equipment. ICT capital stock is then obtained using (11), and the measured capital stock in machinery and equipment is adjusted to obtain non-ICT equipment by subtracting the measured hardware and communication stock.

Table 1

Sectoral contribution to value added growth.

	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
Aggregate production function					
Aggregate value added growth	5.7	4.9	6.1	6.6	8.3
Aggregate production possibility frontier					
Aggregate value added growth	5.8	5.1	6.4	6.6	7.8
Contribution from:					
ICT sectors	1.5	1.9	2.5	2.6	2.8
ICT producing sectors	0.2	0.2	0.4	0.5	0.4
ICT using manufacturing	0.3	0.4	0.0	0.4	0.4
ICT using services	1.0	1.3	2.1	1.7	2.0
Non-ICT sectors	3.6	2.8	2.9	3.4	4.3
Non-ICT manufacturing	0.9	0.7	0.4	0.4	1.4
Non-ICT services	1.1	1.2	1.2	1.5	1.5
Non-ICT others	1.7	0.9	1.3	1.5	1.4
Non-market services	0.7	0.4	1.0	0.6	0.7
Reallocation	–0.1	–0.2	–0.3	0.0	0.5

Note: All growth rates are average annual log differences. The sectoral contribution to aggregate GDP growth rates are sectoral value added growth rate multiplied by their average share in aggregate value added. Source: Authors' calculation using India KLEMS database.

5. ICT and aggregate economic growth

5.1. Contribution of ICT sectors to aggregate value added growth

In Table 1, we provide the growth rates of aggregate value added for the period 1985–2011. The entire 25 years period is subdivided into five sub-periods each consisting 5 years. These periods roughly match with various episodes of economic reforms in India, say the partial liberalization of the mid-1980s, liberalization policies following the balance of payment (BoP) crisis in the early 1990s, and subsequent episodes of further added reforms in the mid-1990s and 2000s. The aggregate economic growth is decomposed into contributions from ICT and non-ICT sectors, where the respective contributions are obtained by weighing sectoral value added growth rates obtained at 2 digit industry level (see Table A1) by their relative size in the aggregate economy. Following van Ark et al. (2003), we classify industries as ICT producing sectors, ICT using manufacturing, ICT using services and non-ICT sectors (see Appendix Table 1). In order to arrive at these classifications, we also examined available information on ICT intensity in various sectors, such as the share of ICT in gross fixed assets in 2 digit industries available from firm level data from CMIE's PROWESS. Our classification of ICT producing sectors is to a large extent in line with the classifications used by CSO (2010), though we had to use a higher aggregation in the case of some sectors due to lack of detailed data. The last row in Table 1 provides the value added reallocation term. The share of ICT sector in total GDP has increased from 21 percent during 1986–1990 period to 27 percent during 2006–2011 period, with the ICT using services sector expanding relatively faster from 15 percent to 21 percent (see Table A2).

During the period 1991–1995 Indian economy witnessed a deceleration in economic growth compared to the mid-1980s, following the BoP crisis. Even though many reforms were initiated during this period they were not paying off immediately, and it is known that the effect of such structural reforms often start paying off only with a time lag. The interesting part, however, is that the ICT sector did not show a deceleration in its contribution to aggregate growth during 1991–1995 period, rather it witnessed a marginal increase by 0.4 percentage point, whereas the overall economy decelerated by 0.7 percentage point. The deceleration in the overall economy was driven primarily by a decline of the non-ICT segments of the economy from 3.6 percent during 1986–1990 to 2.8 percent during the period 1991–1995. Non-market services also witnessed a drop in their growth rate, further contributing to the decline of the aggregate economy. Even though the increase in ICT sectors is visible in all segments of ICT sectors, it is more prominent in ICT using services. Reallocation effect was negative in both the second half of 1980s and first half of the 1990s, indicating that growth was concentrated in sectors with relatively low share in aggregate value added.

During the second half of the 1990s, reforms started gradually paying off. The economy improved its average annual growth rate by about 1.3 percentage point from 5.1 percent to 6.4 percent. This was also the period of IT expansion in the Indian economy, as many software businesses started flourishing. Moreover, the use of ICT in other sectors also started increasing in the 1990s, as facilitated by the external liberalization along with the massive declines in ICT prices. ICT sector contributed about 38 percent of aggregate value added growth, registering an increase in its contribution from 1.9 percent to 2.5 percent, with the largest increase again being in ICT using services. Non-ICT sectors also have witnessed an increase, except the non-ICT manufacturing, even though the pace of increase was slower than the ICT sectors. Reallocation term stayed to be negative during this period as well.

