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Exploring Direct and Indirect Effects of Information and Communications Technology (ICT) Investment: Experience of the Indian Manufacturing Sector

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Abstract

The relationship between the introduction of information and communications technology (ICT) and improvements in the aggregate economic growth and industrial performance has been discussed in the previous literature. ICT is considered as a general purpose technology and an important element of infrastructure that has great implications not only for the advanced economies but also for developing countries in their industrial development and beyond. Due to the importance of externalities emerging from ICT investment and infrastructure, it is critical to understand whether such externalities affect the manufacturing sector in addition to its conventional role as a factor of production. Hence, this paper seeks to explore both the effects (direct and indirect) of ICT under its role as a factor of production and as a critical infrastructure on the performance of the Indian (registered) manufacturing sector using a panel of 22 industries over a period of 1999–2000 to 2007–2008.

Using an econometric analysis of the production function, this paper examines the effect of ICT capital on the output and labor productivity of the manufacturing sector and in the next stage, assesses the link between ICT infrastructure and the manufacturing sector's estimated total factor productivity (TFP). The study has found a significant effect of ICT capital, and the results also suggest the importance of ICT infrastructure in relation to the industrial performance of India. The residual-based co-integration tests also establish a linear relationship between the ICT infrastructure of India and the estimates of manufacturing sector's TFP.

Keywords: ICT capital; ICT infrastructure; Indian manufacturing sector; Production function; TFP; Externalities

1. Introduction

The importance of ICT investment has been analyzed for many advanced economies, particularly for the U.S. due to its rapid development of ICT producing industries, and the diffusion of ICT capital into the rest of the economy accompanied by major technological innovations and the decline in the prices of ICT related goods and services. According to Jalava and Pohjola (2002, 190), the defining

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characteristics of the ICT revolution are the fast improvement in the quality of ICT equipment including software vis-à-vis a sharp decline in the quality adjusted prices of ICT equipment. In highlighting the importance of ICT in the economic development, the role of ICT capital in improving productivity and economic growth has been discussed in the previous literature (see, for example, Jorgenson and Motohashi 2005; Kim 2002; Oliner and Sichel 2003; Jalava and Pohjola 2002), which mainly draws from the experiences of some of the advanced and newly industrialized economies such as the U.S., Finland, Japan, and South Korea. There is also some evidence of the rising importance of ICT investment and capital in the developing economies, since ICT has been regarded as one of the key technologies for industrial development. In the case of China, Heshmati and Yang (2006, 16–17) has shown that ICT has contributed significantly to the economic growth and TFP growth of the Chinese economy, particularly in the 1990s.

The main channels through which ICT affects output and labor productivity growth include, 1) ICT as a capital input; 2) total factor productivity (TFP) increase in the ICT producing sector; and 3) TFP increase associated with the spillover effects related to the usage of new technologies, particularly ICT (see, for example, Oliner and Sichel 2003, 477–503). In estimated production functions, ICT is linked to improved production of a firm, industry or economy through 'capital deepening' and TFP growth via change in capital quality (Dedrick, Gurbaxani, and Kraemer 2003, 5 & 20). These studies have highlighted the role of ICT as a capital input, the importance of ICT production, and particularly its wider usage.

In addition to its direct link to the production processes as a factor input, ICT also has an important element of infrastructure nature which can substantially augment industrial activities of a region. A number of benefits of ICT infrastructure lead to improvements in TFP at the industrial level. In particular, the network externalities emanating from ICT infrastructure make it highly relevant in industrial development. Here, externalities of ICT investment mean an effect of ICT investment beyond its usage as a factor of production; that is, the effect which is not internalized when investment in ICT is made at a firm level. These externalities, however, are captured at a sector/industry level by estimating the effect of aggregate ICT investment and ICT infrastructure on sector/industrial TFPs, since TFP performance is one of the important ways to understand the effect of externalities. One of the reasons for externalities to occur is the pervasiveness of ICT. According to Avgerou (1998, 4), ICT is characterized as the most *pervasive* technical innovation of the post WWII era, the pervasiveness of which affects almost all sectors of the economy. Moreover, there are externalities related to the size of ICT networks; in other words, an increase in network size generates network externalities[1] (Bedi 1999, 5). Hence, in addition to analyzing the role of ICT as a factor of production, this paper seeks to examine the importance of ICT infrastructure including aggregate manufacturing ICT investment, in exploring the direct and indirect impact of ICT on the Indian manufacturing sector.[2]

The remainder of this paper is organized as follows: The next section, Section 2, briefly discusses the previous literature. In Section 3, the source of the data and variable definitions are explained in detail. This is followed by Section 4 that estimates the direct and indirect effect of ICT investment on the Indian manufacturing sector. Sub-section 4.2 reports the first stage analysis in which the direct effect of ICT investment has been considered, while Sub-section 4.3 explores the indirect effect of ICT infrastructure through productivity analysis. The last section, Section 5 concludes the paper by considering ICT's potential as a technology that can drive the performance of the Indian manufacturing sector.

2. Literature Review

There is a growing body of literature that estimates ICT investment and its impact at the industrial level and that looks into particular industries. O'Mahony and Vecchi (2005), using dynamic panel data estimation approach, have established a positive and significant effect of ICT capital on the output growth of non-agricultural industrial sector for the U.S. and the U.K. Using production function econometric estimations for U.S. industries, Stiroh (2002, 11–22) also found positive and significant output elasticity of ICT capital, which corresponds to computer and communications equipment. The link between ICT investment and manufacturing sector's output and labor productivity in the Indian context has been analyzed by Joseph and Abraham (2008), who found out a positive and significant impact of ICT investment on both output and labor productivity of the Indian manufacturing sector for the period of 1998–99 to 2001–02. The results from the previous studies suggest the correlation between ICT capital and output and productivity performances at the industrial level.

Roller and Waverman (2001, 910), in analyzing the relationship between telecommunications infrastructure investment and economic growth of 21 OECD countries, proposed that telecommunications infrastructure creates externalities. In other words, it helps to reduce transaction costs and increase output for firms in various sectors of the economy. The telecommunications infrastructure is said to affect revenues and costs in more indirect ways than many other types of infrastructure investment, in that it increases the available information, and thereby increases the efficiency of commercial activity (Alleman et al. 2002, 3–3). In addition to telecommunications and internet, the aggregate stock of ICT capital also serves as an information infrastructure platform due to the network externalities it generates. According to Duggal *et al.* (2007, 486), the information infrastructure nature of ICT capital helps to reduce transaction costs and to increase organizational efficiency, which in turn becomes a source of TFP growth. The latent characteristic of network externalities – the more the users, the more value is derived by those users – differentiates this type of infrastructure from others, and provides opportunities for a firm to interact and communicate with others at a lower cost and more efficiently (Roller and Waverman 2001, 911).

