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Perspectives on the Sources of Heterogeneity in Indian Industry

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A study of variations in technical efficiency across four industrial sectors in India shows that managerial effectiveness significantly influences efficiency and that considerable benefits derive from location within established industrial clusters for particular industries. Liberalization and globalization are likely to bring significant productivity gains even in low-technology industries as managers gear up to meet the challenges of competition.

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Summary findings

Lall and Rodrigo examine technical efficiency variation across four industrial sectors in India, using a stochastic production frontier technique. The results are comparable to technical efficiency distribution patterns obtained in other countries.

The authors examine heterogeneity in firm-level efficiency against internal, firm-level characteristics and against external characteristics (industry and location).

The results suggest that managerial effectiveness significantly influences efficiency and that considerable benefits derive from location within established industrial clusters for particular industries.

The methodology and findings indicate that the study of industry-specific technical efficiency patterns is a useful analytical tool for tracking domestic firms' response to liberalization and the advance of market forces.

An important policy implication of Lall and Rodrigo's results: There is considerable room for efficiency gains through better organization and management of production processes and improved supply chain management, even in the highly organized corporate sector. These gains could be achieved by purely internal learning processes with no extra investment in physical plant or equipment, or with the help of outside consultants, or through business alliances with partners from industrial countries (a rising trend).

The results also show that greater technical efficiency correlates with better energy use and higher investments in plant management.

How firms can be induced to undertake such investments in the "software" of production is an important issue. Liberalization and globalization are likely to bring significant productivity gains even in low-technology industries as managers gear up to meet the challenges of competition.

This paper—a product of Infrastructure and Environment, Development Research Group—is part of a larger effort in the group to understand the role of economic geography and urbanization in the development process. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Roula Yazigi, room MC2-622, telephone 202-473-7176, fax 202-522-3230, email address ryazigi@worldbank.org. Policy Research Working Papers are also posted on the Web at www.worldbank.org/research/workingpapers. The authors may be contacted at slall1@worldbank.org or crodrigo@gmu.edu. November 2000. (30 pages)

PERSPECTIVES ON THE SOURCES OF HETEROGENEITY IN INDIAN INDUSTRY

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1. INTRODUCTION

Studies of industry evolution in developing countries are becoming increasingly focussed on examining the extent to which firm level performance varies within narrowly defined sectors (Roberts and Tybout 1996, Tybout 1998). This trend is driven by the realization that patterns of evolution are dependent on a number of factors, such as the nature of skill and technology acquisition, market structure, and the relative importance of domestic versus the export markets (Lall 1999). These factors operate differently across industrial sectors, thereby making disaggregated analysis necessary. Some of the heterogeneity, particularly in labor productivity, derives from variation in capital-labor ratios, with higher capital intensity being associated with more technology-intensive production. While in general this variability is associated with product and process variations within each sector, some of the variation derives from imperfect product and factor markets, which enable firms to violate norms of allocative efficiency and yet remain viable.

A considerable part of the observed heterogeneity is the result of productivity variations emanating from spatial and scale effects. Firms locating in or with access to large urban areas can accrue economies of scale through potential increases in demand. In particular, as demand for a firm's goods and services increase, it possible for managers to scale up production, thereby investing in cost reducing technologies and hiring more skilled workers (Lall et al 2000). In addition there are generalized advantages conferred by locating within urban centers, which include access to developed factor and product markets, potential for inter-industry knowledge transfers, good infrastructure and communication facilities, access to a larger, more diverse labor pool, and potential for efficient subcontracting (Glaeser et al 1992, Fujita and Thisse 1996, Bell and Albu 1999). Moving beyond the general benefits of locating in urban areas, firms also benefit from being located in proximity to firms engaged in similar activities. These localization economies include increased potential for intra-industry knowledge spillovers, linkages and access to industry-specific specialized labor. Given that economic activity is not uniformly distributed across or within spatial units, it becomes important to examine the role of industry concentration as a factor influencing efficiency variations[1].

Within the firm, the quality of organizational and managerial efficiency in the individual production unit, influences inter-firm as well as inter-industry productivity variations. These determinants of productivity are associated with the efficiency with which factors, technology and material inputs are utilized. They reflect the level of competence of the entire production unit taken as a whole and depend mostly on the quality of management. The rapidly growing literature on technical efficiency is largely concerned with estimating the extent of this source of productivity variance (Coelli et al 1999). In practice however, effects deriving from scale and location externalities, tend to get bundled in with purely internal effects in the estimation of technical inefficiency.