In the first half of 2000s, the economy witnessed further, though moderate, improvement in GDP growth from 6.4 percent to 6.6 percent. This modest improvement was emanated from a 0.1 percent point increase in ICT sector contribution

Table 2

Sectoral contribution to value added growth, alternative grouping of ICT sectors.
Source: Authors' calculation using India KLEMS database.

	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
ICT producing sectors (excl. 30–33)	0.03	0.13	0.28	0.37	0.35
ICT using manufacturing (incl. 30–33)	0.47	0.40	0.10	0.53	0.45
Difference B – A					
ICT producing sectors	–0.16	–0.04	–0.07	–0.15	–0.05
ICT using manufacturing	0.16	0.04	0.07	0.15	0.05

Note: ICT producing sector in this table excludes industries 30 to 33, whereas in Table 5, it is included in ICT using manufacturing (see text).

and nearly half a percentage point from non-ICT sectors. While the contribution of ICT producing sector and ICT using manufacturing improved marginally, the contribution of ICT using services did decline. The contribution of non-market services also declined, and there was no value added reallocation during this period.

During 2006–2011, the period when the world witnessed the 2008 global financial crisis, Indian economy did see an increase in GDP growth, at 7.8 percent per annum. The largest improvement in this period was contributed by the non-ICT sectors, and in particular non-ICT manufacturing. This, perhaps, is a reflection of India's insulation from the global economy in its manufacturing sector – exports in particular –, while its service sector is more globally integrated.²⁴ However, ICT sectors also added to this growth improvement, by contributing almost 35 percent of total GDP growth. While ICT sector contribution improved from 2.6 percent point to 2.8 percent point, non-ICT sector improved from 3.4 percent to 4.3 percent, and more importantly, the reallocation term turned out to be positive at 0.5 percentage point.

It may be noted that due to non-availability of separate data on factor inputs and output in India KLEMS, we had to consider industries 30–33 (as per ISIC revision 3.1), i.e. office, accounting and computing machinery (30), electrical machinery and apparatus n.e.c. (31), radio, television and communication equipment (32) and medical, precision and optical instruments, watches and clocks (33) as a single cohort. As can be seen from Table A1, this group of industries is kept under ICT producing manufacturing in our industry grouping. However, it is likely that only office, accounting and computing machinery, and radio, television and communication equipment consist of industries that are ICT producing, while the other industries are more of ICT users.²⁵ According to the ASI data, the combined size of industries 30 and 32 is only one-third of the value added of the entire industry group, and the share of office, accounting and computing machinery is as small as 5 percent. Therefore, the grouping of the entire industry group as ICT producing sector might overstate the contribution of ICT producing sector to total value added and TFPG.

Indeed, this adds a caveat to our empirical analysis of relative contribution of ICT using and ICT producing sectors. However, given that the sector is clearly an ICT-intensive one –either in terms of use or produce – it is still worth including it in the ICT sector. In addition, to understand the quantitative impact of attributing this sector to ICT producing sector, we also considered the other extreme (i.e. attributing it entirely to ICT using sector). The results are presented in Table 2, which suggests an increase (decline) of contribution from ICT using (producing) sectors to aggregate value added growth by 0.1 percentage point in all sub-periods, except during 1991–1995, during which it declined by less than 0.05 percentage point. In relative terms, this implies a decline in the contribution of ICT producing sectors by more than 1.7 percent during 1986–1990 and 2001–2005 period, and by nearly 1 percent during the other sub-periods. Indeed, it does overstate the contribution of ICT producing sectors, but the contribution of ICT sector remains unchanged.

5.2. Computer and related services and aggregate value added growth

In Fig. 5, we provide the size and growth of the computer related services since 2005. Since the data is not available for this sector for earlier years, we do not have a longer. As is evident from the Figure, the share of computer related services sector in aggregate GDP has increased from just about 1.2 percent in 2000 to 3.5 percent in 2012, which was accomplished by high growth rates in the pre-global financial crisis periods. Even though the growth rate declined during the crisis years, it is picking up again. On average, during 2001–2005 period, the sector witnessed a growth rate of about 21 percent, which declined to 12 percent during 2006–2012 period. However, given the increase in GDP share, its contribution to aggregate GDP growth remained at about 0.4 percentage point throughout the period (constituting approximately 5 percent of total growth).

Clearly, the role of ICT sector, both producing and using, in driving aggregate economic growth has improved over time. Except from a setback in the recent period, that also include the years of global financial crisis, the relative role of ICT sector has improved over time. The total ICT sector contributed a quarter (1.5 out of 5.7 percent) of total growth in the mid-1980s

²⁴ Export of commercial services from India constitutes 3.3 percent of global export, whereas its merchandise export is 2.5 percent. Import of services also shows a slight dominance over merchandise imports, by less than half a percentage point (WTO, 2013).