Another important characteristic of ICT infrastructure is its public-private nature that requires it to take private aggregate ICT capital into account along with other telecommunications infrastructure. Duggal *et al*. (2007, 486) pointed out that, "....Even though much of the investment in the information sector is private, it depends strongly on public licensing, regulation, and support in being a 'common carrier' that serves industry and the population at large, just as infrastructure, in the broad sense, is supposed to do". According to the spillover effect of ICT, firms benefit not just from a private investment in an asset but also from a growth in the asset stock of all firms which may drive the increase in labor productivity via capital deepening, and may lead to TFP growth in a constant or increasing returns to scale (Dedrick, Gurbaxani, and Kraemer 2003, 20). Moreover, the importance of private ICT capital and the spillovers emerging from aggregate ICT investment available across the economy have also been discussed by Meijers (2007, 12–23) using the Barro model of spillovers (Barro 1999, 125–126). The network effect of ICT, which is made possible due to standardisation of the technology, has been the point of discussion in Meijers (2007, 8–9).

Based on the aforementioned literature on ICT infrastructure and the importance of private ICT investment due to its infrastructural nature, this paper incorporates aggregate ICT investment in the Indian manufacturing sector as a whole into the Indian ICT infrastructure analysis and its impact on the Indian manufacturing sector. In the case of India, there are a number of studies establishing the link between availability of different forms of infrastructure and its impact on the Indian manufacturing industries. In particular, Mitra *et al*. (2002, 406–415) did extensive work showing that the endowment of infrastructure at the state level is critical for the manufacturing sector in terms of TFP and technical efficiency (TE) improvement. Hulten *et al*. (2006, 299–303) did also show the positive externalities of public infrastructure and its impact on the productivity of the manufacturing industries across the states of India. There has been less focus on the ICT infrastructure other than the number of telephone lines, since the emergence of ICT infrastructure is relatively recent. In a recent study, Sharma and Sehgal (2010, 107–114) explored the impact of different types of infrastructure including ICT infrastructure on the Indian manufacturing sector. They found relatively weaker links of ICT infrastructure with the industrial performance. However, the growing importance of ICT infrastructure has been clearly demonstrated in the previous literature mentioned earlier.

3. Data and Methodology

3.1 Production Function

The data utilized for the first stage analysis is primarily collected from the Annual Survey of Industries (ASI), made available by the Central Statistics Office (CSO), a division of the Ministry of Statistics and Programme Implementation (MOSPI), the Government of India (GOI). The information on all the variables at the two digit level of sector disaggregation is used from the ASI dataset. The sample period of the data used for this study is from the fiscal year 1999–2000 to 2007–2008 (ending as on March 31st). The choice of this time frame relies heavily on the latest availability of data on all the variables, particularly on the (unpublished) ICT investment which has been used by the author to compute ICT capital at the two-digit level of sector disaggregation using the ASI data. The ICT and non-ICT capital is derived from the unit-level dataset and aggregated at the two-digit level so that it can be plugged into other variables made available by the CSO. The number of two-digit level industries utilized in this study is twenty two, all of which fall into the manufacturing sector category. The time series of the ASI data used for this analysis covers only the registered manufacturing sector.[3] All the variables are at the two digit level of sector disaggregation.

Variable names and definition:

Output (Y):

Output of all the industries is measured as the gross value added (GVA). Following ASI's definition, net value added and depreciation figures are added to compute the nominal GVA. The figures in nominal value have been deflated and converted into the constant figures. The deflators are taken from the Wholesale Price Index (WPI) of India with 1993–1994 as a base year. The two-digit level industry classification (as per the National Industrial Classification (NIC) 1998 of the Indian industry) is matched with the WPI commodity index and the suitable price index is utilized to deflate the figures. For industries where specific WPI index is not available, corresponding group index is taken as the second best choice.

Non-ICT capital (K^N):

Non-ICT capital is the type of capital that includes land, buildings, plant and machinery, transport equipment, and others. The annual figures of non-ICT capital are in nominal value. To calculate capital stock from the fixed assets, perpetual inventory method (PIM) in its simplest form is adopted. The time series of the non-ICT capital stock is calculated into two stages. In the first stage, the initial capital stock is computed for non-ICT assets. Due to the lack of detailed information on the investment pattern and detailed age structure of non-ICT and ICT assets by industry prior to 1998–1999, the initial capital stock for the year 1999–2000 for non-ICT assets is calculated following Goldar *et al*. (2003, 8–9). The gross fixed capital value (GFC) in 1999–2000 has been multiplied by 2 for firms in the Census category and by 1.5 for firms in the Sample category to get the replacement value of non-ICT assets.[4] This figure, being a nominal value, is converted into the real value by using WPI index for the category of 'Machinery & Machine Tools' with 1993–94 as a base year. In the second stage, annual gross fixed capital formation (GFCF) figure of the non-ICT assets is considered as nominal investment. This figure is then deflated by using the aforementioned category of 'Machinery & Machine tools'. The time series of the non-ICT capital stock is calculated as,

$$K_t = (1-d)K_{t-1} + I_t$$

where d is the annual (arithmetic) depreciation rate and I_t is the annual investment. The depreciation rate for non-ICT capital is taken as 5 per cent annually following Unel (2003, 18) and Joseph and Abraham (2008, 28).

ICT capital (K^I):

Here ICT capital is a category of investment in computer equipment including software. It does not include telecommunications equipment per se. The calculation of initial capital stock of ICT capital and time series of the same follow the steps and method same as for the non-ICT capital mentioned above. The nominal values of this type, both for the initial capital stock and annual investment figures, are deflated by using the WPI index of 'Computer & Computer Based System' taking 1993–94 as a base year. Moreover, the depreciation rate used for this category is 18 per cent[5] which is higher than three times that of the non-ICT capital. This rate is lower than the one suggested by advanced country studies which is 31.5 percent. The reason to use a lower rate is that though the physical decay of ICT capital is faster partly due to technological improvements and resulting falling relative prices of ICT goods, the productive stock of this asset for developing country case could last longer than the advanced country case due to some lag in technology dissemination.

Labor (L):

To calculate this variable, the number of employees by industry is taken as a proxy. This includes workers, and employees other than workers.

Time trend (T):

This variable is a time trend for each industry i.

