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Information Technology and Productivity in Indian Manufacturing*

ABSTRACT India's manufacturing sector is receiving renewed attention as an underperformer in contributing to the nation's Gross Domestic Product (GDP) and employment growth, with a new National Manufacturing Policy (NMP) stating ambitious goals for increasing the share of manufacturing in GDP. In this context, the role of information technology (IT) as a contributor to manufacturing productivity also needs to be carefully examined. This paper uses five years of panel data for Indian manufacturing plants to examine the relationship of investment in IT to productivity, as measured by gross value added. We find some evidence that plants with higher levels of IT capital stock have higher gross value added, controlling for other inputs. However, this effect is attenuated when plant-level fixed effects are included. One possible interpretation of this result is that unobserved managerial quality is an important factor in the impact of IT capital on productivity. We also explore the impacts of skill composition, the use of imported intermediate inputs, ownership and organizational form on the productivity of IT capital. Furthermore, we examine the demand for IT investment, controlling for possible selectivity biases associated with plants that have positive IT investment. We find some evidence that access to financial capital, electric power from the grid, and skilled workers all matter for the decision to invest in IT capital, but these variables are less important for the level of investment in IT, conditional on it being positive.

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1. Introduction

India's manufacturing sector has played an unusual role in the national growth experience, compared to many other developing countries. In 1950–51, the first year for which the current data series is available, manufacturing was about 9 percent of GDP. By 1979–80, this ratio came very close to 15 percent, but thereafter has barely increased. The highest share of manufacturing for any year was 16.6 percent in 1996–97, and subsequently, the figure has hovered on either side of 16 percent, even in the years when India grew at well over 9 percent per annum.[1] In this context, the new National Manufacturing Policy's (NMP 2012) avowed goal of increasing manufacturing's share to 25 percent by 2022 is ambitious indeed.

The NMP benchmarks India's failure to grow manufacturing's share significantly against the experience of other Asian countries. In South Korea, for example, the share of manufacturing grew from 13.6 percent in 1960 (not much greater than that of India at the time) to 29.6 percent by 1990 (Panagariya 2008, Table 6.2). The pattern in China, however, has been less clear-cut, with manufacturing's share of GDP being estimated at 29 percent in 1965, rising to as high as 40 percent, and then coming down toward 30 percent as the national accounts were recalibrated.[2]

One of the motivations for focusing on manufacturing growth is, of course, its potential to generate employment for the unskilled or semi-skilled. Again, South Korea provides a striking example, having increased the manufacturing sector's share of employment from 1.5 percent in 1960 to 26.9 percent in 1990 (Panagariya 2008, Table 6.2). Again, the numbers for China are less striking: the share of industry (a broader classification than manufacturing) in total employment increased from 18 percent in 1980 to 27 percent in 2008. By contrast, the percentage shares for India have gone from 16 in 1994 to 22 in 2010 (World Bank data). Figures from the Economic Survey of India (2012, Table 9.11) are 11 percent for the share of manufacturing in total employment for India in 1999–2000, 12.2 percent in 2004–05, and 11.4 percent in 2009–10, well below the level for Korea.

India's NMP document quantifies the employment creation challenge, and makes it a central policy issue for the manufacturing sector:

1. These percentages are calculated by the authors from National Accounts data from Reserve Bank of India (RBI) (2012).

2. The Chinese figures are from the World Bank's World Development Indicators (http://databank.worldbank.org/ddp/home.do).

> Over the next decade, India has to create gainful employment opportunities for a large section of its population, with varying degrees of skills and qualifications. This will entail creation of 220 million jobs by 2025 in order to reap the demographic dividend. The manufacturing sector would have to be the bulwark of this employment creation initiative. Every job created in manufacturing has a multiplier effect of creating two to three additional jobs in related activities. (NMP 2012)

Panagariya (2008), writing several years earlier, reaches a similar conclusion to the NMP:

> In contrast to other countries that have successfully transitioned from the primarily rural and agricultural structure to the modern one, rapid growth in India has not been accompanied by a commensurate increase in well-paid formal sector jobs.[3] In large part, this has been due to a stagnant share of industry and manufacturing, especially unskilled-labor-intensive manufacturing, in the GDP. This pattern of growth has meant that the movement of the workforce out of agriculture and into the organized sector has been slow. Modernization of the economy requires the expansion of employment opportunities in the organized sector. (Panagariya 2008, p. 309)

Of course, neither the NMP nor Panagariya is guilty of simple manufacturing fetishism. Clearly, the services sector in India has been successful in generating growth in value added as well as in employment. This includes software and information technology (IT) enabled services, as well as a wide range of other services. The implicit argument, however, is that the services sector alone cannot provide the sustained growth in output or employment that will be needed.[4] There are also issues with respect to the nature of the manufacturing sector itself. For example, Kochhar et al. (2006) suggest that India's manufacturing sector was more diversified, more skill-intensive, and less (unskilled) labor-intensive than average, compared to countries at similar levels of development. This skill bias was accentuated in the 1980s and 1990s, according to their empirical analysis.[5]

3. As elucidated by Panagariya, India's labor laws and infrastructure constraints have led to a classification of firms into the formal, or organized, sector (employing 10 workers and using electric power, or 20 workers even if not using power). Most of the gains in employment in India have come in the informal sector, including rural industry and services.

4. A detailed discussion of services is beyond the scope of the current paper. Singh (2008), for example, provides an analysis of India's service sector in relation to manufacturing and overall growth.

5. Anecdotal evidence suggests that this trend has continued. "Even as high-end engineering boomed, manufacturing jobs dropped slightly between 2004 and 2010, to 50m. Basic industries that soak up labour, such as textiles and leathers, are in relative decline." *The Economist*, August 11, 2012, accessed October 10, 2012, at http://www.economist.com/node/21560263.

In reviewing different countries' development experiences and current policy options, the precise balance between existing and future comparative advantage with respect to labor-intensity and skill-intensity is a matter of debate (e.g., Rodrik 2007; Lin 2011). While the current analysis cannot address these broader issues, the Indian experience has led Arvind Panagariya (2008) to a specific recommendation with respect to development strategy. He argues as follows:

> India must walk on two legs as it transitions to a modern economy: traditional industry, especially unskilled-labor-intensive manufacturing, and modern services such as software and telecommunications. Each leg needs to be strengthened through a set of policy initiatives. (Panagariya 2008, p. 287)

Panagariya's own policy recommendations include somewhat separate discussions for each of his two "legs" of the Indian economy. For labor-intensive industry, he emphasizes labor law reform, bankruptcy reform and privatization, while software and telecommunications require attention to education and urban infrastructure. However, an important potential linkage exists between the two parts of the economy, namely, the use of IT in domestic manufacturing, as a potential avenue to spur productivity and employment growth in that sector. This paper contributes to exploring this linkage.

Accordingly, the rest of the paper is organized as follows. In Section 2, we provide some background on India's manufacturing sector, especially in the context of the use and impact of IT in that sector, but also discussing its broader performance. We review some of the related literature on the impacts of IT investment, including aspects of the macroeconomic evidence, but focusing mainly on studies of firm level data. Section 3 provides an overview of the data used in the paper, which is a panel of five years' plant-level data from India's Annual Survey of Industries (ASI), spanning 2003–07. We discuss some of the features of the data, and provide summary statistics, as well as outlining our empirical methodology.

Section 4 provides the results of our regression analysis of the data. We focus on two behavioral relationships. One such relationship is the factors determining the demand for investment in IT. Another is the factors influencing productivity at the plant-level, as measured by gross value added (GVA). In the latter case, we are particularly interested in the impact of IT capital on GVA. A central finding of our analysis is that, once plant-level fixed effects are accounted for, the estimated impact of IT on GVA is considerably reduced, though it remains statistically and economically significant.[6] We suggest that this finding is consistent with heterogeneity of (unobserved) managerial quality playing a role in the productivity of IT. We find a somewhat similar pattern in the investment demand equation: once plant-level fixed effects are allowed for, the role of existing IT capital stock in determining IT investment demand is negligible, though it remains significant in other estimations. We also find that the decision whether to invest in IT at all is influenced by access to financial capital, outside electricity, and skilled workers.

Our analysis also offers several other innovations. For example, we explore the impact of the skill composition of the labor force on the productivity of IT capital. We also examine the role of imported intermediate inputs in affecting the use and the impacts of IT capital. Another dimension we explore, which has a possible bearing on the role of managerial quality, is the impact of differences in ownership type and organizational form. Thus, the analysis provides a deeper and broader understanding of the role that IT investment has played in the performance of Indian manufacturing plants, by examining how the impact of IT capital on gross value added is affected by these other factors. Section 5 provides a summary conclusion, including some discussion of possible policy implications of our work, especially in the context of the National Manufacturing Policy.

2. Background and Related Literature

2.1. IT and the Economy

We begin this section with an overview of IT in the broader context of economic growth, including macro and cross-country studies as well as micro-level studies from several industrialized economies. In India's case, its software industry has been an important part of the country's growth story, including its contribution to improving the balance of payments and its positive spillovers into information technology-enabled services (ITES), as well as the more subtle impact on attitudes in India (Kapur 2002)—demonstrating that a modern India-based economic activity could be carried out at world class levels. At the same time, the export-oriented nature of the

6. The use of panel data at the plant-level distinguishes our analysis from some earlier studies of IT in Indian manufacturing. Our panel data also potentially allows us to explore the possibility of lagged impacts of IT investment, in keeping with what some studies for other countries have found, but in fact these lagged effects are not important. This finding may reflect our use of IT capital, which captures the cumulated effect of past IT investments.

industry's success has led to persistent concerns about whether India's IT industry would remain an enclave, heightening the dualism characteristic of developing economies. This last fear seems to be partly borne out in some of the criticisms brought up in reports based on India's National Manufacturing Surveys, as discussed later in this section, but even more strongly in the idea of a "digital divide."

The concept of a digital divide refers to inequality of access to new digital technologies, and this inequality can be examined across or within countries. In the case of developing countries, both these dimensions of inequality were viewed as potentially troublesome. Addressing concerns about a digital divide within India, private and public efforts to make information technology (IT) available to a broad cross section of the nation's population began in the early days of India's software boom. Several organizations attempted to build networks of rural Internet kiosks, sometimes bundled with telephone service (Singh 2007). These attempts have met with very limited success, far short of the visions that were articulated of tens of thousands of such kiosks. What has spread, of course, is mobile telephony, driven by technological change, access to spectrum, and vigorous competition among several large corporations. Meanwhile, the government has articulated and begun to implement its own vision of rural Internet access, albeit with the usual implementation difficulties associated with public sector delivery of services in India.

Empirical aggregate level studies of the impact of IT on productivity or growth include single country time-series analyses (regression-based as well as through growth accounting) and cross-country regressions. Early evidence for the positive effects of IT on output or growth was hard to come by. In 1987, economist Robert Solow quipped: "You can see the computer age everywhere but in the productivity statistics." A decade later, Robert Gordon, carrying out a sequence of empirical analyses for the US (the global leader in IT adoption), still found little or no empirical evidence of aggregate productivity growth that could be attributed to the use of IT. Later studies for the US, however, found that IT investment was having a discernible positive effect on productivity growth (e.g., Schreyer 2000; Jorgenson 2005).

In the first decade of the new millennium, several cross-country analyses also began to appear. These typically included some measure of progress in ICTs more broadly, including communication technologies along with IT, and findings of positive impacts associated with cross-sectional variation were typical. Several studies extended to considering developing countries, and not just industrialized nations where IT adoption might be more advanced. Lee and Khatri (2003), Pitt and Qiang (2003) and Qiang, Pitt and Ayers (2004) are examples of such studies, while Indijikain and Siegel (2004) have surveyed many additional empirical analyses. Studies such as Kenny (2002, 2003) pointed out the importance of a skilled workforce in increasing the returns to investment in IT.