²⁵ This issue warrants further attention, and calls for more industry details in the India KLEMS database, so that future research will be able to measure the contribution of ICT producing manufacturing more precisely. We are thankful to one of the referees for pointing out this limitation of the paper.

Fig. 5. Size and growth of computer related services, 2001–2012.

Source: National Accounts Statistics.

Table 3

Decomposition of aggregate GDP Growth into contribution from factor inputs and total factor productivity growth (aggregate production possibility frontier).

Source: Authors' calculation using India KLEMS database.

	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
Value added	5.8	5.1	6.4	6.6	7.8
Capital input	3.6	3.8	4.0	4.2	5.6
ICT Capital	0.5	1.0	0.9	0.6	1.4
non-ICT Capital	3.0	2.8	3.1	3.6	4.2
Labor input	1.6	1.5	1.1	1.6	0.9
Employment	0.9	0.8	0.6	1.0	0.2
Labor composition	0.7	0.6	0.5	0.6	0.7
Total factor productivity	0.7	–0.2	1.2	0.8	1.3

Note: All growth rates are average annual log differences.

which reached near to 40 percent (2.6 out of 6.6 percent) during 2001–2005. ICT producing sector improved their relative contribution from 2.6 percent to about 7 percent during 2001–2005, whereas the non-ICT sector lost it from 64 percent to 50 percent. As we mentioned before, our definition of ICT sectors is restrictive, and if we were able to treat software services as part of our ICT definition, which is now buried elsewhere due to lack of separate data on growth accounting variables, the impact would have been larger. For instance, as we see from Fig. 5, computer related services add another 0.4 percentage point contribution to aggregate GDP growth during the period 2006–2011. As can be seen from Fig. 2 the share of computer related services in GDP has been higher and increasing compared to that of ICT manufacturing and communication services.

5.3. Contribution ICT capital and TFP to aggregate value added growth

Decomposition of aggregate GDP growth into factor input contributions and TFPG (Table 3) suggests that the TFP growth during the period 1991–1995 was negative, and has in fact decelerated from half a percentage during 1986–1990 period. This is not surprising given the turbulence Indian economy has been witnessing during the early 1990s. TFPG improved to 1.2 percent during 1996–2000, though declined to 0.8 percent during 2001–2005 period. It regained during 2006–2011 period, registering about 1.3 percent per annum. Yet, in general, productivity growth in Indian economy has been quite lower. According to the Conference Board Total Economy Database (TED), India's TFPG during this period turned out to be 1–4 percentage lower than that of China, and in general Chinese TFPG has been quite high compared to India during its fast growing period of 2000s. A number of factors might be playing a role here, among which a major one is the large share of informal sector in the Indian economy, which might drag down aggregate productivity substantially. A recent study by de Vries, Erumban, Timmer, Voskoboynikov, and Wu (2012), for instance, observe that increasing informalization has resulted in a growth-reducing structural transformation in India, whereas formalization has helped attain a growth acceleration in Brazilian productivity. Added to this is the rigidity in the (formal) labor market that restricts expansion of, particularly, formal manufacturing sector, and several supply side constraints including weak infrastructure. It has been shown that in order to maintain cost-competitiveness, formal firms sub-contract activities to informal sector, where they can benefit from the labor market flexibility (Siggel, 2010; Mazumdar & Sarkar, 2008; Ramaswamy, 1999). However, even such sub-contracting helps creation of only a few jobs in the modern segments of the informal sector, while the traditional informal sectors are least benefitted (Moreno-Monroy, Pieters, & Erumban, 2014). The use of ICT and the possible productivity effects

Table 4

Decomposition of aggregate labor productivity, aggregate production possibility frontier

Source: Authors' calculation using India KLEMS database.

	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
Labor productivity	3.8	3.2	5.1	4.2	7.3
Capital deepening	2.5	2.7	3.3	2.8	5.3
ICT Capital deepening	0.5	0.9	0.9	0.5	1.3
Non-ICT Capital deepening	2.0	1.8	2.4	2.3	4.0
Labor composition	0.7	0.6	0.5	0.6	0.7
Total factor productivity	0.7	−0.2	1.2	0.8	1.3

Notes: Aggregate labor productivity growth rates are growth rates of aggregate economy GDP per worker. All growth rates are average of annual log differences.

may also largely be limited to the formal segments of the economy. In general, our TFPG estimates would be lower than aggregate TFPG estimates in several previous studies, because we also account for asset composition of capital, including hardware, software and communication (i.e. ICT) and education composition of workers, which were otherwise buried in the TFPG estimates.