3.2 ICT Infrastructure

The ICT infrastructure is composed of telecommunications, the internet, and the manufacturing sector's aggregate ICT capital stock following previous studies (see, for example, Duggal, Saltzman, and Klein 2007; Sharma and Sehgal 2010). The telecommunications and internet infrastructure correspond to 'access to telecommunications' and 'internet density', respectively in a narrower sense.[6] The 'access to telecommunications' related data is retrieved from the Compendium of Selected Indicators of Indian Economy (Government of India 2009a). The 'internet density' related data is collected from World Development Indicators (The World Bank n.d.), and the aggregate ICT capital is calculated using the ICT capital variable from the first stage analysis.

Variable names and definition:

Access to telecommunications (*Tele*):

The access to telecommunications is represented by the number of telephones (sum of fixed-lines plus wireless in millions). This is an annual time series for a period of 1999–00 to 2007–08, common for all the manufacturing industries.

Internet density (*Net*):

Internet density, that is, the number of users per 100 people is used as a proxy for internet infrastructure. These are the annual figures at the national level for a period of 1999–00 to 2007–08, common across the manufacturing industries.

Aggregate manufacturing ICT capital stock (*ICTCap*):

The aggregate ICT capital is the annual sum of ICT capital stock across the manufacturing industries. This is an approximation for the ICT environment and infrastructure available across the industries.

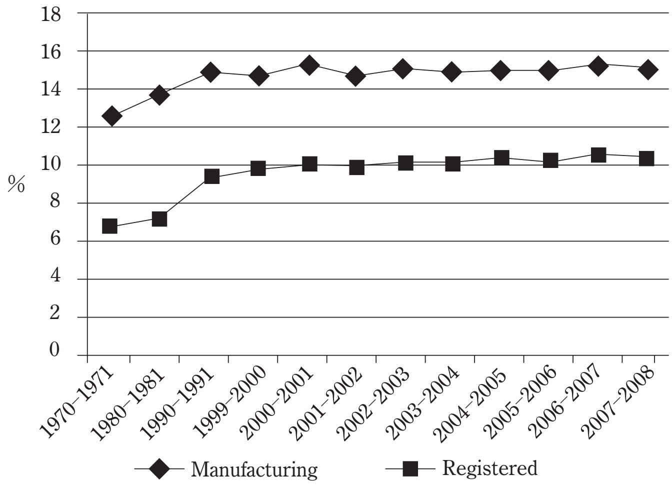
4. Estimating the Direct and Indirect Effect of ICT Investment on the Manufacturing Sector

4.1 Background of Estimation

The Indian manufacturing sector has experienced transformation since the 1980s and in particular in the 1990s, the period marked by the gradual industrial policy reforms and liberalization of the trade regime of 1990–91. The impact of trade liberalization and industrial policy reforms on the productivity of the manufacturing sector has been discussed in Goldar and Kumari (2003). The sector grew steadily and experienced a modest increase in its value added over the period in terms of the share it occupies in the gross domestic product (GDP) of the economy, as can be seen from Figure 1.

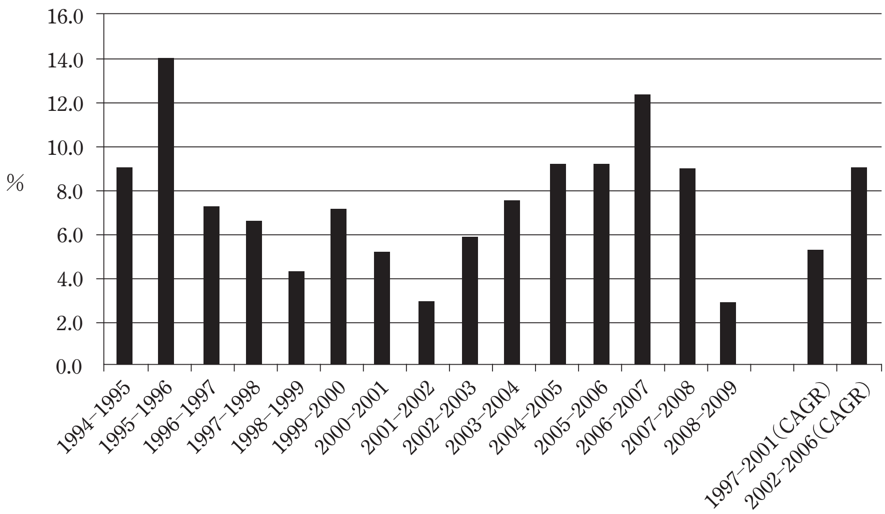
The manufacturing sector as a whole and the registered manufacturing sector both recorded a modest increase, as a percentage share of national GDP, from 12.6 and 6.7 percent in 1970–71 to 15.2 and 10.3 percent in 2007–08, respectively at 1999–2000 constant prices. It has been estimated at 15.9 and 10.7 percent in 2009–10 (at 2004–05 prices), respectively. Compared to the services sector which is estimated to have accounted for 57.2 percent (at 2004–05 prices) of the GDP, the share of manufacturing is very low and remained between 14–16 percent in the last decade. However, in terms of the annual growth rate (of the Index of Industrial Production (IIP)), the manufacturing sector witnessed two different trends those can be observed between two sub-periods, namely, 1997–2001 and 2002–2007. As can been seen from Figure 2, the period of 1997–2001 witnessed relatively low annual growth rate with a compound annual growth rate (CAGR) of 5.27 percent, whereas that of the

Figure 1 Percentage Share of GDP (at 1999–2000 prices)



Note: The figure is compiled by the author based on the data from the Compendium of Selected Indicators of Indian Economy (Government of India 2009a) and National Accounts Statistics (Government of India 2008b).