Cross-country and aggregate single-country studies may not give much insight into the microeconomic factors that govern IT use and impacts, but several firm-level studies have also been carried out, almost exclusively for industrialized country firms. Baldwin and Sabourin (2002) showed that Canadian manufacturing firms that used either one or more ICT technologies had a higher level of labor productivity than the firms that did not. Gretton et al. (2003) examined Australian firms, and found positive links between ICT use and productivity growth in all the industrial sectors that were analyzed. Maliranta and Rouvinen (2004) found strong evidence for productivity-enhancing effects of ICT in Finnish firms. Clayton et al. (2004) examined the economic impacts in the UK of electronic commerce specifically, and found a positive effect on firms' productivity associated with the use of computer networks for trading. Similar positive results for the impact of IT have been found for firms in the service sector than in manufacturing, including Hempell (2004) for Germany and the Netherlands, Doms, Jarmin, and Klimek (2004) for the US, and Arvanitis (2004) for Switzerland. For the US, Brynjolfsson and Hitt (2003) also find positive impacts of IT investments, with the gains increasing substantially over time.

Firm-level studies for the US have also examined the role of workplace organization in determining the effects of investments in IT. For example, Black and Lynch (2004) find that changes in workplace organization explain a large part of the changes in productivity in the US over the period 1993–96, and these in turn influence the impacts of IT use. In particular, they find a significant and positive relationship between the proportion of non-managers using computers and overall productivity. Similarly, Bresnahan, Brynjolffson, and Hitt (2002) examine how a combination of three related innovations: information technology adoption, complementary workplace reorganization, and new products and services resulted in a significant skill-biased technical change which had an important impact on the demand for labor in the US. They find complementarities among all three of these innovations in factor demand and productivity, leading to increases in demand for other inputs and in productivity.

More recently, Bloom, Sadun, and van Reenen (2012) also use a micro panel data set to connect results at the micro and macro level. They use the variation in management practices between US multinationals operating in Europe and other European firms to elucidate the interaction between management and the use of IT. They find that US multinationals obtained higher productivity from IT than non-US multinationals, particularly in the sectors that were responsible for the post-1995 US productivity acceleration. Incorporating data from an extensive management practices survey, they find that the US IT-related productivity advantage is primarily due to its tougher "people management" practices. These results are therefore quite consistent with earlier work on organizational change, stressing flexibility, however, rather than specific types of worker composition.

2.2. Manufacturing and IT in India

Chandra and Sastry (2002) summarize the findings of the 2001 National Manufacturing Survey. The focus is on the organized manufacturing sector, representing less than 1 percent of the country's firms at the time, but employing 19 percent of its industrial workers and contributing almost 75 percent of gross value added. They are quite critical of Indian manufacturing management, arguing that

> [M]anufacturing strategy of most firms is still not addressing certain fundamental issues of competition: need to change product mix rapidly, need to introduce new products based on indigenous R&D, need to use process innovation and quality improvement process to reduce cost of operations and consequently price of product. One wonders if the industry has a good control of the causal factors that define competitiveness in a low margin environment. (Chandra and Sastry 2002, p. 10)

The study notes the lack of spending on research and development (R&D), and the relatively small numbers of employees with advanced degrees, in the sample firms. The authors also note that Indian manufacturing firms give low priority to investments related to information technology, such as computer-aided manufacturing (CAM), computer-aided design (CAD), computer integrated manufacturing (CIM), and computer-aided engineering (CAE). It is also suggested that domestic IT firms do not have the right products for Indian manufacturing firms in these applications.

Indian manufacturing is also found to have supply chain weaknesses, closely related to the inability to share information throughout the supply chain. The survey finds that only 13 percent of firms use a computer-based decision system for supply chain management, though the percentages are higher for enterprise resource planning (43) and shop floor scheduling (37). Only 23 percent of firms in this sample use the web for placing orders with suppliers, and 11 percent sell online to customers. The overall picture is one of very limited use of IT across the board, but especially in network applications.

The 2007 National Manufacturing Survey, the next one following on the 2002 survey, is analyzed in Chandra (2009). The date of the survey corresponds to the end of our own sample period. Supply chain management remains a key weakness in the later survey, and investments in R&D remain low, despite perceptible benefits to innovation. Investment and usage of IT on the shop floor remain low, at about 45 percent for this later sample, which is not much higher than the 2002 figure. The conclusion of the author echoes the theme of his 2002 analysis.

> Once basic IT investment is done, only then will Indian firms be able to implement and take advantage of automation on shop floors. IT firms in India have failed to develop a viable and low cost IT solution for Indian Manufacturing. Firms other than the large ones are struggling on this count. (Chandra 2009, p. iv)

Several other features of Indian manufacturing (at least the sample for the NMS) emerge from the Chandra report. Indian firms surveyed indicate a focus on quality, and trying to achieve that through process improvement. Large scale and low cost are not major goals of the surveyed managers. These characteristics are consistent with formal empirical work and anecdotal evidence. The 2009 report finds some significant increases in IT use in particular areas of manufacturing, but overall IT adoption remains limited among the sample firms. The report also argues that management weaknesses contribute to lack of innovation, as well as inefficiencies in plant location and supply chains.

Chandra (2009) also summarizes regional differences in IT use among the NMS sample firms. IT use is highest in the South, and lowest in the East, but also in Uttar Pradesh (in the North). Interestingly, IT use tends to be concentrated among managers, and to some extent supervisors, with less IT use by operators on the shop floor. To some extent, the pattern of IT use (or non-use) is symptomatic of under-investment in both physical and human capital, reflecting high financial costs as well as an unfriendly policy environment. At the same time, Indian manufacturing firms are able to make strong profits in this period, despite their inefficiencies.

The most recent detailed policy-oriented document, aside from the NMP itself, is a joint study by the National Manufacturing Competitiveness Council (NMCC) and the National Association of Software and Services Companies (NASSCOM). The study and report (NMCC–NASSCOM 2010) were conducted by a consulting firm, but the academic advisors include people like Pankaj Chandra, suggesting some intellectual continuity. The NMCC–NASSCOM report is specifically focused on promoting IT adoption in Indian manufacturing.[7]

The NMCC–NASSCOM report makes several familiar points, but with newer survey data to back them up. It begins by noting the relatively low penetration of IT in Indian manufacturing, especially among smaller firms, as well as its relatively low productivity in terms of value added per capita. As in the earlier reports discussed above, the link between IT use and productivity is not quantitatively established, but the case is made conceptually, by describing the numerous potential benefits of IT across a range of applications, and several brief case studies are presented in the report.

The fine-grained discussion of the range of IT applications distinguishes the NMCC–NASSCOM report. For example, the report brings out the fact that finance and accounting applications run far ahead of core manufacturing process uses of IT. It also systematically considers eight different manufacturing sectors, providing insights into variation across them in terms of IT use. For example, sectors such as automobiles and automobile components are ahead of sectors such as textiles in IT adoption. Some of this variation is obviously a reflection of differences in the sophistication of products and complexity of production processes, but factors such as size, foreign investment and export orientation also play a role.

The report discusses the barriers to IT adoption in the context of the survey data. In many cases, even when IT is adopted, it is restricted to basic or noncore operations, limiting its impact. However, the hurdles to any adoption at all are many: lack of infrastructure such as reliable power, high costs, unsuitability of off-the-shelf IT solutions, lack of awareness among businesses of IT options, lack of enabling business and policy environments, and especially lack of internal capabilities to make and implement informed decisions. In the context of the last point, the report's conclusion is striking.

> ICT adoption levels in manufacturing firms were primarily influenced by their management team. More than three-fourth of the companies especially in the micro and small firms category are strongly influenced by the owner/management team for their ICT investments. (NMCC–NASSCOM 2010, p. 11)

7. For brevity and consistency, we use the acronym IT: the NMCC–NASSCOM report uses the term ICT, for "information and communication technology." We treat the two terms as equivalent, since modern digital communications (including voice and video) are essentially based on IT.

Overcoming this particular internal barrier to IT adoption will not be easy, according to the report's findings. External influences such as IT consultants and vendors, government agencies, and even peer group companies were found to be limited in impact. This observation suggests that the strictures placed by Chandra (2009) on the domestic IT industry's failure to promote IT adoption may be too harsh. The NMCC–NASSCOM report does note the importance of clients in influencing IT adoption, suggesting that supply chain network effects may be an important avenue for overcoming barriers. Recall that both Chandra and Sastry (2002) and Chandra (2009) emphasized weaknesses in supply chain management among Indian manufacturing firms.

As the NMCC–NASSCOM report emphasizes, increasing IT adoption in Indian manufacturing will require a systemic approach, with broad participation from many parts of the business ecosystem. The report emphasizes the potential role that can be played by national and local industry associations in developing best-practice business process reengineering guidelines to cope with the organizational changes that are often needed to benefit from IT investments. Human capital development to overcome lack of appropriate skills can be addressed through improving the quality of government provided training programs, and tax incentives for firms to spend on this training. Anomalies in the tax code, broader deficiencies in the legal framework, poor telecoms infrastructure and lack of access to finance all receive attention as barriers to IT adoption that can be overcome through policy attention. The report also discusses possibilities for raising requirements for electronic communications in certain contexts, and the possibility of creating a more efficient national market for IT products and services, through information dissemination, creation of electronic market platforms, and award programs. Many of the issues raised reflect the status of IT as a novelty for Indian manufacturing firms, especially the smallest ones.

2.3. Empirical Analyses of IT in Indian Manufacturing

In between the two poles of India's software exporters and its village computer kiosks, the role of IT in the vast middle of India's economy has remained relatively unexplored in formal empirical analyses. A major exception was the work of Gangopadhyay, Singh and Singh (GSS 2008), using the Annual Survey of Industries (ASI) data, which examined the determinants and impacts of IT use among India's manufacturing units. The GSS study found that IT use was possibly constrained by factors such as the availability of electricity and of short term finance. On the other hand, there was evidence that plants that used IT were more profitable and more productive than those that did not. One of the shortcomings of the GSS analysis was that the non-availability of panel data prevented a clear identification of the chain of causality. For example, IT-using plants could be doing better because of better management, which could be the cause of IT investment as well as of superior performance. One goal of the current paper is to deal with this issue by using panel data. A panel analysis, for example, potentially controls for managerial fixed effects.

GSS (2008) also estimate a full set of demand equations for unskilled and skilled labor (proxied by wage and salaried workers, respectively, as is standard in working with ASI data), and find that IT use increases the demand for both types of workers. We are able to build on the GSS study, but using panel data allows us to control better for unobservable factors. Furthermore, we focus on IT investment demand and the productivity impacts of IT capital, but we are able to explore lagged effects, the effects of changes in labor force composition, and the role of imported intermediate inputs.

One of the issues unresolved in GSS was the role of managerial quality. In this context, two other analyses of management practices are relevant. Bloom and van Reenen (2010) found that Indian firms with strong management practices are comparable to the best US firms on this dimension. However, there is a thick tail of badly run (by their measure of management practices) Indian firms, which often neglect basic tasks such as collecting and analyzing data, setting clear performance targets, and linking pay to performance. Bloom et al. (2012) perform a controlled experiment with a sample of Indian textile firms, and indeed find that the treatment firms improved productivity by 17 percent over the control group. This provides very direct evidence that "management matters" for at least a subset of Indian firms. While we cannot provide such a direct test, our results are certainly suggestive of a similar phenomenon in a much larger sample of Indian manufacturing plants.

Joseph and Abraham (2007) also use ASI data. Their analysis covers the four year period 1998–2002. They estimate regressions for labor productivity and growth in labor productivity, as well as a production function. The estimations are conducted using data at the 3-digit industry level, giving 52 annual observations for each regression. The labor productivity regressions (OLS, random effects and fixed effects) all indicate that IT investment intensity positively affects labor productivity, as do capital intensity, skill intensity and plant size. Regressions for the growth in labor productivity give similar results for the impact of IT investment (still specified in level terms).[8] The production function estimated by Joseph and Abraham appears to use data averaged over the four years of their sample. Output is measured as gross value added, and in addition to labor and capital, the specification includes the ratios of cumulated IT and non-IT investments to total capital as additional variables. Only the IT-capital ratio is found to be significant and positive. Furthermore, growth accounting calculations of Total Factor Productivity (TFP) also suggest a positive relationship (albeit nonlinear) between IT investment and TFP growth.