Economic growth in India has been primarily driven by capital investment, similar to what has been shown in the case of East Asian economies in the past (Young, 1995; Krugman, 1994). During the 1980s, out of 5.7 percent growth rate, 3.6 percent came from capital services, and only a half percentage point of it is from ICT capital, while the remaining 3 percent was from non-ICT capital, which includes construction. Even though the dominance of non-ICT capital was maintained throughout, the role of ICT investment in driving aggregate growth has increased substantially from just half a percentage during 1986–1990 to 1.4 percent during 2006–2011. It constituted 10 percent of total GDP growth during 1986–90, which went up to 20 percent during 1991–1995 period. Except from a decline to 9 percent during 2001–2005, the relative contribution of ICT to GDP growth stayed at a maximum of 15 percent of aggregate GDP growth. A comparison of role of ICT in India's economic growth with earlier studies such as Jorgenson and Vu (2011, 2013) and The Conference Board Total Economy Database, shows that our results are higher than these estimates. This is quite possible, given the higher estimates of software investment in National Accounts, as against the WITSA estimates, which form the basis of the data in these studies.

The employment contribution to GDP growth has hovered around 1–1.6 percent. Moreover, it declined consistently over time, except for a surge in 2001–2005 period, during which employment contribution increased. Labor quality contributions to value added growth stayed about a half percentage point to GDP growth. Indeed, India has large demographic dividend, which can be translated into economic growth only if the country invests in advancing its human capital, focusing both on quality of and accessibility to education.

A decomposition of labor productivity growth is more interesting, as labor productivity mirrors both efficiency as well as standard of living. As shown in Eq. (7) labor productivity growth can be decomposed into the intensity of capital use per worker, and overall efficiency in the use of labor and capital inputs – the TFPG. In Table 4, we provide the decomposition of aggregate labor productivity, measured as value added per worker, into contribution of capital deepening (capital per worker), labor quality and TFPG. It is evident that the capital deepening has been increasingly contributing to aggregate labor productivity growth. It has increased consistently from 2.5 percent during the period 1986–1990 to 5.3 percent during the period 2006–2011. Even though non-ICT capital has been dominating, which is not surprising given the high share of construction and machinery assets in the total investment basket, ICT capital deepening has also improved over years. The contribution of ICT capital deepening to aggregate labor productivity growth has increased from just half a percentage during 1986–1990 to 1.3 percent during 2006–2011. In relative terms the contribution of ICT capital deepening increased from 14 percent in the mid-1980s to 18 percent in the late 2000s, and it went even close to 30 percent during the early 1990s.

Thus, while productivity growth only played a subordinate role, investment in information and communication technology has been equally important in driving aggregate growth in India in the post-liberalization period. Whereas the relative contribution of ICT capital to output and labor productivity growth has increased over time, the spillover effect via improved TFPG seem to be less visible, as the TFPG has improved only at a very lower rate.²⁶ It is imperative to note in this context that existing micro level evidence based on plant or firm level data is suggestive of a positive impact of ICT on growth and productivity in India's organized manufacturing sector. For instance, Sharma and Singh (2012) observe that higher ICT stock is associated with higher levels of value added, and they reiterate that the use of ICT has the potential to influence manufacturing performance positively (also see Kite, 2012, 2013a, 2013b). Similar conclusions have been made by Joseph and Abraham (2007), who observe a positive effect of ICT investment intensity on both labor productivity and TFP,

²⁶ A simple regression of TFPG on ICT capital stock suggests a significant positive elasticity of 0.35 suggesting a 1 percent increase in ICT capital can improve TFPG by about 0.35 percentage point, while the elasticity of aggregate capital stock, including non-ICT, is 1.1, suggesting an even faster increase in TFPG. In both cases, the R^2 is about 0.12. While this might be indicative of a lower ICT spillover effect the sheer magnitude of this effect should be evaluated using appropriate econometric approach, which is beyond the scope of the present paper.

Table 5

Decomposition of aggregate manufacturing growth into contribution from factor inputs and total factor productivity growth, production possibility frontier.

Source: Authors' calculation using India KLEMS database.

	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
Value added	8.4	7.0	2.9	6.1	12.3
Capital input	4.3	5.4	6.1	4.4	6.6
ICT Capital	0.3	0.5	0.3	0.4	0.4
Non-ICT Capital	4.0	4.9	5.8	4.0	6.1
Labor input	1.2	1.1	1.0	1.2	0.6
Employment	0.8	0.7	0.7	0.9	0.3
Labor composition	0.4	0.4	0.3	0.3	0.3
Total factor productivity	2.9	0.5	–4.2	0.5	5.2

All growth rates are average annual log differences.

even though the ICT intensity in the sector is low. In addition to finding a positive ICT effect on productivity, [Kite \(2012, 2013a, 2013b\)](#) observe that the use of outsourced ICT makes larger contribution than in-house ICT.