Figure 2 Manufacturing Sector's Annual Growth Rate (at 1993–94 prices)



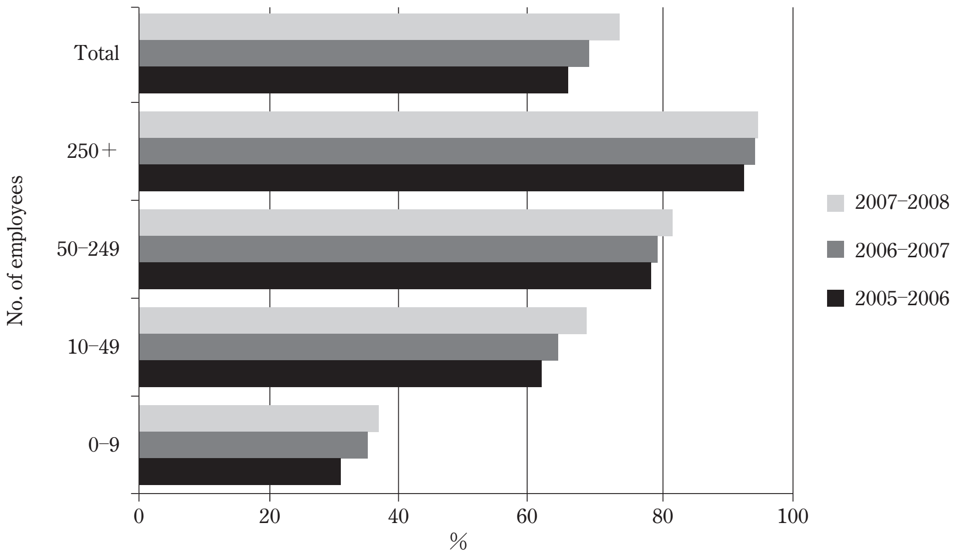
Note: The figure is compiled by the author based on Table 3.12 and Table 7.1.3. of the Handbook of Industrial Policy and Statistics (Government of India 2009b) and Planning Commission Eleventh Five Year Plan 2007–12 (Government of India 2008a), respectively.

period 2002–2006 was 8.82 percent (Government of India 2008a).

The annual growth rate declined to 2.9 percent in 2001–02 before it picked up again from 2002–03 to reach two-digit growth rate of 12.5 percent in 2006–07. There are numerous explanations behind this fall in the first sub-period. These include the Asian Financial Crisis of 1997–98, the fall in domestic demand due to low agricultural output, and the high interest rate (Sharma and Sehgal 2010, 103–104). Moreover, the deterioration in capacity utilization with the rise in investment activities and imports, though not in tandem with demand, caused slowdown in TFP growth in the 1990s, while the recovery was observed in the second sub-period due to a time lag in the manifestation of results of the reforms introduced in the 1990s (Goldar and Kumari 2003, 443).

The usage of computer has seen some increase in the Indian manufacturing sector during the past

Figure 3 Usage of Computer as per the Size of Manufacturing Enterprises



Note: The figure is compiled by the author based on information from Godavarkar and Malik (2010).

few years. Figure 3 shows the percentage of enterprises, under the manufacturing sector of India, using computers and their break down as per the number of employees. The information is available for a period of three years from 2005–06 to 2007–08. The break down of usage of computers, as per the size of enterprises in terms of number of employees, shows increasing usage of computers during the same perid. The number of enterprises, responding to the ASI survey question about computer usage for given three years, is 140160, 144710 and 146385, respectively.[7] The enterprises surveyed regarding the usage of computers fall under the ASI survey of Indian industry, the same source of the dataset used for the manufacturing sector in the first-stage analysis.

As can be seen from Figure 3, the number of enterprises using computer is increasing as a whole; moreover, the usage of computer is highest for enterprises with 250＋ employees followed by enterprises with 50–249 employees, whereas it is relatively low in the case of enterprises with 0–9 employees. This trend suggests that there is an increasing awareness of using ICT in the manufacturing sector, particularly as shown by the growing percentage of computer usage. Hence, this study seeks to analyze the effect of emerging ICT usage on the manufacturing sector.

4.2 First-stage: Estimating the Production Function

To estimate the direct effect of ICT investment on the Indian manufacturing sector, a production function approach is utilized. With this approach, the effect of ICT capital as a factor input will be estimated by adding it into the basic Cobb-Douglas production function of two factor inputs for the Indian manufacturing sector. Following Mitra *et al*. (2002, 401–403) and Sharma and Sehgal (2010, 104), a basic log-linear form of Cobb-Douglas production function is specified as,

$$\ln Y_{i,t} = \alpha + \alpha_1 \ln K^{N}_{i,t} + \alpha_2 \ln K^{I}_{i,t} + \alpha_3 \ln L_{i,t} + \alpha_4 T_i + \gamma_t + \varepsilon_{i,t} \qquad [1A]$$

where Y, K^N, and K^I are the output, non-ICT capital, and ICT capital, respectively in Indian rupees (INR) at 1993–94 constant prices. L is the labor input in numbers. T_i is the time trend specified for each industry i. The term γ_t is a fixed time effect. α_1, α_2, α_3 and α_4 are the parameters to be estimated common for all the industries. The subscripts i and t suggest industry at the two-digit level and time period, respectively. ln represents log form of the variables included. This model is estimated using both fixed and random effect estimators. However, the fixed (time) effect and random effect tests failed to reject the null hypothesis, suggesting applicability of a *pooled ordinary least squared* (OLS) technique.

In addition, the effect of ICT capital on labor productivity is estimated using the production function approach as utilized in the previous model.

$$\ln y_{i,t} = \alpha + \alpha_1 \ln k^{N}_{i,t} + \alpha_2 \ln k^{I}_{i,t} + \alpha_3 T_i + \gamma_t + \varepsilon_{i,t} \qquad [1B]$$

where y, k^N and k^I are the output per labor, non-ICT capital per labor and ICT capital per labor, respectively. The other variables and subscripts are similar to the previous model. In a similar way to the earlier analysis, this model is also estimated using both *fixed effect model* (*FEM*) and *random effect model* (*REM*) estimators, and the test supports the *REM*. However, the results of the *REM* estimation and that of the *pooled OLS* are not different. Hence, to avoid redundancy, only the results of the latter are reported alongside that of the Model [1A] in Table 1.

The estimates show that the coefficients of ICT capital are positive and significant in both the models. The other factor inputs, namely, non-ICT capital and labor in the case of first model and non-ICT capital per labor in the case of second model are also positive and significant. The coefficients of ICT capital and ICT capital per labor in Model [1A] and [1B] explain 13 percent and 26 percent of the variation in the dependent variable, respectively. The coefficient of the 'trend' is also positively significant, controlling for the common time trend affecting the dependent variable. Overall, the results under the poolability assumptions are indicative of the importance of ICT capital in its direct effect as a factor input. Moreover, due to the presence of heterogeneity in the form of different industry groups

Table 1 Effect of ICT Capital on Output and Labor Productivity: *Pooled OLS*

Model [1A] (Output): ln$Y$		Model [1B] (Labor productivity): ln (Y/L)	
Variables	Coefficients	Variables	Coefficientsln
lnK^{N}	0.539 *** (0.047)	lnk^{N}	0.449 *** (0.049)
lnK^{I}	0.127 * (0.072)	lnk^{I}	0.263 *** (0.067)
ln$L$	0.107 ** (0.051)	T	0.066 *** (0.013)
T	0.075 *** (0.013)	constant	3.232 *** (0.405)
constant	6.152 *** (0.888)		
F val.	238.27	F val.	162.43
Prob > F	0.000	Prob>F	0.000
R-sq.	0.823	R-sq.	0.679
Obs.	198	Obs.	198