Technical inefficiency introduces a plant-specific *diminution* of operational productivity in relation to the domestic best practice productivity that can be realized in a particular industry. Using plant level data for four major Indian industries at the three digit level of industrial aggregation, we examine the variation of this technical inefficiency component in relation to various locational and other economic variables. In particular we are interested in testing whether mean technical efficiency is higher - and its variance lower - in relatively modern or technology intensive sectors. Higher efficiency is expected in such sectors for several reasons, which include the adoption of efficient production technologies, higher skill levels of the workforce, a greater likelihood of knowledge diffusion and uniformity of efficiency in the plants being examined.

India has one of the oldest and most widely developed manufacturing sectors in the developing world. Since it has functioned to a large extent like a closed economy for most of the post-1948 period, it is a prime candidate for the study of industrial heterogeneity as described above. Additionally, since significant liberalization has been introduced into some sectors in the early 1990s, the forces of enhanced market competition are likely to have produced further differentiation. In this study, the variation of technical inefficiency, estimated by the stochastic frontier method, is examined in relation to scale, location, extent of infrastructure investment and other determinants.

Page (1984) argues that lower efficiency variation is to be expected in relatively modern industries due to a higher degree of homogeneity in the vintage of capital stock and labor force characteristics. The demand structure of industries is also likely to influence efficiency: firms in industries mainly catering to isolated local markets are likely to exhibit higher variations in (and have lower overall) efficiency as the incentive to raise productivity is held back by limited market size. In contrast, firms in industries accessing large domestic and global markets are likely to be relatively more efficient as their survival and profitability depends on their ability to compete with other producers.

A technique for measuring technical inefficiency of a plant, along with allocative efficiency, was proposed by Farrell (1957). The technical inefficiency of an individual plant in relation to a number of plants, is the productivity shortfall of the individual plant in relation to the optimal production frontier for the set of plants as a whole. Farrell's idea has been implemented through two distinct approaches. The first is a non-parametric technique of data envelopment analysis (DEA) and the second is the parametric frontier production technique (Coelli et al 1999). It is the latter approach which is of particular interest in the present research and is described below in more detail.

In the frontier technique, productivity is calculated by correcting for varying factor inputs in accordance with some assumed production function (as described explicitly in the next section). The resulting measure is actually an index of total factor productivity (TFP). Technical inefficiency is the TFP shortfall with respect to the best practice TFP for the entire set of plants. The technique of frontier production estimation, was implemented with a deterministic frontier by Aigner and Chu (1968), and with a stochastic frontier by Aigner, Lovell and Schmidt (1977). Since the latter technique takes account of measurement error and other sources of noise in the inputs, it is the one that has been most widely adopted.

This paper is organized in five sections. Following this introduction, Section 2 develops the stochastic frontier model. Description of the data, variables and industry sectors chosen are provided in Section 3. Section 4 presents the main results from the empirical analysis and Section 5 puts together a conclusion.

2. THE STOCHASTIC FRONTIER MODEL

The stochastic frontier model as pioneered by Aigner, Lovell and Schmidt (1977) begins by treating the neoclassical production function $Y = F(x)$ as a theoretical ideal. Thus, in equation 1, Y_i is output for the i-th plant, $F(x_i)$ is the deterministic core of the frontier production function which could be Cobb-Douglas, CES or translog and x_i is a vector of inputs. In one formulation energy, materials and intermediates are included as separate inputs. In another approach, which is preferred here due to the diverse nature of the industries studied, only capital and labor are included as factor inputs with energy, materials and intermediates being subtracted from output to yield a value-added measure of Y_i. Deviations from the theoretical optimum arise from two sources. These are (a) a symmetrically distributed random error term v_i, which accounts for plant specific random disturbances, measurement errors, etc. and (b) a one-sided error term u_i (u_i is positive or zero) which is identified as the *technical inefficiency* TIE_i for the *i*-th plant.

$$Y_i = F(x_i).\exp(v_i - u_i) \qquad (1)$$

The stochastic frontier is represented by $Y_i = F(x_i).exp\ (v_i)$, with $v_i \sim N[0, \sigma^2_v]$, where $Y_i = F(x_i)$ would have been the deterministic frontier in the absence of disturbances v_i and u_i. *Technical efficiency* TE, distinct from technical inefficiency as defined above, is identified as the *shortfall below the stochastic frontier* as specified in equation 2.

$$TE_i = Y_i / [F(x_i) \bullet \exp(v_i)] = \exp(-u_i) \qquad (2)$$

Thus a technical inefficiency value of $u_i = 0$, corresponds to the maximum technical efficiency of 100 percent in relation to the stochastic frontier. In the case of a Cobb-Douglas production function, the above equations are most conveniently expressed in log-linear form as follows, with the plant index i suppressed for convenience.

$$\ln Y = \beta_0 + \sum_k \beta_k \ln x_k + v - u \qquad (3)$$

$$\ln TE \ = \ \ln Y - \beta_0 - \sum_k \beta_k \ln x_k - v \ = \ -u \qquad (4)$$