6. ICT and manufacturing growth

Using the growth accounting we also decomposed the aggregate manufacturing value added growth into contributions from ICT capital, non-ICT capital, labor input and productivity. In [Table 5](#), we provide the value added decomposition results for aggregate manufacturing sector. In this case, we do not distinguish between hardware, software and communication equipment, rather treat ICT equipment as a single asset as we had no separate information available on each of these assets. Since the depreciation rates and asset prices differ between software and hardware, treating them as a single asset may affect the relative weights of these assets in the aggregate ICT capital. To tackle this issue partially, we used a weighted depreciation rate of these three assets, derived from the aggregate economy. Also note that the results for manufacturing here are not strictly comparable with some earlier studies on Indian manufacturing. In addition to the methodological differences, the results here are for the total manufacturing, which includes both registered (formal) and unregistered (informal) segments, while earlier works are mostly confined only to the registered manufacturing. It may also be noted that, though ideally one would have preferred to use a weighted growth rate of industry inputs and output to obtain aggregated manufacturing growth rates (Tornqvist), the results here are based on simple aggregation of sectoral value added and inputs, necessitated by the lack of sectoral ICT data. Therefore, the analysis is similar to our aggregate production function approach in the previous section.

Value added in India's manufacturing sector grew at an annual average rate of about 8 percent during 1986–1995 period, and it declined drastically to below 3 percent during the second half of the 1990s. The manufacturing sector started picking up again in 2000s, registering 6.1 percent growth during 2001–2005 and further 12.3 percent during 2006–2011. However, almost all growth in the sector was attained via factor accumulation and productivity growth has been quite negligible. Except for 2006–2011 period manufacturing productivity growth has been quite low, even negative during 1996–2000 period. The liberal reforms in the 1990s were mostly aimed at improving the competitiveness and productivity in the manufacturing sector. However, the weak productivity performance clearly is reflective of many supply side bottlenecks the sector witnesses even today. Despite these, the reforms seem to be paying off, as the productivity growth is improving, particularly since the mid-2000s.

Whereas most of the value added growth has been driven by non-ICT capital investment, ICT capital stayed around 0.4 percentage point. It does not even show any improvement. Perhaps, the ICT surge might have been in the services industries, and the resulting productivity gain may have been happening in the services sector rather than in the manufacturing sector. For instance, [Verma \(2012\)](#) suggested a substantial productivity gain in services sector, which is growing more rapidly.

Even though the use of ICT has increased in some segments within the manufacturing, the overall diffusion is still quite limited, as ICT has not been given enough priority in many manufacturing firms in India ([Chandra & Sastry, 2002](#); [Chandra, 2009](#)). It has been argued that energy deficiency and financial constraints had an important role in hindering the diffusion of ICT in the manufacturing sector. The role of ICT in enhancing aggregate productivity may have been further constrained by the persistence of a large informal sector. Available statistics is suggestive of substantially lower ICT use in informal manufacturing sector compared to formal sector. More than 95 percent of enterprises and more than 85 percent of workers in Indian manufacturing are in the unorganized (informal) sector, while more than 95 percent of output is produced in the organized sector (based on data for 1999–2001 period from [Ray, 2004](#), as reported in [Kotwal, Ramaswami, & Wadhwa, 2011](#)). This story is not limited to manufacturing alone. [de Vries et al. \(2012\)](#) shows that more than 90 percent of workers are employed in the informal sector in the Indian economy. Even more staggering is that the average worker in the unorganized sector receives less than 10 percent of worker's wage in the organized sector. To a large extent the inability of Indian economy to climb the productivity ladder might be a result of its large informal sector, which is less efficient. And its ability to modernize by enjoying the fruits of liberalization by means of imported technology and adaption of ICT is constrained by, among others, extremely low credit availability to the unorganized sector (see for e.g. [Banerji & Duflo, 2004](#); [Kotwal et al., 2011](#)). Thus the Indian economy, in particular its manufacturing sector, still seems to have much potential to tap the benefits

Table 6

Sectoral contribution to aggregate total factor productivity growth.

Source: Authors' calculation using India KLEMS database.