Notes: Dependent Variable: ln$Y$ and ln$y$; *** denotes significance at 1%, ** at 5% and * at 10% critical level; Robust standard errors are reported in parenthesis.
Source: Author

in the dataset, the analysis is extended to account for the heterogeneity of industries. In the next, the group (industry) effect model is estimated by modifying Model [1A] and [1B].

$$\ln Y_{i,t} = \alpha + \alpha_1 \ln K^{N}_{i,t} + \alpha_2 \ln K^{I}_{i,t} + \alpha_3 \ln L_{i,t} + \alpha_4 T_i + \mu_i + \varepsilon_{i,t} \quad [2A]$$

$$\ln y_{i,t} = \alpha + \alpha_1 \ln k^{N}_{i,t} + \alpha_2 \ln k^{I}_{i,t} + \alpha_3 T_i + \mu_i + \varepsilon_{i,t} \quad [2B]$$

where μ is a group effect term for each industry i. All the other variables and subscripts are same as those for Model [1A] and [1B].

These models are estimated using fixed effect as well as random effect estimators. In the case of Model [2A], the 'Hausman specification test' fails to reject the null hypothesis that the individual effects are uncorrelated with the other regressors of the model, suggesting preference for the random effect model. The *REM* is estimated using the *feasible generalized least squared* (*FGLS*) estimator following Green (1997, 626–631). Since the heteroscedasticity and autocorrelation tests of the panel dataset indicate group wise heteroscedasticity and autocorrelation of first order in the error term, group wise heteroscedastic *FGLS* model is applied to account for heteroscedasticity and autocorrelation. The results of both the models, *FEM* and *FGLS*, are reported in Table 2.

The estimated coefficient of ICT capital in the *FEM* model has shown negative sign though it is insignificant, contrary to the results of Model [1A]. However, the estimator of *FGLS*, after accounting for the heteroscedasticity and correcting autocorrelation in the error term, has shown a positive and significant impact of ICT capital. Except for the *FEM* estimation, the results are comparable to those of Joseph and Abraham (2008, 18–21) and corroborating the view that ICT capital does have positive effect as a factor input on the manufacturing sector.

Model [2B], which estimates the effect of ICT capital (per labor) on the labor productivity, is also estimated using both the fixed and random effect estimators. The 'Hausman specification test' result[8] supports the *REM* estimator; thus to account for heteroscedasticity and first order autocorrelation in the error term, as is the case of Model [2A], the *FGLS* estimator is applied. Table 2 reports the results from both the estimators, *FEM* and *FGLS*. In the case of *FEM*, ICT capital per labor is insignificant with negative sign, in contrast to the results of Model [1B]. This suggests that the impact of ICT capital on labor productivity turns insignificant when the within group estimation is applied, removing industry effects. However, the *FGLS* coefficient of ICT capital per labor is positive and significant.

Table 2 Effect of ICT Capital on Output and Labor Productivity: Group Effect

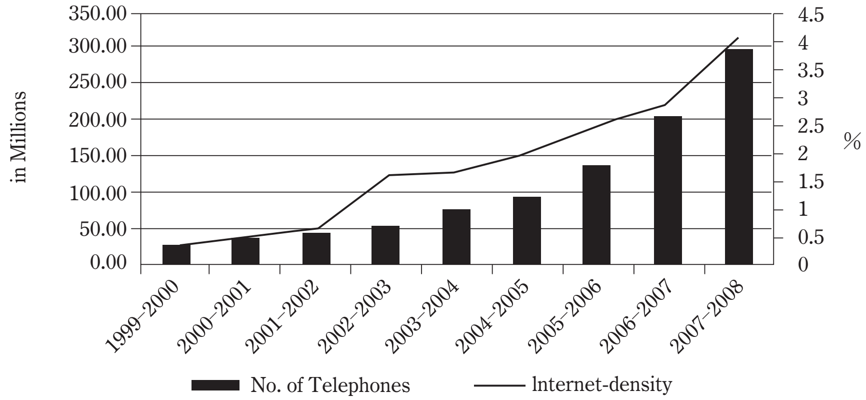
Model [2A] (Output): ln*Y*			Model [2B] (Labor productivity): ln (*Y*/*L*)		
Variables	*FEM*	*FGLS*	Variables	*FEM*	*FGLS*
$\ln K^N$	0.603 *** (0.133)	0.429 *** (0.044)	$\ln k^N$	0.482 ** (0.177)	0.390 *** (0.050)
$\ln K^I$	− 0.060 (0.045)	0.228 *** (0.047)	$\ln k^I$	− 0.070 (0.045)	0.250 *** (0.045)
$\ln L$	0.718 *** (0.186)	0.220 *** (0.042)	T	0.065 *** (0.008)	0.049 *** (0.008)
T	0.055 *** (0.009)	0.056 *** (0.007)	constant	6.101 ** (2.380)	4.269 *** (0.470)
constant	1.171 (3.112)	5.487 *** (0.626)			
F value/Waldchi2	55.19	1320.90	F value/Waldchi2	30.09	349.93
Prob >	0.0000	0.000	Prob >	0.0000	0.000
R-sq.	overall = .722		R-sq.	overall = .550	
No. of observations	198	198	No. of observations.	198	198

Notes: Dependent Variable: ln*Y* and lny; *** denotes significance at 1%, ** at 5% and * at 10% critical level; Standard errors are robust and adjusted for clusters in the industry groups (for *FEM*), and are reported in parenthesis.
Source: Author

4.3 Second-stage: ICT Infrastructure and Productivity

In this section, the paper explores the indirect effect of ICT on the manufacturing sector by analyzing the relationship between ICT infrastructure and the estimates of TFP. In the first sub-section, the estimates of TFP are computed followed by the second sub-section in which the impact of ICT infrastructure is analyzed based on the estimated TFP. The ICT infrastructure, in particular the 'access to telecommunications' in terms of number of telephones (including fixed-line and wireless), has seen a rising trend during the period of the study. In the case of the internet, although the number of subscribers is small, it is also growing at a higher rate as can be seen from Figure 4.