In this formulation, $TIE = -u$, is the "TFP-shortfall" since in the absence of technical inefficiency u and random disturbance v, $exp\ \beta_o$ is the absolute, Hicks-neutral TFP. When u and v are present however, the stochastic frontier for any given plant is $(\beta_o + \Gamma_k \beta_k \ln x_k + v)$. In practice it is more convenient to work with and report the "efficiency shortfall" or technical efficiency TE. The above model is easily generalized to the case of a translog production function with the introduction of second order terms. The approach adopted here is to use the somewhat modified translog form of equation 5, introduced by Torii (1992), with value-added (VA) per employee va = VA/L as the variable to be explained. Here, L is the total number of employees, K the capital stock and k = K/L the capital/labor ratio. The equation to be estimated is then as follows.

$$\ln va = \beta_o + \beta_1 \ln k + \beta_2 \ln L + \beta_3 \ln^2 k + \beta_4 \ln^2 L + \beta_5 \ln k . \ln L + v - u \quad (5)$$

The value-added form of the production function avoids problems created by correlation between capital and energy, materials and other intermediate inputs.

The general approach adopted by Aigner, Lovell and Schmidt and most other analysts, has been to estimate the production function with some assumption about the distribution of the one-sided disturbance term u. A similar approach is adopted here. For each industry examined, it is possible to estimate the above coefficients by maximum likelihood techniques and the parameters of the u, v distributions. From these, the individual plant TIE values can be calculated as described below.

The inefficiency term u is modeled as either a half-normal or exponential distribution. A method for calculating the mean technical inefficiency for the set of plants and estimating the technical inefficiency of each individual plant, is given by Coelli et al (1999; pp.189-90), and shown here. Here $\phi(z)$ is the standard normal probability function and $\Phi(z)$ the cdf of the standard normal. Also $\varepsilon = v - u$, $\lambda = \sigma_u / \sigma_v$, $\sigma^2 = \sigma^2_u + \sigma^2_v$, $\gamma = \sigma^2_u / (\sigma^2_u + \sigma^2_v)$ and $\sigma^2_A = \gamma(1-\gamma)\sigma^2$.

$$E(\exp - u) = 2(1 - \Phi(\sigma\sqrt{\gamma})).\exp(-\gamma\sigma^2 / 2) \quad (6)$$

$$E[u_i | \varepsilon_i] = -\gamma\varepsilon_i + \sigma_A \phi(\gamma\varepsilon_i / \sigma_A)/(1 - \Phi(\gamma\varepsilon_i / \sigma_A) \quad (7)$$

The above is the minimum formal structure needed to separate out the individual plant specific technical inefficiencies for a given industrial sector.

The resulting technical efficiency values are then regressed against the variables chosen to explain its variation; these are spatial location SL, industry concentration LQ, managerial effectiveness ME, age of plant AG, and energy usage EU, as indicated in the following equation. The reasons for the choice of these particular variables are set out immediately below in Section 3.

$$\ln TE_i = \gamma_o + \gamma_1 \ln SL_i + \gamma_2 \ln ME_i + \gamma_3 \ln AG_i + \gamma_4 \ln LQ_i + \gamma_5 \ln EU_i + \ldots + e_i \quad (8)$$

3. Data Sources, Variables and Sectors Selected

(a) Data sources

The plant level data for this study are drawn from the Annual Survey of Industries (ASI), which is published by the Central Statistical Office of the Government of India. The individual plant or "factory" is the unit of analysis used in the survey and the data are based on returns provided by factories[2]. The ASI covers factories registered under sections 2m(i) and 2m(ii) of the Factories Act 1948, employing 10 or more workers and using power, and those employing 20 or more workers but not using power on any day of the preceding 12 months.

Data on various firm level production properties such as output, sales, value added, labor cost, employees, capital, materials and energy use have been used in our study. We closely examined data quality issues by examining the data as well as reviewing the comments of other researchers on this issue. We dropped observations for which information was either incomplete or where the sum of various components were found to be inconsistent with reported aggregates, on the basis of usual accounting principles. The geographic attributes allow us to identify each firm at the district level[3].

Goldar's (1997) insightful review indicates problems with depreciation figures for capital as well as the head count index for measuring labor input. In this paper, we use the gross (undepreciated) value of capital stock to circumvent the depreciation issue, which appears to be justified in a cross sectional analysis. In addition, to capture variations in hours of work, we use employee man-days instead of the number of employees as the variable to best represent labor input.

(b) Variables selected to explain heterogeneity

We have used several variables to explain inter-firm variations in efficiency, even when they are part of the same industry sector. For example, let us consider the effect of firm age on productivity. The Schumpeterian approach of "creative destruction" suggests that new inventions make old technologies or products obsolete. Hence, one would expect newer entrants to be more productive than older plants. Newer plants are likely to have better technology embodied in new capital as well as easier access to "off-the-shelf" technological and managerial advances, obtained from consulting services and suchlike.