Industry	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
Aggregate production possibility frontier					
Aggregate TFPG (with ICT split)	0.67	–0.20	1.22	0.77	1.33
Aggregate TFPG (without ICT split)	1.03	0.44	1.70	0.96	1.72
Contribution from:					
ICT sectors	0.18	0.37	0.88	0.78	0.72
ICT producing sectors	0.06	–0.01	0.16	0.37	0.25
ICT using manufacturing	0.06	0.14	–0.20	0.13	0.12
ICT using services	0.06	0.23	0.92	0.28	0.34
Non-ICT sectors	0.79	0.08	0.06	–0.50	0.13
Non-ICT manufacturing	0.29	–0.05	–0.53	–0.16	0.67
Non-ICT services	0.30	0.37	0.46	–0.08	–0.02
Non-ICT others	0.21	–0.24	0.13	–0.25	–0.52
Non-market services	0.14	0.04	0.44	–0.09	0.12
Capital reallocation	–0.25	–0.05	0.29	0.48	0.19
Labor reallocation	0.17	–0.02	0.02	0.27	0.55

Notes: All growth rates are average of annual log differences.

of its external oriented ICT sector, in enhancing ICT investment effect within the country. Moreover, the meager role of productivity obviously is a matter of concern for the sustainability of India's India's growth in the longer-run, as capital accumulation cannot be sustained if not productive, due to diminishing returns.

7. Industry origins of aggregate TFPG: the role of ICT sectors

To understand the indirect impact of ICT use on TFPG, we look into the industry origins of aggregate total factor productivity using Eq. (10). We decompose aggregate TFPG into contributions from 26 2-digit industries and factor reallocation effects. The sectoral contributions are then aggregated based on the role of ICT in different sectors.

The industry origins of aggregate TFPG are provided in Table 6. The table provides the contribution of various sectors, and the reallocation of capital and labor to aggregate productivity growth. However, these sectoral TFPG contributions and reallocation will not sum up to the aggregate TFPG reported in Tables 2 and 3, because the sectoral TFPG does not use the split of ICT and non-ICT capital due to lack of sectoral ICT data, while the aggregate TFPG does. In other words, the aggregate TFPG does not account for sectoral heterogeneity, whereas it accounts for asset heterogeneity (in terms of ICT and non-ICT). The implication would be that the aggregate TFPG in Tables 2 and 3 would be lower than the sum across sectors, as ICT contribution to growth is buried in the sectoral TFPG, and hence is added to the Domar weighted aggregate TFPG in Table 5. In addition, the sectoral TFPG's are obtained using a gross output function, and the aggregates obtained from them is basically a production possibility frontier aggregate, while the aggregate results in Tables 2 and 3 are based on direct aggregation. The difference between the sum of sectoral contributions and the aggregate TFPG obtained without splitting capital into ICT and non-ICT, thus being consistent with sectoral estimates, is the reported reallocation effect. Therefore, it reflects the reallocation of the aggregate capital input, and the reallocation effect could be different if ICT assets were treated separately at the sectoral level. Yet, these results are indicative of the relative roles of various sectors in driving aggregate productivity growth, and to see whether the use of ICT produces any spillover effect in terms of higher productivity growth in the ICT sectors.

Among the market sector industries, it is predominantly the ICT using services that are contributing largely to aggregate total factor productivity growth. This is particularly pronounced after 1995, where we see a remarkable increase in the relative importance of ICT using services in driving aggregate productivity. ICT producing sector also has improved their productivity contribution in the post reform period, particularly after 2000. ICT using manufacturing, however, does not show any substantial productivity gain, which is in conformity with our observation of low contribution of ICT capital in the manufacturing sector in general. In general, ICT sectors had improved their contribution to aggregate productivity growth, compared to non-ICT sectors. In the 1980s, ICT sector contributed only 0.18 percentage point to aggregate TFP growth, while non-ICT contributed about 0.79 percentage point. This has changed since the early 1990s, during which ICT sector increased its contribution to 0.37 point while non-ICT contribution declined to 0.08. The contribution of ICT sectors further increased to 0.88 during the mid-1990s. Though it declined marginally to 0.78 and to 0.72 in the subsequent periods, it remained higher than the non-ICT sectors. Thus, we clearly see a reviving role of ICT vs non-ICT sectors in driving aggregate productivity growth.

There is substantial difference in the quantitative magnitude of input reallocation effect over the different sub-periods. The effect of reallocation (of capital and labor combined) on aggregate TFPG during the 1990s was to pull down productivity by almost 0.08 percentage points. The reallocation term was positive only after the mid-1990s and was decisive in driving the aggregate productivity growth during the post-2000 period. When looked at the reallocation effects of capital and labor separately, we see that the capital reallocation term was negative in the mid-1980s and early 1990s, indicating that capital was moving to less productive sectors. This may indicate that during this period capital grew relatively slowly in industries

Table 7

Sectoral contribution to value added growth, alternative industry grouping.