Figure 4 Telecommunications and Internet Trends in India



Note: The figure is compiled by the author based on Table 7.5 of Compendium of Selected Indicators of Indian Economy (Government of India 2009a) and data from World Development Indicators (The World Bank n. d.). The internet density is reported for the year ending December 31.

4.3.1 Estimating TFP of the Manufacturing Sector

This sub-section derives the estimates of TFP level of India's manufacturing sector, which are utilized for the second stage analysis. Moreover, the average TFP growth rates are computed and compared across the industries for two sub-periods. To begin with, TFP is computed for all the manufacturing industries using the estimated parameters of the production function as follows:

$$\ln \widehat{TFP}_{i,t} = \ln Y_{i,t} - \widehat{\alpha_1} \ln K^{N}_{i,t} - \widehat{\alpha_2} \ln K^{I}_{i,t} - \widehat{\alpha_3} \ln L_{i,t} \qquad [3]$$

where $\widehat{\alpha_1}$, $\widehat{\alpha_2}$ and $\widehat{\alpha_3}$ are the estimated coefficients of non-ICT capital, ICT capital and labor, respectively from the first stage analysis of production function. For this analysis, estimated coefficients are taken from the *FGLS* estimates of Model [2A].

The estimated average TFP growth rates by industry are shown in Table 3. The average TFP growth rates are also reported for two sub-periods, each divided into four years ranging from 2000–01 to 2003–04 and from 2004–05 to 2007–08, respectively. This helps to provide insight into two sub-periods and the overall sample period. The average TFP growth has been higher in the second sub-period (2004–05 to 2007–08) than the first one, except for five industries, namely, 'Tobacco', 'Coke and Refined Petroleum Products', 'Office, Accounting and Computing Machinery', 'Motor Vehicles', and 'Other Transport Equipment'. These estimates of TFP suggest that the overall performance of the manufacturing sector has been relatively better in the second sub-period. This trend of two sub-periods is similar to the results of Sharma and Sehgal (2010, 105) even though the division of two sub-periods is different. For the entire sample period, 'Coke and Refined Petroleum Products' has shown the highest average TFP growth, followed by 'Office, Accounting and Computing Machinery', 'Basic Metals', 'Motor Vehicles' and 'Other Non-Metallic Mineral Products'.

Table 3 Estimates of the Average TFP growth of the Industries, 2000–01 to 2007–08

Industry	Average TFP growth (2000–01 to 2003–04)	Average TFP growth (2004–05 to 2007–08)	Average TFP growth (2000–01 to 2007–08)
Food and Beverages	0.986	1.108	1.047
Tobacco	1.024	1.011	1.017
Textiles	1.017	1.091	1.054
Wearing Apparel	0.952	1.092	1.022
Leather	1.002	1.073	1.037
Wood and Products of Wood	1.050	1.095	1.072
Paper and Paper Products	1.017	1.130	1.073
Printing and Publishing	0.962	1.104	1.033
Coke and Refined Petroleum Products	1.314	1.115	1.215
Chemicals and Chemical Products	0.998	1.070	1.034
Rubber and Plastic Products	1.023	1.045	1.034
Other Non-Metallic Mineral Products	1.007	1.194	1.100
Basic Metals	1.101	1.148	1.125
Fabricated Metal Products	1.056	1.121	1.089
Machinery and Equipment n.e.c.	1.026	1.114	1.070
Office, Accounting and Computing Machinery	1.193	1.171	1.182
Electrical Machinery and Apparatus n.e.c.	1.033	1.167	1.100
Radio, Television and Communication Equipment	1.054	1.127	1.090
Medical, Precision and Optical Instruments	1.061	1.094	1.077
Motor Vehicles	1.141	1.076	1.109
Other Transport Equipment	1.124	1.068	1.096
Furniture; Manufacturing n.e.c.	0.969	1.092	1.030

Source: Author

4.3.2 Estimation of the Second-Stage

The analysis is carried out following Sharma and Sehgal (2010, 108). The ICT infrastructure, as has been specified earlier, is divided into three main components; namely, aggregate manufacturing ICT capital, access to telecommunications (sum of fixed-line and wireless telephones) and internet density. These components are regressed separately on the estimates of TFP of the manufacturing sector using *pooled OLS* technique. The estimates of TFP obtained from the second-stage analysis, using *FGLS* parameters of the production function, are utilized for the analysis. The functional form of the models to be estimated is as follows:

$$\ln\widehat{TFP}_{i,t} = \alpha + \beta \ln ICTCap_t + \theta_1 \ln K^{N}_{i,t} + \theta_2 \ln L_{i,t} + \mu_{i,t} \quad [4]$$

$$\ln\widehat{TFP}_{i,t} = \alpha + \beta \ln Tele_t + \theta_1 \ln K^{N}_{i,t} + \theta_2 \ln L_{i,t} + \mu_{i,t} \quad [5]$$

$$\ln\widehat{TFP}_{i,t} = \alpha + \beta Net_t + \theta_1 \ln K^{N}_{i,t} + \theta_2 \ln L_{i,t} + \mu_{i,t} \quad [6]$$

where $\widehat{TFP}_{i,t}$ is the estimate of TFP level derived for industry i for a period t, *ICTCap* is the aggregate manufacturing ICT capital stock, *Tele* is the access to telecommunications and *Net* is the internet density. ln indicates that the variables are in logarithmic form. All the ICT infrastructure variables are common across the industries. All the above three models are extended by including industry specific characteristics in terms of non-ICT capital and labor to the RHS variables of the models.

To check whether the individual series are stationary or not, panel unit root tests have been applied to individual series of the models. For the TFP, non-ICT capital and labor series, the Levin-Lin-Chu (LLC) panel unit root test and Im-Pesaran-Shin (IPS) panel unit root test have been applied. For the individual ICT infrastructure components, the Dickey-Fuller (DF) and Augmented Dickey-Fuller (ADF) time series unit root tests have been used. For a panel dataset, the LLC test may be viewed as a pooled DF test or an ADF test when lags are included, with the null hypothesis that of nonstationarity of the series (Levin, Lin, and Chu 2002, 2–3). The test assumes common AR (1) coefficient for each individual unit in the panel; however, the main advantage of using this test is that it can be employed on large-N, small-T panels such as the ones used in this study. On the other hand, the IPS test allows for heterogeneity of the panel and performs the test based on the mean of the individual DF t-statistics of each unit in the panel (Im, Pesaran, and Shin 2003, 54). The test assumes nonstationarity of all series under the null hypothesis. These two tests would increase the robustness of the analysis. The results of the tests are reported in Table 4.