The most recent study of the impacts of IT on productivity of Indian firms is that of Kite (2012). Kite uses the PROWESS database from the Centre for Monitoring the Indian Economy (CMIE). This data covers large and medium sized firms listed on India's stock exchanges, as well as public sector enterprises. Services firms (including financial services) are included, as well as manufacturing firms. The analysis covers four years, 2005–08, with most firms in the sample reporting data for more than one of the years.

Kite focuses on expenditure on IT outsourcing, proxied by a reported measure of "expenditure on software and other professional services," but also has measures of in-house software and hardware use. She estimates production functions using gross output rather than value added, so intermediate inputs are included as an explanatory variable. Her basic result is that all the three IT variables have positive and significant impacts on output. She also argues that excluding expenditure on IT outsourcing overstates the output elasticity of in-house IT expenditures. The results are shown to be robust to a variety of changes in the sample, specification and estimation method.

Kite goes on to estimate a stochastic frontier production function model to explore how IT outsourcing affects technical efficiency and productivity, as well as going on to derive an estimated aggregate impact of IT outsourcing on India's total growth. This latter figure is calculated to be 1.3 percentage points of growth per year, or 14 percent of the total GDP growth over the sample period. Kite notes that this figure is quite similar to estimates for the US and other developed countries in the 1990s. At various points in the paper, we contrast our data and results with those of Kite, but here we highlight once again an important issue that has only been formally dealt with by GSS (2008), despite its importance in policy-oriented discussions

8. Joseph and Abraham also mention two studies based on limited surveys of Indian manufacturing firms, which also find positive impacts of IT investment: Lal (2001) and Basant et al. (2007). Kite (2012) references a firm-level study by Commander et al. (2011), which is related to the earlier study of Basant et al. (2007).

of IT use in Indian manufacturing, namely, the reasons why IT use is not greater, despite its potential contribution to productivity.

3. Data and Methodology

3.1. Data Overview

We use data from India's Annual Survey of Industries (ASI). This data covers manufacturing plants (also commonly referred to as units or factories) across a range of industries, and with national coverage.[9] Until recently, plant identifiers were not available for the data, making it impossible to construct a true panel. Given this restriction, GSS (2008) worked with a cross section of data, or in some cases with pooled data, but without being able to allow for plant fixed effects. More recently, Sharma (2012) constructed a synthetic panel, creating cohorts of firms for each year. While the cohort approach has some significant advantages, for the purposes of the current analysis, it is useful to work with the plant-level data, and we are able to benefit from the recent availability of plant identifiers to construct such a panel.

The ASI data is affected by missing values, and possible reporting errors, so it can be a challenge to use. In this case, we have benefited from the earlier work of Sharma (2012) in cleaning the data. Nevertheless, the number of usable observations is considerably smaller than the total sample size of 15,000 to 50,000 units that are surveyed annually (the number having increased over recent years, after having decreased in the 1990s). The main factor restricting our sample, however, is the presence of plants in every year of the panel. To avoid losing too many observations in the cross section, we restrict the panel to cover the last five years of our data set, going from 2003 to 2007. This gives us about 8,000 plants in our sample. The shorter time period has some advantages, in the sense that these years cover a relatively uniform growth period of the Indian economy, and it is later than the GSS data, allowing us to distinguish our results more clearly. Missing observations and zero values further reduce the estimated sample size. In our regressions, the number of plants is about 2,500 per year. When the dependent variable has missing observations, we also address the possible biases that can arise from selection effects.

The original data are in current values, and while year fixed effects go some way to capturing changes in price levels, they do not deal with

9. GSS (2008) provide a detailed discussion of the ASI data, including the sampling frame, stratification, and other aspects of the sampling methodology.

differences in rates of inflation for different categories of goods. In order to ensure that differential changes in prices are not affecting the relationship between our variables, we deflate each variable according to industry-wise wholesale price indices for each year, using data from the Economic Survey of India, 2012. We do not have a separate deflator for IT capital but use the index for machinery and machine tools.[10] It is also worth remarking at this stage on the choice of ASI data versus the PROWESS data set, which is more commonly used.[11] The latter data set is typically in better shape, having been constructed and validated by CMIE, which is a private firm, and therefore it is more popular with researchers. PROWESS panel data has also been available for some time. The data set is at the firm level, however, and many of the variables in the ASI data are not in PROWESS. In particular, for our purposes, it is useful that the ASI data includes figures for different types of labor, which are not available in the PROWESS data. The latter is also restricted to listed firms and public enterprises, so it gives a much narrower cross-section of Indian manufacturing firms than the ASI data. On the other hand, PROWESS includes service sector firms, which are not in the ASI data. In sum, each data set has its merits, but the ASI data is better suited for our purposes, and relatively under-analyzed.

Given the complexities of the data set, we next provide various summary statistics and graphs to give an initial overview of the properties of the data. Accordingly, Table 1 reports summary statistics for the main variables used in our analysis. Of particular interest is the variable that measures combined hardware and software assets—we refer to this as the IT capital of the plant.[12] Annual IT investment is also reported in the ASI data, and has the same combination of hardware and software included. It should be noted that because of missing observations, the number of observations differs across variables. As long as there is not a systematic pattern of missing observations, reporting the means for different variables with different numbers of observations still provides useful information.

10. Some authors have used software price deflators from other countries, when separate data on hardware and software is available. One possibility might be that hardware prices have fallen relative to other goods. In our case, discussions in surveys of IT use in Indian manufacturing (e.g., NMCC–NASSCOM 2010) suggest that the cost of IT capital has not come down so rapidly. If we are underestimating the real amount of IT capital by deflating later years' amounts too much, then our results will be biased upwards.

11. In addition to Kite (2012), see, for example, Alfaro and Chari (2009).

12. Here it must be also be acknowledged that the PROWESS data used by Kite has separate figures for hardware and software.

TABLE 1. Summary Statistics

	Whole data		*ITK > 0*		*ITK = 0*		*For sample used in the regression*	
Variable	*Obs*	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*
Gross Valued Added (INR)	23841	3560450	14016	5589169	9825	666349.7	12856	5881595
Plant and Machinery (INR)	38120	2870858	19367	5043062	18753	627532.4	12856	5541915
Transport Equipment (INR)	33277	46163.29	18491	73202.21	14786	12349.09	12856	79706.75
Stock of ITK (INR)	26169	48802.43	19427	65738.96	6742	0	12856	74213.04
Skilled Workers	33687	78.57841	18586	112.3726	15101	36.98523	12856	120.6595
Production Workers	37941	294.339	19231	359.7769	18710	227.079	12856	385.0094
Total Employment	38502	360.2158	19359	466.9185	19143	252.309	12856	505.7222
Skill Composition	33681	0.2318955	18582	0.259475	15099	0.197954	12856	0.258986
Short-term loans (INR)	24550	758357	14602	880092.3	9948	203327.1	10117	1094322
Profits (INR)	31411	1425284	18088	1656997	13323	298384.9	12856	2249648
Electricity Used (External, KWH)	21279	6271616	12503	9599056	8776	1531076	7641	9061525
Electricity Used (Own, KWH)	37366	4480455	19070	7414924	18296	1421846	12615	7920286

Source: Authors' calculations from ASI survey data, 2003–07.

Note: Data used is from Annual Survey of Industries for years 2003–07.

In addition to statistics for the entire sample, we also report the corresponding numbers for each of two subsamples. The first category is plants that report positive levels of IT capital, as measured by the value of hardware and software stock. The second category is all other plants, which either report zero levels of IT capital stock, or have missing values. The latter could be genuine missing values, or they could be cases where the stock is zero. To deal with this problem, we will also consider a two-stage selection correction procedure in the regression analysis, as described later in this section.

The main message of Table 1 is that there is a distinct difference between plants that have positive stocks of IT capital and other plants, across every dimension of comparison. Plants that have positive stocks of IT have higher productivity, as measured by gross value added, higher profits, more workers of each type, and higher levels of equipment and machinery.[13] In the case of some variables, the differences are at the level of one order of magnitude, though they are less pronounced for the labor variables. These patterns were originally pointed out in GSS (2008), and of course there is nothing that can be inferred from these summary statistics with respect to causality. One point worth noting, that was not featured in GSS, is the higher levels of skill composition of the workforce in IT-using plants. Here skill composition is simply the ratio of salaried workers (a proxy for skilled workers) to the total workforce. The other category of workers is production workers, who are identified in this analysis with unskilled workers.

Finally, the last set of data in Table 1 is for the plants that are in our regression analysis. In creating a balanced panel of plants with positive IT capital, we lose a few observations, and the plants are on average slightly larger than those for which IT capital is positive. The comparison across the different sets of data in Table 1 suggests that the restriction of our data set for the regression analysis does not involve an obviously biased subsample.

Table 2 provides summary statistics by region, defined as North, South, East and West. The West region stands out in terms of larger plants, with higher investment, and particularly with higher stocks of IT capital, as well as higher profits and employment. The North region is next in these characteristics, followed by the South and then the East, though the latter two are not so far apart in many respects, in terms of average characteristics of

13. Barry Bosworth has pointed out to us that profits are a very high share of gross value added. We have examined the data carefully, including the calculations of GSS (2008), and find this to be a consistent property of the data, probably reflecting definitional idiosyncrasies. For our regressions, we focus only on GVA. GSS found very similar results when GVA is replaced by profits.

TABLE 2. Summary Statistics by Region

	NORTH		*EAST*		*WEST*		*SOUTH*	
Variable	*Obs*	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*
Investment in IT (INR)	7541	7880.60	5488	5335.99	5508	10771.54	7632	5903.50
IT Capital Stock (INR)	7541	47175.73	5488	37254.14	5508	74847.73	7632	39917.00
Short Term Loans (INR)	6979	695371.9	5020	417785.4	4694	1149655	6784	804419.6
Profits (INR)	8609	1241761	7430	910802	5567	3059907	8467	988599.2
Gross Value Added (INR)	6789	1667300	5903	3029796	4443	6576671	6706	3945772
Plant and Machinery (INR)	10093	2392712	10270	3036944	6567	4373495	11190	2267855
Transport Equipment (INR)	9381	44885.58	8241	47450.92	6132	62491.88	9523	35793.44
Employment of Production Workers	9960	245.16	10061	259.43	6629	314.45	11291	357.02
Employment of Skilled Workers	8794	82.39	8355	67.37	6232	112.59	10306	63.85
Skill Composition	8792	0.263	8354	0.220	6231	0.262	10304	0.197
Total Employment	10063	315.68	10305	309.84	6699	417.18	11435	411.43

Source: Authors' calculations from ASI survey data, 2003–07.
Note: Data used is from Annual Survey of Industries for years 2003–07.

the plants. The West and North regions are distinct from the other two in terms of having higher skill compositions of the labor force.

The next set of summary statistics is in Table 3, which presents data for just three variables, but with a breakdown by industry. The three variables used for illustrating the substantial differences across industries in the sample are investment in IT capital, gross value added and skill composition of the labor force. There is considerable variation across industries in the last of these variables, and it appears that there is some positive association of skill composition with the relative level of investment in IT capital (after adjusting for size, as measured by gross value added).

It is also useful to get a sense of the variation in the data over time. We illustrate this through some line graphs for selected variables. Figure 1 displays the time pattern over the five years for stock of IT capital, stock of plant and machinery, and gross value added, all measured in Indian Rupees. For the second and third variables, we display the pattern for all plants, as well as for each category of plant divided by whether they report positive IT capital stock or not. The stock of IT capital increases over the five-year period.[14] The real value of the stock of plant and machinery for plants without IT capital does not increase, while there is a small increase in this stock for plants with IT. On the other hand, the average for all plants increases more rapidly, suggesting that the proportion of plants with IT capital is going up over the five-year period. In the case of gross value added, the increase in GVA for plants with IT capital is quite dramatic, and much greater than for plants without IT capital. Whatever the causality, there is a striking difference between the performance of the two categories of plants.[15]

We also illustrate the trends for selected variables, after scaling to correct for size and growth effects. Thus, in Figure 2, we display the trends associated with the stock of IT capital and GVA as ratios to the stock of plant and machinery. The stock of IT capital as a ratio to the stock of plant and machinery is relatively constant.[16] In the case of the ratio of GVA to the stock of plant and machinery, the difference in trends across the two types of plants (with and without IT capital) found in Figure 1 is preserved, even after normalizing by the growth in the stock of plant and machinery.