Hence they are less likely to be locked into specific, outmoded production processes and are expected to have younger, more recently educated workers, leading to the deployment of higher human capital. Recent research also establishes that "learning effects" are considerable and have a major impact on productivity (Kim and Nelson 2000).

However, there are arguments that link age to higher manifested productivity as well. In addition to the above effects, the economies of many developing countries, have been heavily regulated. Specifically in India, many markets have been sheltered and until recently, protected from foreign competition as well as new domestic competitors.[4] As a result, older firms represent successful survivors in an evolutionary process. They have learned to thrive in the system, to establish symbiotic relationships within the political and regulatory framework, secure access to finance, and establish smoothly-functioning buyer-supplier linkages. In an economic environment of imperfect competition and regulated markets, firm age is likely to be positively associated with output and productivity. It is clear then that the age variable, used in the analysis, represents the net outcome of the above contradictory tendencies.

The quality of managerial/supervisory staff employed by the firm is likely to have important efficiency effects. Managerial efficiency is generally a non-measurable variable but is likely to have significant effects in industry and plant level productivity (Leibenstein, 1966 and 1978; Rodrigo 2000). In theory, managerial staff with higher education and more experience are likely to be more effective in allocating resources efficiently as well as have more knowledge of market opportunities and technological innovations. Due to the absence of data that proxies organizational capability, we used the degree of managerial control which is measured by the ratio of managerial staff to other staff in the plant.

Scale economies at the plant level in developing countries are likely to be quite important for several reasons. These include productivity gains deriving from increases in scale, which may be due to investment in cost saving technologies, and the interaction of fixed production costs and transport costs. Fixed production costs induce plants to serve consumers from a single location, while transport costs work the other way, i.e. firms prefer to locate near large markets. Production needs to be expanded to capture firm-level scale economies deriving from supplying a large market. Increasing internal returns to scale can lead to imperfectly competitive market structures and thereby affect pricing behavior, product diversity, productivity and growth (Roberts and Tybout, 1996).

We use two different measures to examine the effects of scale effects at the industry and urban area levels to explain variations in technical efficiency. The benefits of locating in close proximity to other firms in the same industry are measured through an index of concentration called the location quotient (LQ). as defined below. This index reflects the degree to which an industry is concentrated in the particular region in comparison with the size of the industry in the national economy as a whole.

$$LQ_{KR} = \frac{\sum E_{K,R} / \sum E_R}{\sum E_K / \sum E} \qquad (9)$$

In the above equation, E represents employment and subscripts K and R represent industry and region respectively (Hoover, 1975; Isard, 1956). An LQ in excess of 1, means that the industry in more concentrated in the region than in the nation. We use this employment LQ in the empirical analysis. Our prior expectation is that as the scale of the industry in a given area increases relative to the nation, we should get net positive and significant localization economies, through increases in both pecuniary and non-pecuniary (i.e. technological) externalities generated by interaction between firms in the same or inter-related industries. Beyond industry level scale effects, variations in urban scale effects are likely to influence efficiency at the plant level. We measure urban scale by the size of the urban population in the district.

(c) The Leather Products Industry[5]

The leather products industry is clearly at the low end of the technology-skill spectrum and present in most developing countries on account of roots in pre-industrial society. Despite that, however, it is the fourth largest foreign exchange earner in India, accounting for around 5 percent of the world market for leather products. It occupies a place of prominence in the economy not only on account of its growth and export potential, but also because of its capacity to employ large numbers of people. Currently it employs over 2 million workers. India has a comparative advantage in leather products, deriving from its large bovine population and abundance of low-skilled, inexpensive labor. The data in the sample used for analysis cover 500 plants in 1994, located in sectors ISIC 233 and

324 which are manufacture of leather footwear, wearing apparel and various other consumer goods made of leather.

The Indian leather industry has experienced a major rejuvenation, from being a producer of low valued added goods in the sixties, to an exporter of high value added finished fashion goods in the nineties. The footwear segment of the industry constitutes less than 25 percent of the domestic market since leather is costlier than substitutes for footwear. Yet domestic demand is expected to grow rapidly as the middle-class and urban populations expand. The most dynamic part of the market, however, is footwear and leather apparel production for export. The leather garments industry includes manufacture of jackets, trousers, skirts etc., the bulk of which is earmarked for export.

A number of major Indian companies, some with international participation, have embarked on the marketing and export of shoes, garments and other leather products. In line with the ongoing processes of liberalization, major players are now permitted to set up shoe and component manufacturing units, with an export commitment of 75 per cent. India currently does not have a significant share of the world market for leather garments, but prospects appear to be promising.