The results show that the estimates of TFP derived from the *FGLS model* are stationary in both the tests of LLC and IPS. The results of ADF test show that *ICTCap* is also stationary. The series of *Tele* is nonstationary at the level; however, the first differenced series is stationary around a trend. The series of *Net* is nonstationary at the level as well as at the first difference. The series of K^{N} is stationary at the level in the LLC as well as IPS tests. In the case of L series, it is also stationary in

Table 4 Unit Root Tests

Variables	DF	ADF	LLC	Augmented LLC	IPS	Augmented IPS
ICTCap	−2.181	−4.242 ***(1)				
Tele	3.394	3.664(1)				
Tele D1	−4.719 ****t*					
Net	1.203	1.126(1)				
Net D1	−2.084	−1.398(1)				
TFP			−8.895 ***	−16.544 ***(1)	−1.888 **	−2.261 ***(1)
K^N			−5.204 ***	−4.551 ***(1)	−1.640	−2.652 ***(2)
L			−1.843	−5.190 ***(2)	−1.489	−2.167 ***(2)

Notes: *** denotes significance at 1%, ** at 5% and * at 10% critical level; lags are reported in parenthesis; *t* denotes trend.
Source: Author

both the tests. The results, although mixed, are robust to both the LLC and IPS tests. All the series are stationary either at the level or at the first difference, except for the *Net* series which is integrated of order 2 (*I* (2)).

The paper applies co-integration test on the combinations of these series, as specified in the models [4], [5] and [6]. To test for co-integrating relationships of these models, the LLC and IPS tests on the estimated residuals of the three models are applied using Granger procedure (Gujarati and Porter 2009, 762–764). Both the tests are augmented by using lags (up to two as the optimum) of the estimated residuals of the models [4], [5] and [6]. The results of the tests are reported in Table 6, showing significance at 1 and 5 percent critical levels. It confirms that the variables of all the aforementioned three models have linear combinations, and are co-integrated. Table 5 reports the estimates of the Model [4], [5] and [6].

From the results of Table 5, it has been found that the ICT infrastructure has a positive and significant effect on the manufacturing sector of India. Model [4] estimates the effect of aggregate ICT capital on the estimates of TFP of the manufacturing sector. The aggregate ICT capital is considered as a proxy for the availability of sector wide network of information technology (IT) and as a part of the ICT infrastructure. The model is estimated by the *pooled OLS* methodology, with and without industry characteristics. The estimated coefficients of aggregate ICT capital are positive and statistically significant in both the variants (Model [4(A)] and Model [4(B)]) of the model. These results give insight into the potential of externalities emerging out of ICT capital and affecting the manufacturing sector as a whole. There will be a 0.53 percent increase in the TFP with every 1 percent increase in the aggregate ICT capital stock across the manufacturing sector. However, the results need to be interpreted cautiously and cannot be overemphasized given the low explanatory power of Model [4(A)]

Table 5 ICT Infrastructure and TFP: Regression Analysis

Model [4]			Model [5]			Model [6]		
Variables	Model [4(A)]	Model [4(B)]	Variables	Model [5(A)]	Model [5(B)]	Variables	Model [6(A)]	Model [6(B)]
ln*ICTCap*	0.527 * (0.300)	0.541 * (0.304)	ln*Tele*	0.245 *** (0.043)	0.255 *** (0.044)	*Net*	0.157 *** (0.028)	0.163 *** (0.029)
$\ln K^N$		0.033 (0.032)	$\ln K^N$		0.035 (0.029)	$\ln K^N$		0.035 (0.029)
ln*L*		−0.079 (0.057)	ln*L*		−0.100 * (0.053)	ln*L*		−0.099 * (0.053)
constant	−7.978 (7.789)	−8.207 (7.946)	constant	1.255 (0.776)	1.392 (0.948)	constant	5.433 *** (0.056)	5.740 *** (0.646)
F value	3.09	1.47	F value	32.60	11.15	F value	31.59	10.92
Prob > F	0.081	0.224	Prob > F	0.000	0.000	Prob > F	0.000	0.000
R−sq.	0.014	0.029	R-sq.	0.136	0.160	R-sq.	0.130	0.153
Obs.	198	198	Obs.	198	198	Obs.	198	198

Notes: Dependent Variable: $\ln\widehat{TFP}$; *** denotes significance at 1%, ** at 5% and * at 10% critical level; Robust standard errors are reported in parenthesis.
Source: Author

Table 6 Co-integration Test Results

Variables	Residual (Model [4])	Residual (Model [5])	Residual (Model [6])
LLC	−8.745 ***	−8.708 ***	−8.709 ***
LLC (1)	−15.713 ***	−15.526 ***	−15.535 ***
LLC (2)	−27.042 ***	−25.923 ***	−25.968 ***
IPS	−1.875 **	−1.873 **	−1.873 **
IPS (1)	−2.184 ***	−2.164 ***	−2.165 ***
IPS (2)	−2.263 ***	−2.193 ***	−2.196 ***

Notes: *** denotes significance at 1%, ** at 5% and * at 10% critical level; (1) denotes augmented by lag 1 and (2) denotes augmented by lags 2.
Source: Author

and failing of goodness-of-fit in Model [4(B)].

The steps same as for Model [4] have been carried out for the Model [5] and [6]. The results of Model [5] indicate that the access to telecommunications is critical in the development of the manufacturing sector. The reduction in transaction and communications costs, efficient ways of communication, and availability of information are some of the main advantages emanate from the availability of telecommunications. The coefficients in both the variants of the model are positive and statistically significant (at 1 percent critical level). The result of *Tele* shows that there will be a 0.24 percent increase in the TFP with a 1 percent increase in the number of telephones. In the case of internet density, results from Model [6] also support the importance of access to the internet, which assists in accessing and sharing information, communications and in some other functionality such as e-commerce, and online recruitments. The coefficients of *Net* are positive and significant (at 1 percent critical level). This suggests that with an increase of 1 percent in the internet density, there will be a 0.16 percent increase in the TFP of the manufacturing sector.

Overall the results are significant and supportive of the rising importance of the ICT infrastructure — which is still in the early stage of its development — in the industrial performance and development of the manufacturing sector of India. In comparison to the results from Sharma and Sehgal (2010, 110–111), the ICT infrastructure elasticities from the estimation indicate relatively strong effects on the manufacturing sector through the indirect channel of TFP. However, the comparison may not be fully plausible due to differences in the dataset used in both the studies.