Source: Authors' calculation using India KLEMS database.

	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
ICT producing sectors (excl. 30–33)	–0.02	0.02	0.14	0.26	0.27
ICT using manufacturing (incl. 30–33)	0.14	0.12	–0.18	0.24	0.10
Difference from Table 5					
ICT producing sectors	–0.08	0.03	–0.02	–0.11	0.02
ICT using manufacturing	0.08	–0.03	0.02	0.11	–0.02

Note: ICT producing sector in this table excludes industries 30–33, whereas in Table 5, it is included in ICT using manufacturing (see text).

with high capital productivity. However, in the post 1996 period, we see a positive capital reallocation. Labor on the other hand, shows a positive reallocation term throughout, except during the early 1990s, indicating a movement of labor from less productive to more productive sectors. This is also in accordance with the recent findings in [de Vries et al. \(2012\)](#) and [McMillan and Rodrik \(2011\)](#) when analyzing labor productivity.²⁷

As in the case of value added contributions in Tables 1 and 2, in order to quantify the impact of attributing industries 30–33 entirely to ICT producing manufacturing, we also computed the contribution of ICT using and ICT producing manufacturing to aggregate TFPG, by moving this sector from ICT producing category to ICT using category (see Table 7). The results suggests that when the industry is moved entirely into the ICT using sector, TFPG contribution from ICT producing sector declines within a range of 0.02 to 0.1 percentage point during 1986–1990, 1996–2000 and 2001–2005. In the other two periods, it increases by about 0.03 percentage point. In fact the contribution of ICT producing sector to overall TFP growth in the first half of the 1990s moves from negative to positive territory, whereas in the mid-1980s it turned negative. Thus, the inclusion of this entire sector in ICT producing segment causes both overestimation and underestimation of the sector's contribution to aggregate TFPG.

An important observation which is evident from the above analysis is that of an increasing role of both ICT using services and ICT producing industries in driving aggregate productivity growth in Indian economy. More importantly their relative contribution to aggregate TFPG has increased after the late 1990s.

8. Summary and concluding remarks

This paper is an attempt to document the role of ICT in driving economic growth in India by means of direct investment contribution and also indirect impact on productivity growth in ICT using and ICT producing sectors of the economy. We examine economic growth, labor productivity growth and total factor productivity growth (TFPG) along with contributions of ICT capital, non-ICT capital, employment and educational composition of workers during the period 1986–2011 using a carefully constructed national accounts consistent data – India KLEMS – on various indicators. While the present study is, perhaps, the first of its kind, it opens further avenues for future research, by improving the quality of data, in particular that of ICT investment in Indian economy.

An important finding of our study is the improving productivity in ICT using services, within the market services segment. It has been argued by previous researchers as well that services sector productivity has been driving growth in the Indian economy. Our industry origins approach further substantiates this finding, but with the added evidence of faster productivity contributions from ICT using services. Since the production of ICT goods is heavily concentrated in the advanced countries, where evidences also suggest the effect of ICT on manufacturing sector through ICT producing sectors, India seems to have benefitted more in ICT using sectors, which is predominantly the service sector. ICT producing sectors, which include telecommunication services, also show significant improvement in TFPG contribution. Capital accumulation has been the main driver of economic growth in India, and productivity growth has been generally weak, albeit marginal improvement in post-reforms period. The faster capital accumulation in the post-reform period might be a reflection of Schumpeterian creative destruction process ([Schumpeter, 1942](#)), where significant churning in the market in the form of replacement of many inefficient firms, and old capital by new. The contribution of ICT investment to aggregate output and productivity growth has improved over years. Yet, the ICT use and its productivity enhancing impact, particularly in the manufacturing sector, seem to be low. We do not have enough evidence on the role of ICT capital in ICT using and ICT producing sectors, however, it is quite likely that ICT investment in these sectors might be playing an important role, which is to be explored in the future research. However, evidently, ICT using and producing services have improved their

²⁷ However, [de Vries et al. \(2012\)](#) who study the structural transformation and its effect on growth in BRIC countries, also suggest that such a growth enhancing labor reallocation disappears, once accounted for the dualism in the Indian economy. When a distinction is made between formal and informal manufacturing sectors, the labor reallocation term is almost zero. Following this observation, if one assumes that the reallocation term is nearly zero, one may think that the ICT contribution to productivity growth is even larger than what is reported in Table 5. However, from our results, it is hard to make such a conclusion, as we see substantial difference between labor and capital reallocation effects. Even if we assume that the labor reallocation effects would disappear if informality is taken into account, as we see larger reallocation effect in capital particularly after 1996, it is difficult to make such a conclusion without a comprehensive attempt to underscore the impact of informality and the role of ICT capital at sectoral level.