(d) **The Motor Vehicle Industry**[6]

The Indian motor vehicle industry has existed from the early 1940s and exhibits the characteristic patterns of adaptive evolution brought about by economic liberalization. The data analyzed here pertain to 475 units manufacturing vehicles intended to transport less that 10 persons (ISIC 384) and auto part suppliers. It excludes heavy vehicles and all other transport equipment including motorcycles and scooters. The industry has expanded rapidly in the last two decades from its relatively modest beginnings and is now clustered in several parts of the country.

Of those plants that were in continuous operation since 1947, Hindustan Motors Ltd (HML) began the assembly of Morris cars in 1948. Premier Automobiles Ltd (PAL) started to assemble Fiat cars in 1947 and commercial vehicles in collaboration with Chrysler. Ashok Motors Ltd commenced production of Austin cars and commercial vehicles in 1950. HML began production of the sturdy Ambassador car around 1957. Though the market for first generation passenger cars, such as the Ambassador was always very limited and these are now increasingly out of favor with Indians, export sales to developing countries have been growing steadily on account of their sturdy design which is well suited to poor road conditions. Mahindra and Mahindra, a part of the Mahindra Group began the manufacture of general-purpose utility vehicles, such as the Mahindra Jeep in 1945. It later moved into manufacturing tractors and light commercial vehicles and has long collaborated with Ford to produce some Ford models in India. TELCO, another company dating from 1945 is associated with the Tata group; it is a producer of luxury vehicles and trucks, with strong export sales. TELCO has collaborated with Daimler-Benz of Germany. Kathuria (1996) provides a complete survey of the evolution of this industry.

The decisive breakthrough in the auto industry came in 1983 when Maruti, in collaboration with Suzuki of Japan, brought out the first Indian "mass market" car. Until then the car market had been stagnant at a level of about 30,000 – 40,000 units per year for the decade ending 1983. Maruti's aim was to produce a modern, relatively low-cost and fuel-efficient car based on Suzuki technology. By March 1994, Maruti had produced one million cars with an annual output of around 120,000 units. By 1997, it had produced two million cars and is by far the market leader.

With liberalization gathering pace since the early 1990s, other brands have also been launched. General Motors has re-entered the market in a joint venture with the Birla group in 1994 and Daewoo and Hyundai have set up subsidiaries in 1995 and 1996 respectively. Fiat produces two of its models in cooperation with PAL. Similar ventures have been started by Volvo and Mazda, for the production of light commercial vehicles. In fact the Indian motor vehicle market has become highly competitive in the late 1990s. Going against the grain of India's former autarchic industrial policies, the new dynamism in the auto industry is based on the rapid indigenization of technology imported from the worlds leading auto manufacturers. Even the hoary HML has joined in by producing more elegent models in collaboration with Mitusbishi motors. While Indian automobiles are not internationally competitive, its commercial vehicles and scooters have strong export markets in other developing countries.

(e) **Machine-Tools Industry**

The machine tool industry has gone through a volatile history in the last few decades, but it is undoubtedly one of India's lesser known success stories. Though dominated by Hindustan Machine Tools (HMT), a public sector company set up in the immediate post War years to support India's rapid industrialization, the sector supports hundreds of smaller specialized producers. Wogart et al (1993) reports the existence of 300 or so small scale manufacturers of basic general purpose machinery and 160 machine tool plants in the organized sector in the late 1980s. The data sample used in the analysis here contains 405 plants in the SIC 357 category.

The sector is generally considered to be competitive with strong export sales,[7] though still dominated by three public sector firms with around 50 percent of the market. HMT alone accounted for 41 percent of sales in 1989-90 and Praga tools for 8 percent. When rapid technological change involving the introduction of computerized numerical controls (CNC) became widespread worldwide in the mid 1970s, it proved a difficult challenge to the large producers (Jacobsson 1985). They were effectively out-competed in the early 1980s by many small but nimbler firms which were able to adopt modern technology faster. However, firms such as HMT have gone through extended re-structuring processes (Wogart et al 1993).

HMT itself had developed CNC technology in the 1970s, but dropped this in favor of CNC systems taken from Siemens AG, when it tied up with the German company in the early 1980s. HMT's exports began in the sixties; increased export demand led to the formation of HMT(I), a subsidiary devoted to export sales. Currently HMT claims to export to 38 countries and provide a range of equipment and consultancy, technical and engineering services from concept to commissioning on a turnkey basis. Its website lists projects in Algeria, Indonesia, Kenya, Malaysia, Maldives, Mauritius, Tanzania, UAE and other developing countries.[8]

(f) Electronics and Computers

The data set in the sample analyzed consists of 862 plants in the ISIC category 383, covering all electronic devices based on solid state and vacuum technology, including the assembly of computers and all computer-based systems. The spatial distribution of the industry is shown in Map 2. India's best-known "industrial" export, that of software, is however not included here. These are extremely important sectors because they constitute what is now considered "generic" or general-purpose technologies, that underpin progress in communications, information processing including control and instrumentation, defense and aerospace, consumer electronics and other activities.