14. We also examined the behavior of IT investment over time. This annual rate also increases in real terms.

15. Interestingly, there are no perceptible trends in employment levels or skill composition for either type of plant in this data set.

16. We did find that the share of annual IT investment to the stock of plant and machinery did increase from 2004 onward.

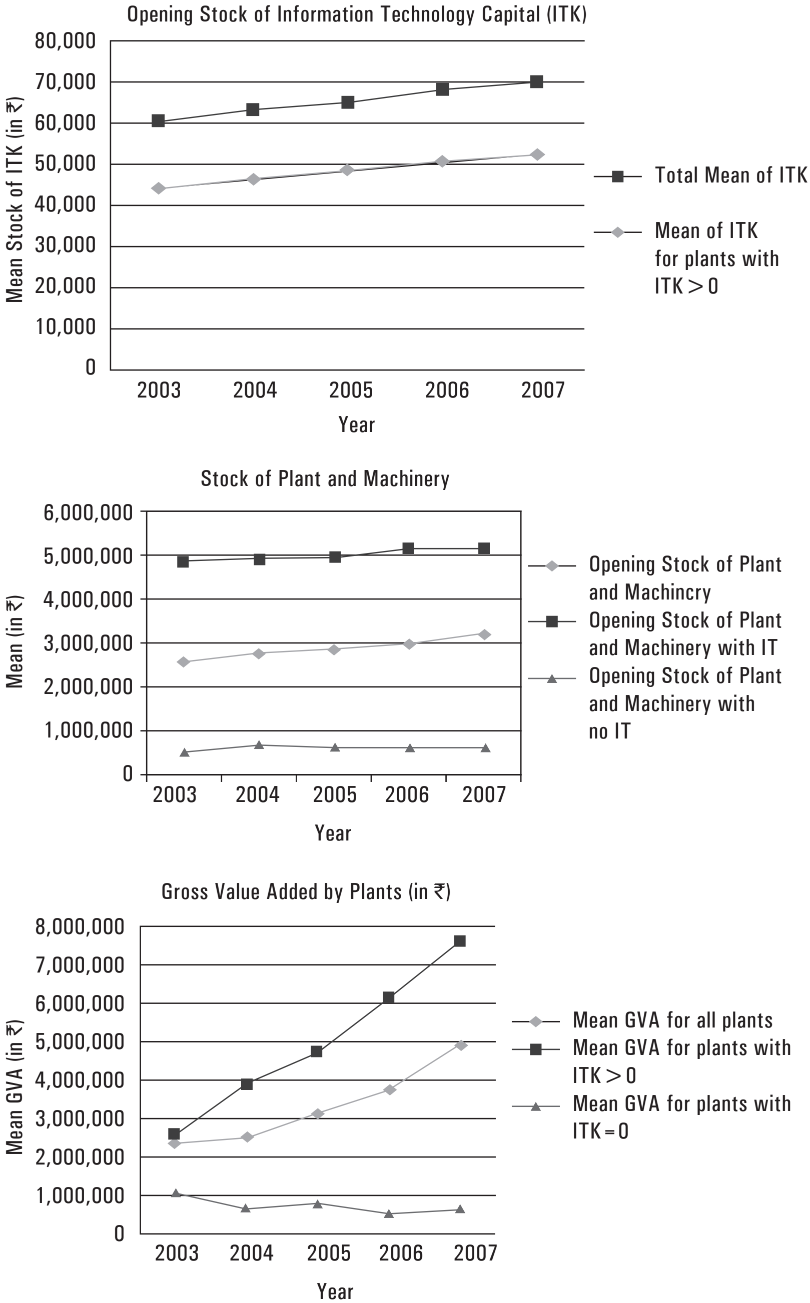
TABLE 3. Summary Statistics by Industry

	Gross value added (INR)		*Investment in ITK (INR)*		*Skill composition*	
	Obs	*Mean*	*Obs*	*Mean*	*Obs*	*Mean*
Manufacture of Food and Beverages	5582	729783.1	5182	2377.39	7830	0.217421
Manufacture of Tobacco Products	531	1756950	536	4125.813	887	0.122224
Manufacture of Textiles	2957	1059625	3133	4429.889	4152	0.16006
Manufacture of Wearing Apparel	497	487892.7	691	3751.073	868	0.170738
Tanning and Dressing of Leather Manufactures	404	589026.3	477	3722.112	546	0.183199
Manufacture of Wood and Wooden Products	0	0	303	1635.266	460	0.292009
Manufacture of Paper and Paper Products	0	0	575	7992.88	703	0.2306
Publishing and Printing	558	-220203	675	20280.92	729	0.377984
Manufacture of Chemicals and Chemical Products	2844	5199434	3029	12153.55	3672	0.267725
Manufacture of Rubber and Plastic Products	716	1985985	844	5017.176	952	0.230513
Manufacture of Other Non-metallic Mineral Products	1885	1860147	1636	7323.875	2676	0.20283
Manufacture of Basic Metals	1473	5352452	1631	10904.93	1862	0.225596
Manufacture of Fabricated Metal Products	801	388880	902	2992.697	968	0.236739
Manufacture of Machinery and Equipment	1492	1203041	1611	10250.69	1684	0.312336
Manufacture of Electrical Machinery and Apparatus NEC	858	1877375	939	8435.887	1020	0.280435
Manufacture of Radio, Television and Communication Equipment	372	1467062	457	7046.228	503	0.338064
Manufacture of Medical, Precision and Optical Instruments	518	562697.1	592	4988.25	587	0.335726
Manufactures of Motor Vehicles, Trailers, and Semi-trailers	659	3501614	756	19641.23	833	0.232911
Manufacture of Other Transport Equipment	629	2029383	702	10086.86	755	0.252078
Manufacture of Furniture	555	335705.3	514	1282.662	567	0.255691

Source: Authors' calculations from ASI survey data, 2003–07.

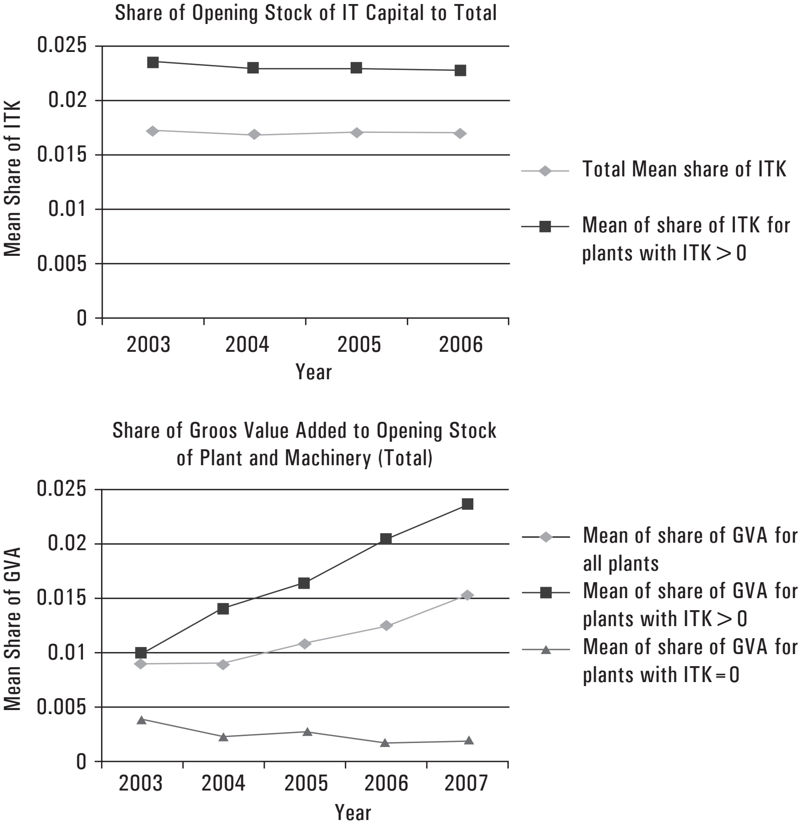
Note: Data used is from Annual Survey of Industries (henceforth, ASI) for years 2003–07.

FIGURE 1. Trends of Selected Variables



Source: Authors' calculations from ASI survey data, 2003–07.

FIGURE 2. Trends in Ratios of Selected Variables to Stock of Plant and Machinery



Source: Authors' calculations from ASI survey data, 2003–07.

Finally, in this overview of the data, we also calculated some correlation coefficients. Using deflated data, the correlation between GVA and the stock of IT capital in the data is 0.400, while the correlation between GVA and annual investment in IT capital is lower, but still clearly positive, at 0.214. Skill composition also shows a positive correlation with the IT measures, having correlations of 0.142 with the IT capital stock and 0.112 with investment in IT. We would expect these correlations to be lower, since skill composition does not increase with the scale of the firm, but the positive correlation with IT measures is consistent with the kinds of evidence on the role of human capital in complementing IT that was presented in the previous section.

3.2. Empirical Methodology

The data display several clear patterns, all pointing to a positive association between the use of IT in Indian manufacturing plants and various characteristics of inputs and performance. The patterns are similar to those found in GSS (2008). What is not clear from this kind of data description, of course, is the nature of causal relationships—are the relationships observed in the scatter plots, or in the systematic differences between plants that report using IT and those that do not, due to the use of IT, or are both IT use and performance due to other factors, such as managerial skill, labor force composition or underlying technologies?

We examine this issue using standard regression techniques. In particular, we estimate production functions for our panel data, which allows us to include plant-level fixed effects. We can also use lagged variables as instruments to deal with endogeneity of the input variables. The dependent variable in these regressions is gross value added (GVA). We estimate equations in log linear form, which corresponds to a Cobb-Douglas production function in the absence of any other controls. Since there is missing data on the dependent variable, as well as cases where the value of the variable is negative, we also consider the possibility of selection bias in our estimates, by using two-step Heckman correction procedures.

An important concern in this analysis is that time-varying unobservable characteristics of plants may be affecting the relationship between the stock of IT capital and the gross value added. These will not be controlled by plant fixed effects. In order to overcome this issue, we use instruments that are orthogonal to the error term (and therefore, also plant fixed effects) within a Generalized Method of Moments (GMM) framework. Along the lines of Blundell and Bond (1998), the instruments used in this analysis are both the lagged (first and second) values of the dependent variables, and the lagged (first and second) values of their differences.[17] The results from the GMM

17. We use the "system" version of GMM as developed by Blundell and Bond (1998), and implemented in the STATA software package. GMM estimators may be subject to their own biases, including problems created by weak instruments, but they provide a useful alternative to the OLS estimates. In any case, in our specifications, we typically use beginning of period stocks or lagged flow variables to deal with simultaneity issues that would arise for OLS.

specification are presented alongside the results from the OLS specification as a robustness check for each model. Year fixed effects that control for changes in policy or any event that occurred in a year and affected all plants uniformly are included in both the GMM and OLS specifications.

In addition to the production function, we also estimate IT investment demand equations. The objective is to understand the factors that influence the decision to invest in IT, as well as those that determine the level of IT investment in cases where it is undertaken. Here also, we deal with two levels of selection—IT investment may be zero, or it may be missing. We allow for the possibility that each of these forms of selection may bias the estimated IT demand equation, and therefore again use the two-step Heckman procedure with two levels of selection.

The algebraic forms of the estimating equations are standard, but we present them here for concreteness. The basic production function has a standard Cobb-Douglas form and is given by

$$\begin{aligned}\ln(GVA)_{it} &= \alpha + \beta_1 \ln(PM)_{it} + \beta_2 \ln(TE)_{it} + \beta_3 \ln(ITK)_{it} \\ &\quad + \beta_4 \ln(SL)_{it-1} + \beta_4 \ln(UL)_{it-1} + u_i + v_t + \varepsilon_{it} \qquad (1)\end{aligned}$$

where *GVA* is gross value added, *PM* is stock of plant and machinery at the beginning of the period, *TE* is stock of transport equipment at the beginning of the period, *ITK* is IT capital stock at the beginning of the period, *SL* is number of skilled employees, and *UL* is number of unskilled employees. We will also estimate various extensions of this base specification, incorporating regional dummies, measures of ownership and organization, characteristics of importing inputs, interaction terms, and so on.