5. Concluding Remarks

The study has used two-stage analysis, in which first the production function approach has been used to account for the direct effect of ICT capital as a factor of production on India's manufacturing sector. After accounting for heteroscedasticity and autocorrelation, the results have shown a significant effect of ICT capital on the output of the sector. In a similar way, the impact of ICT capital per labor on labor productivity has also been positive and significant.

In the second stage, the indirect effect of ICT infrastructure on India's manufacturing sector has been analyzed. First, the estimates of TFP of the manufacturing sector are computed by applying estimated parameters of the production function. Next, in estimating the effect of ICT infrastructure, each element of the ICT infrastructure has been regressed against the estimates of TFP of the manufacturing sector. The unit root tests have been carried out on all the panels including those of the ICT infrastructure and TFP. After the regression analysis, co-integration tests on estimated residuals of the three models have been employed. The results of these tests confirm that the variables are co-integrated, and help to identify the relationship between ICT infrastructure and the estimates of TFP. The results from this analysis have shown that the ICT infrastructure, which includes aggregate manufacturing ICT capital, telecommunications and the internet, has significant impact on the manufacturing sector of India.

The direct effect of ICT investment shows that ICT is critical for the industrial development, since it works as a factor of production and affects the output and labor productivity positively. However, this depends on the intensity of ICT investment and is limited to industries those invest in ICT capital directly. On the other hand, externalities emerging from the ICT infrastructure — encompassing aggregate sector wide stock of ICT capital, access to telecommunications, and the availability of internet — is critical for the manufacturing sector, since it is not only affecting an individual firm but also helps to increase the performance of the overall sector. This indirect effect depends on the availability of ICT infrastructure and the sector wide stock of ICT capital.

The analyses and results of the study, within the given dataset, provide insights into the relationship between ICT investment and performance of the manufacturing sector of India. From the production process point of view, investment in ICT capital, which consists of computer and software, improves how production and non-production activities are conducted and contribute to output and labor productivity. Moreover, the network effects and network externalities that characterize the ICT infrastructure play an important role in adding value to the sector as the network increases. In a period of globalization and liberalization of trade regimes, competitiveness has become a necessity for survival. Under such circumstances, ICT infrastructure helps to increase competitiveness through its indirect effect on the manufacturing TFP. It also helps in opening up new business opportunities through various channels of communications and information dissemination.

Notes

1 Although the terms 'externalities' and 'network externalities' are used interchangeably, the term 'externalities', excluding the one referred to in the previous literature, indicates 'network externalities' of ICT infrastructure.

Due to the network effect and pervasiveness of ICT, externalities of ICT infrastructure are largely explained by the network externalities. It also helps to understand the rationale behind the relationship between ICT infrastructure and manufacturing sector's TFP.

2 The term 'sector' is used to indicate the Indian manufacturing sector as a whole and the term 'industry' is used to indicate two-digit level industry/industries that fall under the manufacturing sector category.

3 Classification of the 'registered manufacturing sector' is given in the appendix.

4 By taking clues from Goldar *et al*. (2003, 9), the replacement value which has been calculated in this manner, is a compelled choice due to data limitations. The census category of the dataset has firms with 200 or more workers during the sample period until 2003–04 and 100 or more workers from 2004–05. On the other hand, the sample category of the dataset has the remaining firms with less than 100 workers. Due to this classification, the census category firms are assumed to be large-sized and relatively old firms compared to the sample category firms. Hence, the gross fixed assets of the census category are multiplied by 2 and that of the sample category by 1.5.

5 The service life of computers is considered to be around 5 years on average (Meinen 1998, 25). Although Jorgenson and Stiroh (1999, 111) have used a depreciation rate of 31.5 per cent on ICT capital for the U.S, it seems too high in the case of a developing country such as India. Heshmati and Yang (2006, 10) have used different rates, but have preferred 15 percent depreciation rate for the Chinese ICT capital. Considering the service life of around 5–6 years for ICT capital, depreciation of 18 percent as an annual average rate of wear and tear has been applied in this case.

6 Although the proxies such as "sum of fixed lines and wireless in millions" and "number of users per 100 people" refer to users, they are the proxies used in the previous literature to approximate the availability of ICT infrastructure. Since there are many factors, including government policies that enable the availability of ICT infrastructure as well as many indicators of the same, the outcome in terms of number of users may find its way to explain the availability of this infrastructure.

7 The information used in the paragraph is taken from Godavarkar and Malik (2010).

8 The 'Hausman Specification Test' results of Models [2A] and [2B] are specified in the appendix.

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Appendix

Appendix A: Classification of the 'registered manufacturing sector'

Coverage of the Annual Survey of Industries extends to the entire Factory Sector comprising industrial units (called factories) registered under the Sections 2 (m)(i) and 2 (m)(ii) of the Factories Act, 1948. The sections 2m (i) and 2m (ii) refer to any premises including the precincts thereof (a) whereon ten or more workers are working, or were working on any day of the preceding twelve months, and in any part of which a manufacturing process is being carried on with the aid of power, or is ordinarily so carried on or (b) whereon twenty or more workers are working or were working on any day of the preceding twelve months and in any part of which a manufacturing process is being carried on without the aid of power, or is ordinarily so carried on (Government of India 2011).

This classification of coverage of the ASI implies that the 'registered manufacturing sector' is the one that includes factories registered under the Factories Act, 1948 as specified above.

Appendix B: Hausman Specification Test, Model [2A]

hausman fixed random

Coefficients	(b) fixed	(B) random	(b−B) Difference	sqrt (diag (V_b−V_B)) S. E
K^N	0.603	0.566	0.038	0.127
K^I	−0.060	−0.036	−0.023	0.017
L	0.718	0.414	0.304	0.050
T	0.055	0.068	−0.013	0.001

b=consistent under Ho and Ha; obtained from xtreg
B=inconsistent under Ha, efficient under Ho; obtained from xtreg
Test: Ho: difference in coefficients not systematic
chi2(4) = (b−B)'[(V_b−V_B)^(−1)](b−B)
= 5.93
Prob>chi2=0.2048
(V_b−V_B is not positive definite)

Appendix C: Hausman Specification Test, Model [2B]

hausman fixed random, sigmaless

Coefficients	(b) fixed	(B) random	(b−B) Difference	sqrt (diag (V_b−V_B)) S. E
k^N	0.482	0.574	−0.092	0.113
k^I	−0.070	−0.035	−0.035	0.019
T	0.065	0.066	−0.001	0.002

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic
chi2(3)=(b−B)'[(V_b−V_B)^(−1)](b−B)
= 6.03
Prob>chi2 = 0.1100