The products that fall within the above category are too diverse to lend themselves individually to brief summaries such as in the other categories. Adequate descriptions of individual product lines are provided in the references cited here. In general, the general consensus is that with the exception of the high profile software export sector, India's achievement (both in terms of quantity and quality) has fallen far short of what is desirable or needed, and what has indeed been achieved by other, much smaller developing countries such as Korea and Taiwan, which started from levels not too far removed from that of India in the early 1950s.[9]

The major problem is that from its inception in 1947, electronics has been more-or-less dominated by the public sector through direct production and regulation of private sector efforts. From the 1960s to the 1980s, 13 public sector electronic enterprises were set up. By 1990 India's output in electronics was around 1/3 of that of the domestic market of Brazil or Korea. Exports were miniscule compared to those of Korea. But quantitative measures are only part of the story. Quality, in consumer electronics for example, was much below international standards (Sridharan 1996). The reasons attributed for this poor performance are excessive reliance on indigenously developed technologies, i.e. relative isolation from international innovation, absence of a link between R&D and production technology, and the reservation of several items that have economies of scale in manufacture, for exclusive production in the small-scale sector (Agarwal 1985).

Between 1981 and 1991 steady liberalization in these sectors have sharply reduced the role of the public sector, its share in gross electronics output falling from 56 percent in 1971 to 43 percent in 1981 and 30 percent in 1988-89. This was partly because the private sector dominated computer and consumer electronics industries exhibited much faster growth. From 1991 most of the market has been opened up to MNCs as well joint ventures, and many foreign firms have entered the market. The major development in this industry is the extraordinary success of the software export industry, currently worth in excess of some $5 billion per year and growing at a very rapid rate. In this respect India's achievement is superior not only to other developing countries, but even to most advanced industrial countries.[10] Software, however, is not included in the sample used in this study.

4. ANALYSIS OF TECHNICAL EFFICIENCY VARIATION

(a) Distribution of technical efficiency

The maximum likelihood parameter estimates obtained for the four industrial sectors selected are reported below in Table 1. While the main focus of this study is the variation of technical efficiency obtained from the error terms, it is important to consider the reliability of the parameter estimates, as the former depend on the reliability of the latter. In all cases, initial estimates through OLS are used as starting values in an iterative process leading to the final estimates based on Maximum Likelihood techniques, which are reported here. The results indicate that the procedure is reliable for all four industries and the parameter estimates in general are significant. The variance parameter estimates, lambda and sigma, are highly significant in all cases. The variables used are defined in Section 2; note in particular that $k = K/L$, the capital-labor ratio.

The distribution of technical inefficiency, as indicated by the u_i values, for the motor vehicle and machine tools industries, is pictured in the histogram of Figure 1. The patterns for the other two industries are very similar in shape: they show a highly skewed F-shaped distribution, which is an approximation to the half-normal distribution assumed in the theory. From a practical point of view however, the distribution of the technical efficiency transform $exp(-u_i)$ is more useful since it maps the efficiency of each plant in relation to the stochastic frontier for that industry. The distribution of technical efficiency for the machine tools industry is shown in Figure 2. The distribution follows a near-normal pattern centered on mean-median value of around 60 percent with the majority of plants within the 35 percent through 85 percent bracket. The mean value of 0.57 and the standard deviation of 0.14 are taken as the main indicators of the "state of the industry", for purposes of inter-industry and inter-regional comparison.

The mean values and standard deviations of technical efficiency for the four industries are clearly in the same range (Table 1). The mean for the leather products industry is somewhat lower at 0.44 than the values for the other three in the 0.53 - 0.59 range. The variation of TE for the electronics and computers and the motor vehicle industries are lower than for the other two, possibly indicating more competitive conditions, at least in the 1990s. However, there is clearly no striking difference between the results for the modern and older industries.

(b) Sources of technical efficiency variation

Several variables have been used to explain inter firm efficiency differences. These variables represent several characteristics directly influencing production such as its age, managerial effectiveness, and energy usage, as well as features external to the firm's internal production function such as the concentration of firms involved in similar activities and the characteristics of the location where it is based. These variables have been described in Section 3.