The IT investment demand equation as estimated can be thought of as a conditional demand function. We do not have input price data, and we regress investment in a given year on the inputs in the production function. We also attempt to control for financial and infrastructure constraints on the demand for IT investment. Finally, we include inverse Mills ratios to correct for possible selectivity biases caused by the fact that the demand equation includes only observations with reported, positive levels of the dependent variable. These selectivity correction terms are derived from the standard two-step Heckman procedure, where the first step involves estimating probit equations for whether IT investment is reported or not, and whether reported IT investment is positive or not. The probit equations are specified similarly to the demand equation, but include external electricity, and exclude internal electricity and IT capital.[18] The investment demand equation is as follows.[19]

$$\begin{aligned}\ln(ITI)_{it} = \alpha_1 &+ \gamma_1 \ln(PM)_{it} + \gamma_2 \ln(TE)_{it} + \gamma_3 \ln(ITK)_{it} \\ &+ \gamma_4 \ln(SL)_{it-1} + \gamma_4 \ln(UL)_{it-1} + \gamma_5 \ln(STL)_{it-1} + \gamma_6 \ln(\pi)_{it-1} \quad (2) \\ &+ \gamma_7 \ln(EO)_{it} + \lambda_1 IMR_1 + \lambda_2 IMR_2 + u_{1i} + v_{1t} + \varepsilon_{1it}\end{aligned}$$

4. Results

4.1. Role of Plant Fixed Effects

The basic production function results are presented in Table 4. The specification is in logs, so a Cobb-Douglas form is being estimated. The dependent variable is gross value added (GVA). The first three variables are capital stocks, measured at the beginning of the period, thus reducing simultaneity problems. The third of these, IT capital, is of particular interest for us. The labor variables are the numbers of salaried and production workers respectively, interpreted as skilled and unskilled employees. To deal with endogeneity, we use lagged values of these two variables.[20] Table 4 presents four specifications. The first column is a base specification with only year fixed effects, estimated by OLS. All the coefficients except that of transport equipment are statistically significant, have the right signs, and have reasonable magnitudes. The sum of the coefficients, which is a measure of returns to scale, is quite close to one for the base specification.

Adding plant-level fixed effects (column 2) increases the magnitude of the transport equipment coefficient, but reduces the magnitude of all the other coefficients.[21] The coefficient of IT capital stock is now much smaller, but is still statistically significant, and its economic significance

18. We estimated several alternative specifications of the probit equations—the importance of profits was robust across specifications.

19. *STL* stands for short-term loans, π for profit and EO for electricity purchased from outside (the grid).

20. Of course, if there is serial correlation in the error terms, using lagged values will not solve problems created by endogeneity. In GSS (2008), since a panel was not available, endogeneity was dealt with by using industry averages for the employment variables.

21. In the previous version of this paper, we also tried a specification with industry fixed effects. The impact on the coefficient magnitudes was somewhere in between the no cross-sectional fixed effects and plant-level fixed effects. Our industry fixed effects estimates were quite close to those of GSS (2008).

TABLE 4. Production Function Estimation

	(1) OLS with year FE	(2) OLS with plant and year FE	(3) First differences with year FE	(4) GMM IV with year FE
Plant and Machinery	0.387***	0.234***	0.225***	0.573***
	(0.0189)	(0.0536)	(0.0524)	(0.113)
Transport Equipment	0.0310***	0.0517***	0.0425**	0.172***
	(0.0113)	(0.0179)	(0.0179)	(0.0541)
ITK	0.215***	0.0418**	0.0377*	0.175**
	(0.0180)	(0.0199)	(0.0219)	(0.0721)
Lag (Production Workers)	0.172***	0.117***	−0.00660	0.343***
	(0.0207)	(0.0347)	(0.0321)	(0.0753)
Lag (Skilled Workers)	0.225***	0.0919***	0.0500	0.120*
	(0.0220)	(0.0334)	(0.0322)	(0.0680)
Constant	3.853***	8.088***		−0.172
	(0.161)	(0.719)		(1.897)
N	11194	11194	7277	11194
adj. R^2		0.047	0.017	

Source: Authors' calculations from ASI survey data, 2003–07.
Note: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$)
All variables reported are in logs. Data used is from ASI for years 2003–07.

is not negligible. The magnitude of the IT capital stock coefficient is now quite similar to that in Kite (2012).[22] The third column reports estimates for first differences, which are quite similar to the full fixed effects estimates.

The fourth column reports estimates using the Blundell and Bond (1998) GMM estimator for panel data. Several of the coefficients are now quite high, and the sum of the coefficients is great than one. The coefficient of IT capital is in between the higher OLS estimate and the lower fixed effects estimate. The important point is the economic and statistical significance of this coefficient across the different estimation methods. In subsequent specifications, we focus on the OLS with plant fixed effects and GMM estimates.

We also estimated the production function with lags on the beginning of period stocks, including IT capital. We did not find any results to suggest that the impact of IT capital occurs with a lag. Hence, the results presented here for Indian manufacturing plants are somewhat different than the results of Bresnahan et al. (2002) for US data—they found substantial lags in the effects of IT on productivity. One possible source of difference is our use of stocks rather than per period investments. It could also be the case that

22. B. N. Goldar, in his comments on the conference draft, pointed out that the OLS coefficient without plant fixed effects implies an implausibly high marginal product of IT capital, given the low level of IT capital relative to plant and machinery.

Indian manufacturing plants have more current and immediate opportunities to enhance productivity through IT investment, than was the case for US firms in the 1990s.

One possible interpretation of the difference between the estimates without and with plant fixed effects is that the productivity of IT capital, more than other inputs, is correlated with unobservable managerial ability, which is captured in the plant fixed effects. Of course, it is possible that there are other explanations, such as different omitted inputs. However, our interpretation is consistent with the work of Bloom, Sadun, and van Reenen (2012), comparing the productivity of IT use by American and European managed firms. This interpretation also provides one possible explanation for why the higher productivity of IT-using firms is not easily mimicked by other firms—they do not have access to an input that is, for various reasons, in short supply in India, that is, managerial expertise or quality (Bloom et al. 2012; NMCC–NASSCOM 2012).

4.2. Selectivity

In the regressions reported in Table 4, one possible issue is that observations where GVA is negative or missing are excluded. This could create a selectivity bias. Accordingly, we checked for both sources of bias, using a two-step Heckman procedure. We estimated a probit equation where the dependent variable was 0 if GVA was missing and 1 otherwise, and a second probit regression where, for observations where GVA is not missing, the dependent variable was 0 if GVA was negative and 1 otherwise. We then reestimated the production function with inverse Mills ratios calculated from the two probit regressions. Neither Mills ratio in this last regression was statistically significant. Moreover the coefficients were quite comparable in magnitude to the production function without the selectivity correction. Hence, we reach the conclusion that selectivity of firms based on missing or negative GVA is not an issue, and we proceed in subsequent regressions without selectivity corrections.

4.3. Intermediate Imports and Skill Composition

Work by one of the authors (Sharma 2012) suggests that imports of intermediate goods have been important in affecting the skill composition of the workforce in Indian manufacturing plants. Several of the papers discussed in the literature review of Section 2 find that the composition of the workforce is a significant factor in affecting the productivity of IT investment at the firm level. Accordingly, we explore the impact of the use of intermediate imports and of skill composition on the production function estimates. These results are reported in Table 5. We estimate each specification by OLS as well as GMM. All the OLS regressions in Table 5 include year and plant fixed effects, while the GMM estimates include year fixed effects.

The first two columns of Table 5 add a dummy variable that is 1 for plants that use imported intermediate goods and 0 otherwise to the baseline specification. The coefficient has the expected positive sign in both the OLS and GMM estimates, and it is statistically significant. Plants that use intermediate goods imports are more productive on average, as measured by GVA. In both cases, the coefficient of IT capital remains positive and significant. The third and fourth columns of Table 5 add an interaction term of IT capital with the import dummy. The interaction term coefficient is negative and significant at the 10 percent level in the OLS estimation, but negative and insignificant in the GMM case. Hence, there is weak evidence that IT capital and imported intermediates might be substitutes to some extent.

The fifth and sixth columns of Table 5 reports results when only skill composition is added to the baseline regression. While the original coefficients are relatively stable to this inclusion (though the coefficient of IT capital is no longer significant in the OLS estimation), the new variable is statistically significant, but does not have the expected sign. We might have expected a positive coefficient, consistent with plants that have relatively more skilled workers being more productive. One possibility is that the estimated negative coefficient is capturing some variation, across industries, which is not being captured in the plant fixed effects. However, this remains a subject for further investigation. The seventh and eighth columns add an interaction term of skill composition with the stock of IT capital. This regression yields a result that is somewhat consistent with previous studies of the effect of joint IT and human capital investment. The coefficient of IT capital is now insignificant, while that of skill composition is more strongly negative. However, the interaction term has a positive coefficient, statistically significant at the 5 percent (OLS) or 10 percent (GMM) level, indicating complementarity between IT capital stock and the proportion of skilled workers.[23]

23. We also estimated a specification with both additional variables (though not with the interaction terms), and the coefficients were quite stable across the specifications. In particular, the coefficient of IT capital had a similar magnitude and degree of statistical significance across specifications. We also estimated the production function using skill composition lagged by one year, to examine whether investments in skilled labor take time to have a positive impact. However, in this case, the coefficients of the new variable and interaction terms were not statistically significant.

TABLE 5. Imported Intermediates and Skill Composition

	(1) OLS	(2) GMM	(3) OLS	(4) GMM	(5) OLS	(6) GMM	(7) OLS	(8) GMM
Plant and Machinery	0.244***	0.475***	0.222***	0.480***	0.299***	0.518***	0.303***	0.483***
	(0.05)	(0.0971)	(0.05)	(0.0898)	(0.04)	(0.107)	(0.04)	(0.0997)
Transport Equipment	0.050***	0.153***	0.050***	0.158***	0.045***	0.165***	0.045***	0.160***
	(0.02)	(0.0479)	0.02	(0.0477)	0.02	(0.0521)	0.02	(0.0504)
ITK	0.043**	0.147**	0.063***	0.183**	0.033	0.180**	–0.007	0.0789
	(0.02)	(0.0622)	(0.02)	(0.0744)	(0.02)	(0.0726)	(0.03)	(0.0868)
Production Workers (Lag-1)	0.112***	0.322***	0.112***	0.314***	0.093***	0.256***	0.096***	0.244***
	(0.03)	(0.0688)	(0.03)	(0.0687)	(0.03)	(0.0579)	(0.03)	(0.0574)
Skilled Workers (Lag-1)	0.090***	0.103*	0.089***	0.106*	0.080**	0.191***	0.078**	0.195***
	(0.03)	(0.0622)	(0.03)	(0.0612)	(0.03)	(0.0612)	(0.03)	(0.0603)
M	0.352***	0.493***	0.738***	1.257**				
	(0.04)	(0.0717)	(0.20)	(0.577)				
M*ITK			–0.039*	–0.0788				
			(0.02)	(0.0583)				
Skill Composition					–0.628***	–1.187***	–2.185***	–5.014**
					(0.15)	(0.284)	(0.72)	(2.101)
Skill Composition*ITK							0.163**	0.402*
							(0.07)	(0.209)
Constant	8.110***	1.608	7.963	1.215	7.695***	1.071	8.003***	2.575
	(0.70)	(1.577)	(0.71)	(1.513)	(0.64)	(1.767)	(0.65)	(1.726)
R-sqr	0.062		0.062		0.053		0.054	
N	11194	11194	1194	11194	11065	11065	11065	11065
Year Fixed Effects		Yes		Yes		Yes		Yes

Source: Authors' calculations from ASI survey data, 2003–07.

Note: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$). All Variables except M and Skill Composition in Logs. All models include Year FE. Data from ASI (2003–07).