productivity, even though Indian economy is yet to exploit the benefits of its export oriented ICT sector across the board. Indeed there is more potential for exploiting the benefits of ICT in Indian economy, and as argued by Kite (2013a, 2013b), ICT sector India, with export orientation, can definitely help Indian firms to improve their competitiveness in the world markets. Presumably, the existence of a large informal sector, which is featured by lack of credit availability on the one hand, and a flexible labor market on the other, limits both the ability and incentive to adopt ICT on a large scale. Appropriate policies that would help the arena of ICT use expand beyond the services is essential to tap the full benefit of ICT in India.

The Software services industry has been a driving force of India's ICT revolution, with it being one of the largest exporting segments. However, from the supply side analysis, this paper looked at the contribution of ICT investment to growth in the aggregate economy and manufacturing sector only. Future research should also focus on the specific impact of ICT within the software services producing sector in India by treating computer related and software services sector separately in the analysis. The current study was unable to examine the contribution of ICT investment to growth in this sector and also its TFPG due to lack of data. However, we observed that its direct contribution to aggregate GDP growth has improved. It is also likely that manufacturing firms are using ICT services from services sector firms, and the quantitative magnitude of this indirect contribution could be large (see Kite, 2012), which cannot be ignored. Finally, it may be noted that our distinction of ICT and non-ICT sectors, which is done at a high aggregate industry level, warrants further improvement, as more disaggregated industry level classification might provide a better and adequate distinction between the two.

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Appendix A

See Tables A1 and A2.

Table A1
Industries and industry groups.

	Industry	ISIC	Industry group
1	Agriculture, Hunting, Forestry and Fishing	AtB	non-ICT others
2	Mining and Quarrying	C	non-ICT others
3	Food Products, Beverages and Tobacco	15t16	non-ICT manufacturing
4	Textiles, Textile Products, Leather and Footwear	17t19	non-ICT manufacturing
5	Wood and Products of Wood (20)	20	non-ICT manufacturing
6	Pulp, Paper, Paper Products, Printing and Publishing	21t22	ICT using manufacturing
7	Coke, Refined Petroleum Products and Nuclear Fuel	23	non-ICT manufacturing
8	Chemicals and Chemical Products	24	non-ICT manufacturing
9	Rubber and Plastic Products	25	non-ICT manufacturing
10	Other Non-Metallic Mineral Products	26	non-ICT manufacturing
11	Basic Metals and Fabricated Metal Products	27t28	non-ICT manufacturing
12	Machinery, nec.	29	ICT using manufacturing
13	Electrical and Optical Equipment	30t33	ICT producing sectors
14	Transport Equipment	34t35	ICT using manufacturing
15	Manufacturing, nec. recycling	36t37	ICT using manufacturing
16	Electricity, Gas and Water Supply	E	non-ICT others
17	Construction	F	non-ICT others
18	Trade	G	ICT using services
19	Hotels and Restaurants	H	non-ICT services
20	Transport and Storage	60t63	non-ICT services
21	Post and Telecommunication	64	ICT producing sectors
22	Financial Services	J	ICT using services
23	Public Administration and Defense; Compulsory Social Security	L	Non-market services
24	Education	M	Non-market services
25	Health and Social Work	N	Non-market services
26	Other services	K+O+P	Non-ICT services

ICT sector classification are based on van Ark et al. (2003) but also considered the ICT/total fixed asset ratio from Centre for Monitoring Indian Economy's Prowess database, Gross Additions in ICT/Gross addition to total fixed capital from Central Statistical Organization's Annual Survey of Industries for organized manufacturing and ICT investment/total investment from National Sample Survey Organization's unorganized manufacturing survey.

Table A2

GDP share of ICT and non-ICT sectors (%).

	1986–1990	1991–1995	1996–2000	2001–2005	2006–2011
ICT producing sectors	1.8	2.1	2.2	2.4	2.3
ICT using manufacturing	3.8	3.6	3.5	3.1	3.4
ICT using services	15.1	16.5	18.3	20.0	21.1
Non-ICT manufacturing	11.6	11.8	12.0	11.1	11.0
Non-ICT services	17.6	17.3	17.2	19.2	20.3
Non-ICT others	40.0	38.7	35.7	32.4	30.8
Non-market services	10.1	10.1	11.1	11.8	11.2

Note: Industry classifications are based on Table A1 and therefore ICT producing sector includes industry 30to33 (electrical and optical equipment). See discussion in main text.

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