The sources of technical efficiency are explored using two procedures, which differ by the treatment of effects related to characteristics of the firm's location. The first approach representing urban scale is measured by the size of urban population in the district. In addition, a quadratic term is included to test for the existence of threshold effects beyond which efficiency increases or decreases with urban size. The effect of urbanization URB is represented by the following equation:

$$URB = b1 * \ln(UPOP) + b2 * \ln(UPOP)^2 + \varepsilon \qquad (10)$$

Here, $\ln(UPOP)$ and $\ln(UPOP)^2$ are urban population and its squared term respectively. This formulation of the effects of urbanization suggests that efficiency would increase in larger urban areas, and that scale economies (or diseconomies) accrue after a certain city size. It must be noted here that our analysis only captures the net benefits of urbanization. Thus, we cannot comment on the source of urbanization benefits -- whether firms benefit from well functioning transport networks, labor market effects, inter industry linkages, knowledge sharing or the socio-cultural environment, or associated costs – congestion, pollution, or crime.

In the second approach, we measure the effects of urbanization by introducing city fixed effects for the large metropolitan areas. The rationale behind this is that in addition to size effects, there are historic and socio-cultural characteristics that influence the location of an industry in a region (for example, the tanneries in Calcutta), which are difficult to measure but are important for analytic purposes. In addition, economic diversity of large metropolitan regions encourages inter industry knowledge transfers, which tend to enhance average levels of efficiency in the region. In principle, introduction of the fixed effects terms captures some of these city specific characteristics. There are some pitfalls of taking administratively defined entities (Indian districts in this case) as the unit of analysis for capturing the efficiency gains from location in urban areas. Often times, either the extent of metropolitan areas/agglomerations extends beyond administratively defined boundaries, or there are several specialized sub-centers within a large agglomeration, which cannot be identified using information at the district level.

Figure 3 provides a schematic of these ideas, where L is the metropolitan area or agglomeration and S is the specialized sub center. We consider these cases (A, B, and C) using the Bombay metropolitan areas for reference. In case A, the specialized sub center and the agglomeration are part of the same jurisdiction. Take for example, the Indian motion picture industry which is highly concentrated, and localized in the Bandra suburb of Bombay. In principle, while urbanization benefits can be adequately represented for the motion picture industry as the same benefits accrue to all firms from locating in an urban area (such as Bombay), the estimation of localization benefits is likely to be biased. This is because the industry is not spread throughout the metropolitan area, but clustered in one sub center. If spatially disaggregated data were available (for both firm location and regional attributes), it would be possible to estimate more realistic measures of industry concentration, which take into account localization in tightly clustered geographic space.

In case B, the sub center and the agglomeration are in adjacent jurisdictions. An example is the Bombay metropolitan area and its adjacent district, Thane. Even though these two entities belong to different jurisdictions, they are part of the same agglomeration. Economic activities in Thane are closely linked to activities in the Bombay district. We are likely to get biased estimates of urbanization benefits if the linkages between sub centers of this type and the large metropolitan area, are not considered. This is because the urbanization benefits accruing to firms in the sub center (Thane) are not only a function of its own level of urbanization but also influenced by the characteristics of the agglomeration to which it belongs (Bombay, in this case). To test if there is any validity in this hypothesis, we also extend the metropolitan area fixed effects to include adjoining districts which are part of the agglomeration. In the empirical tests reported in Table 3, we use fixed effects for the five major agglomerations in India – Bangalore, Bombay, Calcutta, Delhi, and Madras.

In case C, the sub center and the agglomeration are not spatially adjacent but are economically linked. The linkages may have been established through trade and commerce or through a transport corridor linking two distant markets. It is difficult to examine these linkages in great detail due to the paucity of data on economic interactions between these regions. It is quite likely that the interaction between Bombay and a distant sub center (say, Pune) is a function of urbanization in both regions and the availability and quality of infrastructure linking these regions. In the presence of good infrastructure, the potential interaction between regions that are distant from each other increases, and in the absence of good infrastructure, even nearby regions appear distant from each other. This is a situation in which data paucity precludes the examination of this hypothesis.

(c) Results

In Table 2, we present the results of the analysis using urban population as the indicator of urban scale effects. With the exception of Electronics and Computer products, the other models are statistically significant. At the plant level, managerial quality and energy intensity appear to be important sources of efficiency variations. The negative coefficient for worker- employment ration, an inverse index of the degree of managerial control, indicates that fewer number of workers as a proportion of total employment is associated with higher technical efficiency. The negative coefficient for "energy share" indicates that energy conservation positively influences technical efficiency. These signs on these estimates are consistent for all industry sectors in the sample. These results suggest that effective managerial control and effective energy use enable the plant to operate closer to the domestic best practice frontier. The coefficient for plant age is not significant for any sector, indicating no rise in efficiency with age. Since effective liberalization begins only in 1991, just three years before the data were collected, this result is consistent with the general idea that learning effects were minimal under the high protection provided by the import substitution regime (Lall 1987, 1999).