4.4. IT Intensity and Skill Intensity

We also examined the possibility that the impact of IT depends on the IT intensity of the plant in question. Thus, if the ratio of IT capital to other capital is high, the effect on value added might be different than if the ratio is low. Accordingly, we divided the sample into three roughly equal-sized subgroups, based on the degree of IT intensity, labeled low, medium, and high. We estimated the production function including dummies for the medium and high cases (with the low IT intensity dummy being the excluded one), as well as a specification interacting these dummies with the level of IT capital. Note that even the specification without interaction terms admits the possibility that IT intensity matters, while the interaction terms would reinforce or damp down this effect, depending on the signs of the coefficients. These results are presented in Table 6. The first two columns present the OLS and GMM results without the interaction terms. The OLS estimates suggest that there is no significant difference in the impact of IT capital for medium or high versus low IT intensity.[24] Adding in the dummies actually makes the IT capital term statistically insignificant as well.

The GMM results provide a different picture, with significant values for the medium and high IT intensity firms, but the estimated coefficient of plant and machinery in the GMM case is implausibly high. The third and fourth columns of Table 6 add interaction terms between the IT intensity dummies and the level of IT capital. In the OLS case, the results suggest that IT capital matters most for plants with medium IT intensity. The GMM estimates are again quite different in their implications, but the coefficient of plant and machinery is again implausibly high. Overall, it is difficult to reach firm conclusions about the variation of the impact of IT capital with IT intensity, and this issue deserves further investigation.

Table 6 also reports results for different degrees of skill intensity (measured at the plant-level) and the interaction of skill intensity with the level of IT capital. Columns 5 and 6 report results for OLS and GMM without interaction terms. In both estimations, medium and high skill intensity plants actually have lower base levels of productivity. Once interaction terms between skill intensity and IT capital are introduced, the OLS (column 7) and GMM (column 8) results diverge. The OLS estimates suggest that there are complementarities between skill intensity and the level of IT capital, but this possibility does not show up in the GMM estimates. On the other hand, the GMM estimates continue to show a positive and significant base

24. In an earlier draft, we also examined industry level IT intensity, and found that it had no significant impact in OLS estimates.

TABLE 6. Plant-wise IT and Skill Intensity

	IT intensity				*Skill intensity*			
	(1) OLS	*(2) GMM*	*(3) OLS*	*(4) GMM*	*(5) OLS*	*(6) GMM*	*(7) OLS*	*(8) GMM*
Plant and Machinery	0.241***	1.187***	0.236***	0.914***	0.234***	0.526***	0.238***	0.508***
	(0.0561)	(0.137)	(0.0558)	(0.111)	(0.0546)	(0.100)	(0.0551)	(0.0912)
Transport Equipment	0.0518***	0.274***	0.0527***	0.184***	0.0525***	0.158***	0.0527***	0.149***
	(0.0179)	(0.0733)	(0.0178)	(0.0534)	(0.0179)	(0.0503)	(0.0178)	(0.0483)
ITK	0.0295	0.0664	0.0163	0.157*	0.0429**	0.168**	0.00148	0.159**
	(0.0233)	(0.0852)	(0.0242)	(0.0873)	(0.0201)	(0.0701)	(0.0286)	(0.0807)
Skilled Workers (Lag-1)	0.0927***	0.247**	0.0920***	0.155**	0.0956***	0.142**	0.0954***	0.130**
	(0.0334)	(0.0997)	(0.0334)	(0.0754)	(0.0334)	(0.0601)	(0.0334)	(0.0589)
Production Workers (Lag-1)	0.117***	0.212**	0.116***	0.180**	0.111***	0.329***	0.112***	0.314***
	(0.0346)	(0.105)	(0.0347)	(0.0835)	(0.0344)	(0.0640)	(0.0343)	(0.0618)
Medium IT/Skill Intensity	0.0719	0.544***	–0.446*	2.170**	–0.160***	–0.128*	–0.511**	0.00406
	(0.0495)	(0.206)	(0.251)	(1.020)	(0.0383)	(0.0748)	(0.217)	(0.574)
High IT/Skill Intensity	0.0563	0.986***	–0.178	3.600**	–0.215***	–0.210**	–0.808***	–0.0987
	(0.0634)	(0.296)	(0.313)	(1.487)	(0.0461)	(0.0956)	(0.251)	(0.718)
Medium IT/Skill Intensity*			0.0546**	–0.232**			0.0383*	–0.0145
(ITK)			(0.0249)	(0.106)			(0.0221)	(0.0607)
High IT/Skill Intensity*			0.0248	–0.344**			0.0631**	–0.0135
(ITK)			(0.0301)	(0.146)			(0.0253)	(0.0743)
Constant	8.070***	–8.892***	8.243***	–4.046**	8.241***	0.797	8.540***	1.354
	(0.730)	(2.052)	(0.752)	(1.732)	(0.726)	(1.636)	(0.732)	(1.487)
N	11194	11194	11194	11194	11194	11194	11194	11194
adj. R^2	0.047		0.048		0.051		0.051	

Source: Authors' calculations from ASI survey data, 2003–07.

Note: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$). All variables except Intensity Measures are in Logs. Data from ASI for 2003–07.

coefficient for IT capital, but this is not the case for the OLS regression. Thus, the evidence for the hypothesis that a high enough skill intensity of labor is required for IT capital to be productive remains mixed.

4.5. Region Effects

Next we consider the possibility that there are differences across regions in the impacts of IT capital on gross value added. Surveys of Indian manufacturing (e.g., Chandra 2009) often note that there are substantial regional variations in the characteristics of manufacturing firms and industries across different regions of India. GSS (2008) note the differences in patterns of IT use across regions, as we have done in Table 2. Results for estimations with regional dummies and with interaction terms between the regional dummies and the coefficient of IT capital are presented in Table 7, for OLS and GMM estimations. We find that, despite the variation across regions in characteristics of plants, including their use of IT, there is no evidence that the impact of IT use varies across the four regions. Columns 1 and 2 present the OLS and GMM results, respectively, when regional dummies are included only in interaction with the ITK variable. Columns 3 and 4 estimate GMM with just regional dummies and then with interaction effects between the regional dummies and the level of IT capital as well.[25] In no case are any of these new terms statistically significant. Thus, despite the substantial differences in plant characteristics across the four regions, these do not seem to translate into differences across regions in the impact of IT capital on gross value added.

4.6. Agglomeration

One important aspect of IT use is its newness as a technology, and the implied possibility that mechanisms of technology diffusion may be important. GSS (2008) consider this possibility in modeling the IT investment decision, by considering state-level and industry-level agglomeration effects. The underlying idea is that IT investment (especially the decision whether to invest or not) will be influenced by the proportion of plants in that industry or state that already use IT. We can extend this logic to the possibility that the productivity of an IT-using plant may depend on the proportions of plants in the same state or the same industry that also use IT. The underlying

25. The case of OLS estimation with regional dummies is omitted, because the regional dummies are collinear with the plant fixed effects.

TABLE 7. Regional Effects

	(1) OLS	(2) GMM	(3) GMM	(4) GMM
Plant and Machinery	0.234***	0.470***	1.311***	1.058***
	(0.0536)	(0.181)	(0.211)	(0.130)
Transport Equipment	0.0515***	0.260*	0.267***	0.269***
	(0.0179)	(0.150)	(0.0910)	(0.0693)
ITK	0.0403	0.152	0.320**	0.144
	(0.0346)	(0.121)	(0.138)	(0.210)
Skilled Workers (Lag-1)	0.0915***	0.255**	0.259*	0.221**
	(0.0333)	(0.124)	(0.143)	(0.105)
Production Workers (Lag-1)	0.117***	0.471***	0.131	0.163
	(0.0347)	(0.109)	(0.145)	(0.106)
East			–2.573	–5.731*
			(1.656)	(3.193)
West			–1.626	1.553
			(1.436)	(2.624)
South			–2.147	–1.968
			(1.966)	(3.631)
East*(ITK)	0.0241	–0.0154		0.641*
	(0.0638)	(0.123)		(0.335)
West*(ITK)	–0.00477	–0.0882		–0.147
	(0.0484)	(0.129)		(0.251)
South*(ITK)	–0.00218	0.0490		0.176
	(0.0499)	(0.115)		(0.353)
Constant	8.086***	–0.537	–10.56***	–6.892***
	(0.719)	(1.387)	(3.161)	(2.660)
N	11194	11194	11194	11194
adj. R^2	0.047			

Source: Authors' calculations from ASI survey data, 2003–07.

Notes: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$). Year Fixed Effects included in all models. Data used is from ASI for years 2003–07.

mechanism in this case will be a combination of learning by doing and information-sharing among plants in the same state or the same industry.

Accordingly, in Table 8, we present results for state-level and industry-level agglomeration effects in the production function, each considered separately. As in GSS (2008), the degree of agglomeration is measured as the proportion of plants that use IT for the state or for the industry in which a particular plant operates. Columns 1 and 2 of Table 8 present OLS and GMM results for state-level agglomeration effects. There is no evidence of positive agglomeration externalities at this geographic level: indeed, the coefficients are marginally negatively significant. Adding interaction terms in columns 3 and 4 does not change this result, and the interaction terms are insignificant for each estimation method.

TABLE 8. Industry and State Agglomeration Effects

	State				Industry			
	(1) OLS	(2) GMM	(3) OLS	(4) GMM	(5) OLS	(6) GMM	(7) OLS	(8) GMM
Plant and Machinery	0.234***	0.572***	0.235***	0.673***	0.234***	0.417***	0.233***	0.370***
	(0.0539)	(0.105)	(0.0539)	(0.0975)	(0.0550)	(0.0980)	(0.0552)	(0.0733)
Transport Equipment	0.0524***	0.152***	0.0519***	0.172***	0.0514***	0.0832	0.0511***	0.122***
	(0.0178)	(0.0512)	(0.0178)	(0.0533)	(0.0179)	(0.0533)	(0.0179)	(0.0467)
ITK	0.0422**	0.157**	–0.0851	0.349	0.0418**	0.0838	–0.0995	–0.957**
	(0.0199)	(0.0652)	(0.0834)	(0.223)	(0.0200)	(0.0630)	(0.0804)	(0.380)
Skilled Workers (Lag-1)	0.0916***	0.0874	0.0922***	0.117*	0.0930***	0.0890	0.0917***	0.0610
	(0.0334)	(0.0666)	(0.0334)	(0.0705)	(0.0334)	(0.0770)	(0.0333)	(0.0653)
Production Workers (Lag-1)	0.119***	0.300***	0.118***	0.251***	0.120***	0.202**	0.119***	0.309***
	(0.0346)	(0.0733)	(0.0346)	(0.0764)	(0.0348)	(0.0859)	(0.0347)	(0.0727)
Industry/State Agglomeration Effect	–0.709*	–0.894*	–2.909**	1.083	0.874**	9.794***	–1.772	–20.01***
	(0.427)	(0.531)	(1.470)	(3.421)	(0.408)	(2.687)	(1.575)	(7.221)
Industry/State Agglomeration Effect*ITK			0.232	–0.257			0.280*	2.188***
			(0.142)	(0.369)			(0.156)	(0.746)
Constant	8.453***	1.052	9.646***	–1.960	7.626***	–0.277	8.991***	13.91***
	(0.761)	(1.518)	(1.111)	(2.011)	(0.793)	(1.703)	(1.071)	(3.854)
N	11194	11194	11194	11194	11194	11194	11194	11194
adj. R^2	0.047		0.048		0.048		0.048	

Source: Authors' calculations from ASI survey data, 2003–07.

Notes: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$). All variables except Industry and State Agglomeration Effects in Logs. Year Fixed Effects included in all models. Data is from ASI for years 2003–07.

Columns 5 and 6 of Table 8 replace geographic agglomeration with industry agglomeration effects. For both estimation methods, the coefficient of industry agglomeration is positive and statistically significant, possibly reflecting diffusion and sharing of knowledge with respect to IT adoption and use. When we add interaction terms, in columns 7 and 8, the results are even more striking, with the positive impact of IT capital being wholly reflected in the interaction term of the degree of IT use in that industry and the level of IT capital in that plant. These results are strongly suggestive of the idea that, to achieve better impacts of IT use, policy should focus at the industry level to encourage IT use. This is consistent, of course, with the recommendations of the NMCC–NASSCOM (2010) report.

4.7. Ownership and Organizational Form

While we do not have data on managerial quality, we can indirectly or partially explore differences in management through a consideration of differences in ownership and organizational form. In each case, there are a large number of categories, and we combine some categories for tractability. In the case of ownership, our baseline category is full ownership by the central government. The included categories of ownership are full ownership by a state government, joint central and state government ownership, joint government and private ownership, and wholly private ownership. The results are presented in Table 9. They suggest that central government ownership leads to lower productivity overall, but to more positive impacts of IT use, since the interaction terms are always negative and almost always statistically significant.

We also consider differences in organizational form, which may also capture differences in effective managerial quality. The reason is that managerial effectiveness may reflect a complex of institutional factors for each plant or firm, proxied by the organizational form. The baseline category in this case is private proprietorship, while the included dummy variables represent, respectively, joint family ownership, partnership, limited liability companies (public or private), government enterprises (excluding handlooms), and a miscellaneous category of other organizational forms, including cooperatives and trusts. The results are presented in Table 10. Statistically significant differences in the impact of organizational form and its interaction with IT capital exist for joint family ownership relative to sole proprietorships, but the results are not stable across the OLS and GMM estimations, so our conclusion must be that the evidence is inconclusive in the case of organizational form and the productivity of IT capital.

TABLE 9. Ownership Form

	(1) OLS	(2) GMM	(3) OLS	(4) GMM
Plant and Machinery	0.235***	0.446***	0.234***	0.434***
	(0.0537)	(0.0779)	(0.0536)	(0.0695)
Transport Equipment	0.0522***	0.173***	0.0533***	0.164***
	(0.0179)	(0.0507)	(0.0179)	(0.0441)
ITK	0.0419**	0.272***	0.133***	0.781***
	(0.0199)	(0.0677)	(0.0467)	(0.288)
Production Workers (Lag-1)	0.118***	0.247***	0.119***	0.251***
	(0.0347)	(0.0710)	(0.0347)	(0.0702)
Skilled Workers (Lag-1)	0.0940***	0.00463	0.0955***	−0.0241
	(0.0334)	(0.0599)	(0.0335)	(0.0611)
Wholly State/Local Government (2)	0.182	0.963***	1.491**	6.373**
	(0.171)	(0.338)	(0.757)	(3.217)
Joint State and Central Government (3)	0.0250	0.818	0.492	4.003
	(0.276)	(0.582)	(0.925)	(3.293)
Joint Sector Public + Joint Sector Private (4)	0.0283	0.872***	1.056**	6.088**
	(0.149)	(0.289)	(0.479)	(3.039)
Wholly Private (5)	0.155	1.236***	1.084***	6.457**
	(0.141)	(0.276)	(0.414)	(3.073)
ITK*(2)			−0.135*	−0.595*
			(0.0788)	(0.307)
ITK*(3)			−0.0418	−0.369
			(0.0847)	(0.306)
ITK*(4)			−0.103**	−0.575**
			(0.0485)	(0.286)
ITK*(5)			−0.0931**	−0.578**
			(0.0437)	(0.290)
Constant	8.109***	0.373	6.988***	−3.913
	(0.740)	(1.202)	(0.834)	(3.085)
N	11178	11178	11178	11178
adj. R^2	0.048		0.048	

Source: Authors' calculations from ASI survey data, 2003–07.

Notes: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$). All variables except Ownership indicators in Logs. Year Fixed Effects are included in all models. Data used is from ASI for 2003–07.

4.8. IT Investment Demand

The final part of our empirical analysis focuses on IT investment. We estimate a demand equation to examine the factors that influence investment in IT capital. Following GSS (2008), we allow for the fact that all plants do not invest in IT. The choice whether to invest is therefore examined using a Heckman selection model. Furthermore, we extend this procedure to the additional issue that some observations are missing—this extension allows us to correct for biases in reporting data about IT investment.

TABLE 10. Organizational Form

	(1) OLS	(2) GMM	(3) OLS	(4) GMM
Plant and Machinery	0.234***	0.549***	0.232***	0.479***
	(0.0536)	(0.0865)	(0.0534)	(0.0715)
Transport Equipment	0.0526***	0.141***	0.0516***	0.125***
	(0.0179)	(0.0475)	(0.0179)	(0.0449)
ITK	0.0427**	0.151**	0.0157	0.472**
	(0.0200)	(0.0602)	(0.126)	(0.238)
Production Workers (Lag-1)	0.116***	0.310***	0.116***	0.316***
	(0.0347)	(0.0711)	(0.0347)	(0.0689)
Skilled Workers (Lag-1)	0.0932***	0.152**	0.0933***	0.135**
	(0.0334)	(0.0642)	(0.0334)	(0.0614)
Joint Family (2)	0.402	0.417	−1.754*	4.509*
	(0.360)	(0.480)	(0.951)	(2.584)
Partnership (3)	−0.337	−0.720*	−0.431	3.172
	(0.249)	(0.391)	(1.155)	(2.206)
Public and Private Limited Companies (4)	−0.375	−0.435	−0.640	2.699
	(0.240)	(0.372)	(1.055)	(1.930)
Governmental Departmental Enterprise + Public Corporation (5)	−0.276	−1.225***	−0.333	0.128
	(0.287)	(0.444)	(1.184)	(2.052)
KVCs, Cooperative Societies, Handlooms and Others (6)	−0.247	−0.912**	0.155	1.215
	(0.271)	(0.415)	(1.127)	(1.997)
ITK*(2)			0.300**	−0.583*
			(0.149)	(0.305)
ITK*(3)			0.0164	−0.436
			(0.137)	(0.269)
ITK*(4)			0.0345	−0.354
			(0.124)	(0.239)
ITK*(5)			0.0111	−0.154
			(0.134)	(0.249)
ITK*(6)			−0.0384	−0.245
			(0.130)	(0.246)
Constant	8.434***	1.122	8.671***	−0.557
	(0.755)	(1.209)	(1.267)	(2.004)
N	11185	11185	11185	11185
adj. R^2	0.047		0.048	

Source: Authors' calculations from ASI survey data, 2003–07.

Notes: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$). All variables except indicators for Organization in Logs. Year Fixed Effects are included in all models. Data used is from ASI for 2003–07.

The first two columns of Table 11 present results for the two probit regressions that are used in correcting for possible selectivity biases. The first probit (column 1) assigns a value of 1 if the IT investment level is reported and 0 if the value is missing. The second probit (column 2) considers the set

TABLE 11. Investment in IT

	(2) Probit for missing values	(1) Probit for zero values	(3) Investment demand (OLS with Plant Fixed Effects)	(6) Investment demand (GMM Blundell and Bond)
Short-term loans (lagged)	0.0187	0.0281**	−0.00724	0.0208
	(0.0128)	(0.0139)	(0.0332)	(0.0385)
Profits (lagged)	0.0838***	0.0949***	0.0705	0.240**
	(0.0168)	(0.0186)	(0.0690)	(0.0990)
Plant and Machinery	−0.0904***	−0.0553**	0.128	−0.438***
	(0.0239)	(0.0241)	(0.165)	(0.124)
Transport Equipment	0.0198	0.0686***	0.141	0.185**
	(0.0152)	(0.0163)	(0.0898)	(0.0882)
Electricity used from an external source	−0.0241**	−0.0173		
	(0.0109)	(0.0116)		
Production Workers (Lagged)	−0.268***	−0.0101	0.254	0.0799
	(0.0300)	(0.0313)	(0.158)	(0.237)
Skilled Workers (Lagged)	0.369***	0.180***	−0.224	0.390
	(0.0359)	(0.0358)	(0.191)	(0.322)
ITK			−0.109	0.577***
			(0.114)	(0.111)
Own electricity used			0.0209	0.0599
			(0.0239)	(0.0366)
Inverse Mills Ratio (Zero Investment)			5.595	1.738
			(6.500)	(8.084)
Inverse Mills Ratio (Missing Investment)			−9.797	7.479
			(6.272)	(10.41)
Constant	1.100***	−0.884***	5.630	−3.099
	(0.232)	(0.241)	(4.106)	(5.282)
N	5357	4632	3859	3859
Pseudo R^2	0.06	0.06		
adj. R^2			0.016	

Source: Authors' calculations from ASI survey data, 2003–07.

Notes: Standard errors in parentheses (* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$). All variables except Inverse Mills Ratios in Logs. Models (3) and (4) include Year Fixed Effects. Data used in from ASI for years 2003–04.

of observations where the IT investment level is reported, and assigns 1 if it is positive and 0 if the level is reported as zero. Several additional variables are included in the probits compared to the production function, including a variable that measures the amount of electricity purchased from the grid. We also include two measures of financial capacity of the unit, namely, the previous year's profit and the extent to which short-term loans are used by the unit, also lagged. In both the probits, the profit variable has the expected positively signed coefficient, which is also statistically significant—one possible interpretation is that access to retained earnings is important for decisions to invest in a new technology. In addition, the number of skilled workers has a significant coefficient with the expected sign. The two probits suggest that the factors influencing whether IT investment is missing in the data or is reported as zero are not that different.

The final two columns of Table 11 presents the IT investment demand equation, with inverse Mills ratios calculated from the two probit regressions being included to correct for selection biases. The first of these columns reports OLS results with year and plant-level fixed effects, while the second column reports GMM results. The specification also includes the amount of electricity used that is generated from a captive power plant (something quite common in India because of the shortage and unreliability of electric power from the grid). The OLS results are quite inconclusive, since none of the estimated coefficients is statistically significant. In the case of the GMM estimates, it seems that the existing stock of IT capital, availability of skilled workers and higher profits all have positive impacts on the level of IT investment for the subset of firms that do invest in IT. In neither estimation are the inverse Mills ratios statistically significant, implying that there is no evidence of selectivity bias in the investment demand equation.

The first column of Table 11, without plant fixed effects, is not inconsistent with the estimates and interpretation in GSS (2008), but the addition of plant fixed effects provides a somewhat different possibility in terms of the underlying causal story, paralleling our earlier discussion in the context of the GVA production function.

5. Conclusions

India's manufacturing sector has not grown as much as one might have expected for a fast-growing developing country like India. The new National Manufacturing Policy sets ambitious goals for rectifying this perceived deficiency. One possible route to achieving higher productivity and faster growth in manufacturing is the use of IT, for boosting efficiency and supporting other forms of innovation (e.g., new products). Case studies have developed the idea that IT can play this kind of role, while noting the limited adoption of IT in Indian manufacturing. However, empirical studies of the impact of IT on Indian manufacturing are rare. This study aims to contribute to our empirical understanding of the impact of IT on Indian manufacturing, as well as barriers to its adoption.

In this paper we have used five years of panel data for Indian manufacturing plants to examine the relationship of investment in information technology to productivity, as measured by gross value added. This provides some new evidence on the impacts of IT in the Indian manufacturing context. We find some evidence that plants with higher gross value added have higher levels of IT capital stock, controlling for other inputs. However, this effect is attenuated when plant-level fixed effects are included. We interpret this result as an indication that unobserved managerial quality is an important factor in the impact of IT capital on productivity. We also explore the impacts of skill composition and use of imported intermediate inputs on the productivity of IT capital, as well as regional differences, and the relevance of organizational forms and types of ownership.

To investigate possible barriers to IT use in manufacturing, we examine the demand for IT investment, controlling for possible selectivity when estimating demand just for plants with positive investment. The evidence is somewhat mixed, but access to financial capital, in the form of retained earnings from past profits, may play an important role in the decision whether to invest in IT in Indian manufacturing plants. We also find there is some evidence for complementarities between the use of skilled labor and the decision to use IT capital in Indian manufacturing plants.

Our results provide further evidence, beyond previous work of GSS (2008) and Kite (2012) that investment in IT has the potential to have positive impacts on the performance of India's manufacturing plants. The results also complement case study and survey evidence that point toward the same conclusion. Our results also suggest that financial constraints may be the main barrier to investment in IT, rather than infrastructure constraints. Adoption by other plants in the same industry also plays an important role in spurring IT investment within a particular industry. Neither geographic clustering nor regional effects appear to matter significantly for the impact of IT capital on productivity, which is encouraging to the extent that it does not point toward any need for decentralized policies. This observation, together with the relatively large impacts of IT capital implied by our estimates, suggest that national policies to spur the use of IT in manufacturing may be beneficial, and that it may be possible to formulate them in a streamlined manner.

Of course, our results cannot be completely conclusive given the nature of the data exercise, and if variations in managerial quality play a role, then encouraging investment in IT in plants that lack appropriate management or other complementary inputs may not be efficient. At least our study indicates that these issues may need to be tackled jointly. This aligns with the case study and survey evidence, and distinguishes our approach and results somewhat from the previous work of GSS (2008) and Kite (2012), which also found positive impacts of IT use on Indian firms' economic performance.

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Comments and Discussion

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This is an excellent paper on the impact of Information Technology (IT) investment on productivity in Indian manufacturing. The study uses panel data for Indian manufacturing plants for five years, 2003–04 to 2007–08, drawn from the *Annual Survey of Industries* (ASI). Since the analysis is based on the unit level data of the ASI, its coverage is confined to the registered or organized manufacturing sector. This is, however, not a disadvantage, because, for the issue under investigation, it is the registered manufacturing units that should be considered for the analysis.

To assess the impact of IT investment on manufacturing productivity, a Cobb-Douglas production function (or to be more specific, a value added function) has been estimated for the manufacturing plants covered in the study. Skilled and unskilled labor are taken as two types of labor input, along with plant and machinery, transport equipment and IT capital stock, taken separately as three types of capital input. The analysis is enriched by the detailed investigation undertaken on the factors that might determine how much effect IT investment will have on productivity. Several factors have been considered: skill level of workers, use of imported intermediate inputs, location of the plant, agglomeration effects, and influence of the nature of ownership and form of organization.

An attempt has been made in the study to take care of the econometric problem of endogeneity of inputs in the production function. The labor variables, for example, have been taken with one year lag in the model. Also, the regression equations have been estimated by the ordinary least squares (OLS) method as well as by the system version of the generalized method of moments (GMM) technique which would address the problem of endogeneity. It may be mentioned here that many studies on production function estimation based on firm-level panel data (including some for Indian manufacturing) have used the methodologies suggested by Olley-Pakes and Levinsohn-Pertin for addressing the issue of endogeneity. It seems that the methodology adopted in the study for addressing the problem of endogeneity is not as well founded in the theory of producer behavior as the Olley-Pakes and Levinshon-Pertin methodology which as mentioned above have been widely used in empirical studies on production function and productivity.

The main finding of the study is that IT investment has a significant positive effect on productivity in Indian manufacturing, which corroborates the findings of similar studies undertaken earlier (Joseph and Abraham 2007; Gangopadhyay, Singh and Singh 2008). This is an important finding since, as Sharma and Singh note, one possible route to achieving higher productivity and faster growth in Indian manufacturing is the use of IT, which will help in boosting efficiency and support other forms of innovation, for example, introduction of new products. The new *National Manufacturing Policy* has set an ambitious goal of raising the share of manufacturing in aggregate GDP to about 25 percent by 2022 from about 16 percent now. The findings of the paper draw attention to the important role that investment in IT capital can play in attaining this goal.

The results of the econometric analysis show that that there are complementarities between skilled labor and IT investment. Thus, the impact of IT investment on output is greater for a firm that has a relatively higher proportion of skilled workers. Also, there is indication from the econometric results that management quality plays a vital role in exploiting the productivity enhancing potential of IT investment. While one may expect regional clustering to increase the impact of IT investment on productivity, the econometric results do not reveal any such impact.

To analyze the factors determining the firms' decision to invest in IT and the level of investment made, appropriate econometric models have been estimated. The results indicate that access to financial capital, electric power from the grid, and skilled workers all matter for the decision to invest in IT capital, but these variables are less important for the level of investment in IT, conditional on it being positive. Yet, the overall conclusion of the study is that financial constraints are the main barrier to investment in IT capital among Indian manufacturing firms.

Attention needs to be drawn to the fact that investment in IT capital stock is not the only way manufacturing firms can make use of and gain from information technology. The study on the effect of IT on productivity in Indian corporate sector firms undertaken by Grace Kite (2012) presents econometric evidence that points to the productivity enhancing effects of IT investment (corroborating the findings of the Sharma–Singh study under discussion) and also reveals that outsourced IT services contribute to productivity. Interestingly, Kite finds that the elasticity of output with respect to outsourced IT is higher than that with respect to in-house IT capital stock. Does this mean that many Indian manufacturing plants are taking advantage of IT without making any substantial in-house investment in IT capital stock? Evidently, a more comprehensive study of the impact of IT on productivity of Indian manufacturing firms needs to consider not only the investments made by firms in IT capital stock but also the use of outsourced IT services. Why some manufacturing firms have opted for in-house IT investment, some others have opted for outsourced IT services, and others are not using IT at all is an important question to investigate.

IT capital stock per plant (hardware plus software) is only a small fraction of the plant and machinery capital stock per plant. In the Western zone of India, for instance, the IT capital stock is about ₹75 thousand (as reported in the paper), whereas the plant and machinery capital stock is about ₹4.4 million. Yet, the elasticity of output with respect to IT capital stock at about 0.2 is not very low in relation to the elasticity of output with respect to plant and machinery capital stock at about 0.4 to 0.6. The implication is that the marginal product of IT capital stock is very high is comparison with the marginal product of plant and machinery capital stock. Probably, the IT capital stock variable is picking up the influence of certain other factors. One possibility, as indicated by the authors of the paper, is that the IT capital stock variable is picking up the effect of management quality. This is the reason why the introduction of plant fixed effects in the model (or estimating the model in first difference) causes the elasticity of output with respect of IT capital stock to come down drastically to about 0.04. But, even with this elasticity, the rate of return to IT investment is high. The fact that the rate of return to IT investment is high in relation to other capital assets implies that a reallocation of investment toward IT capital would increase productivity in manufacturing plants.

One aspect that is not discussed in detail in the paper, but could have been of interest to other researchers using ASI plant level data is the difficulties encountered by the authors in using unit level ASI data for their econometric analysis. The authors mention that they could create a panel dataset of manufacturing plants for the period 2003–04 to 2007–08 covering about 8,000 plants. A slightly larger figure on the number of plants in the panel dataset is reported by Chattopadhyay and others (2012). They have constructed several panel datasets. In the panel constructed for the period 2003–07 to 2007–08, they include about 10,200 plants. This is higher than the number of plants in the panel constructed by Sharma and Singh. But, the difference could be due to (*a*) difference in coverage and (*b*) difference in the treatment of joint-return units. While Sharma and Singh confine their analysis to manufacturing, Chattopadhyay and others consider the entire set of ASI industries. Where multiple units have submitted a joint return, this is probably being treated as one firm in the study of Sharma and Singh, but not in the study by Chattopadhyay and others.

Sharma and Singh observe that due to missing observations and zero values, they are compelled to work with a much smaller sample of plants; in their regression analysis, they are able to use data for only about 2,500 plants. This observation gives an impression that there are many missing observations and zero values in unit level ASI data, which is probably incorrect. This aspect should have been discussed in greater detail, and the number of missing observations and zero values for different variables should have been pointed out. To discuss this point further, Table 1 of the paper shows that for the five year period under study, Sharma and Singh could get about 38 thousand observations on the value of plant and machinery, but only about 24 thousand observations on gross value added (GVA). The gap seems to be attributable to the non-operating units. Out of the approximately 24 thousand observations where GVA data are available, IT capital stock is zero in about 10 thousand cases. This seems to be the dominant reasons why the effective sample size falls to about 2500.

Among various two-digit industries, the average IT capital stock is the highest for printing and publishing industry at about ₹20 thousand per factory (Table 3 of the paper). However, gross value added per factory in this industry (five-year average) is found to be negative at about –200 thousand rupees. This is the only industry in which gross value added is negative at the sample mean. For paper and paper products industry, there are about 600 observations on IT capital stock and about 700 observations on employment. By contrast, there are no observations on gross value added. This suggests that all firms of this industry which were included in the panel are non-operating units. These facts and figures signal certain problems being encountered in using the unit level data of ASI for preparing a panel dataset for the purpose of econometric analysis. A more detailed discussion of these problems would have been useful to other researchers.

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The paper by Singh and Sharma carries forward the analysis done in Gangopadhyay, Singh, and Singh (GSS 2008) and obtains more refined and richer results. This is largely because when the GSS work was done, there was no panel data available while the current paper uses the newly available panel information. The central theme in the current paper is the use and impact of IT in Indian manufacturing and the reasons why they are as they are. The authors use the Indian ASI data for the years 2003–07. This is an important study given that at one end, India has made huge strides in the global IT industry but the penetration of IT in Indian manufacturing has been relatively shallow. And, whatever penetration there is, it is not uniform either across regions or across sectors.

A major positive aspect of this paper is that it analyses plant-level data. IT-led productivity analyses using financial data have two serious differences with plant-level data used in this paper. First, the financial data is at the level of the company and a company's financials are the aggregate of the activities of all its plants and there could be varying levels of IT use in its different plants which the financial data are unable to separate out. Second, the financials of a company's IT expenditure does not distinguish between IT used in the corporate office vis-à-vis that used in the actual production process. This paper has neither of these two problems.

According to my reading, the major findings of the paper are: (*a*) greater IT use leads to greater productivity; (*b*) the use and productivity of IT in Indian manufacturing are dependent on the managerial skills available in a plant; (*c*) financial constraints are better at explaining the lack of IT than other infrastructural constraints; and (*d*) the level of IT use in a plant is dependent on the overall use of IT in the industry.

I have two major comments on the paper. These are more toward the next round of analysis that needs to be undertaken and less in the nature of what the paper's current shortcomings are. First, a more thorough analysis has to be done regarding the policy implications of the findings. For instance, given (*b*) and the fact that the paper uses plant level data, is the managerial issue one of more and better trained MBAs or, the production of more technically skilled managers on the shop floor. Unfortunately, the ASI data cannot make this differentiation but does point to this possibility. This, then, calls for a more focused survey of the skill levels, and skill types, of the managers in the plants that use more IT versus those that do not but are in the same industry and in the same region. In either case, public investment in skill formation becomes important. Related to this is the second point I wish to make. A number of studies point to the fact that different Indian states have different institutional environments within which firms operate and this, rather than managerial capabilities, could be a major factor (e.g., the Besley and Burgess 2004 paper and Bhaumik, Gangopadhyay, and Krishna [2008] in European Journal of Development Research). The authors, themselves, have noted the difference in IT use, both across regions and across industry.

General Discussion

T. N. Srinivasan questioned the use of plant-level data as opposed to data at the level of the corporation as the latter would allow an examination of investment decisions that involving the return to capital, which cannot be observed at the plant level. The authors responded that the purpose of the present paper involved more of a focus on the production process, which required the plant level data. While it would be interesting to combine observations at both the level of the company and the plant, such a data set was not yet available for India. Devesh Kapoor pointed to a data set of the National Manufacturing Competitiveness Council as a potential supplement to the study since it offers more details regarding the purpose and use of new IT capital investments.

Rajnish Mehra pointed to the lack of a measure of intangible capital and worried that might bias the results of the exercise. Ashok Mody thought that any role for IT capital would have to be small because it was not a major input to most manufacturing plants. He would prefer more of a focus on managerial quality as a key determinant of firms' success. However, the authors noted that there were no available measures of the concept, and in the statistical analysis differences in management performance were absorbed by the fixed effects.

Rajendra Pawar noted that there has been a large number of studies looking at the determinants of firms' success or failure and the role of IT in that process. He thought that it was a complicated problem that required substantial disaggregation to get to the decision levels that mattered. However, those studies suggest that the most important factor seemed to be the knowledge and involvement of top management. Second there was a need for a workforce that understood how to use the IT, and the amount of physical IT capital was a distant third.

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