At the industry level, there do not appear to be significant efficiency benefits of own industry concentration as measured by the LQ. Even when the coefficient on the LQ is significant as seen in the case of the electronics and computer industry, the magnitude is very small. At the regional level, the effect of urban scale on efficiency is significant for one sector -- leather products. Based the formulation of urbanization effects in equation (10) and the empirical form used in estimation (equation 8), the elasticity of urban scale can be computed as :

$$\frac{d \ln TE}{d \ln UPOP} = b_1 + b_2(2 * \ln UPOP) \qquad (11)$$

where UPOP is urban population in the district, b_1 and b_2 are the coefficients on ln UPOP and ln $(UPOP)^2$. In the estimates for leather products reported in Table 2, the coefficient for urban population is negative and that for its squared term is positive. As b_1 is less than zero and b_2 is greater than zero, regions with urban populations less than a certain threshold, say **A,** are likely to be less efficient in the production of the goods and services, and the net benefits of urbanization start showing up after urban population crosses this threshold. The value of **A** – urban population beyond which firms in a region accrue efficiency benefits from regional scale effects – is 608,153 for the leather products industry.

In Table 3, we present the results of the analysis using agglomeration fixed effects. The estimated model for the motor vehicle industry is not significant using this specification. For the other three industries, consistent with estimates reported in Table 2, plant level characteristics such as managerial quality and energy use are important in explaining inter firm efficiency variations. The results for the agglomeration fixed effects are mixed. In the case of leather products, location in Calcutta provides each firm with an added efficiency gain of about 7 percent. In comparison, location in Madras reduces efficiency by 3 percent. Similarly for machine tools, location in Delhi, Bangalore, and Bombay raises efficiency by approximately 5, 3, and 9 percent respectively. For Calcutta on the other hand, firms in the machine tools industry are about 15 percent less efficient than firms in parts of the country.

The results for the electronics and computer industry are quite interesting. Contrary to priors about the dynamism of technology clusters in Bangalore, firms in this agglomeration are not significantly more efficient than similar firms in other parts of the country. This is partly explained by the absence of software firms in the definition of this sector, which are the drivers of productivity and efficiency in this sector. The fixed effects show that firms located in Delhi and Bombay accrue efficiency gains of 2 and 3 percent respectively[11].

5. CONCLUSIONS

This study has examined one important aspect of heterogeneity in Indian manufacturing industry, the variability of technical efficiency compared to the best practice productivity frontier. Since the sample of four industries chosen are sufficiently diverse, it is fair to conclude that the stronger results have general applicability. The results obtained clearly validate the general approach and methodology used for the analysis. They also provide some insights for future paths of investigation of industry features.

Consistent with prior expectations, a considerable range of technical efficiency variation is observed with the average value falling in the 50 – 60 percent band and the standard deviation ranging from 11 to 14 percent, for the relatively technology intensive sectors. Again, as expected, the less technology intensive leather products sector has a lower average at 44 percent of best practice and a higher variance than the motor vehicles or electronics industries. These results are roughly consistent with technical efficiency distribution patterns obtained for other developing countries and even for Japan and the United States (Caves and Barton 1990, Caves 1992). While best practice values of productivity are clearly much higher for highly industrialized countries, it appears that technical efficiency variability is not that much worse for the less developed ones.

An important policy outcome of the results obtained here is the existence of considerable room for efficiency gain through better organization and management of the production processes and improved supply chain management, even in the highly organized corporate sector. These gains could be achieved by purely internal learning processes, such as discussed in Kim and Nelson (2000) or Lall (1999), without any extra investment in physical plant or equipment, or with the assistance of external management consulting services. This critical input could also be obtained through business alliances with partners from industrial countries, which seems to be a rising trend at present.

The question of how firms can be induced to undertake such investments in the 'software' of production[12] is also an important policy issue. It appears that greater technical efficiency variance in the leather products industry is related to the fact that it supplies the global marketplace as well as segmented domestic markets in India (Knorringa, 1999). If so, more competition brought on by liberalization and ongoing globalization are likely to extract significant productivity gains out of even low-technology industries as managers gear up to the challenges of enhanced competition.

The critical role of managerial efficiency is brought out by the finding that higher technical efficiency is correlated with better energy use and higher investment in plant management. The result is significant across all four sectors, and has important policy implications. As in most developing countries many of the smaller firms in India do not draw heavily on professional management expertise. Again, there is considerable scope for enhancing efficiency through increased attention to managerial competence.

The other important findings are that technical efficiency is insensitive to age or industry concentration. While urban scale by itself does appear to be significant for most sectors, it only partially represents the benefits of urban concentration. In addition to scale, regional economic diversity and socio-cultural features of metropolitan areas are central to examining the benefits of urbanization. Due to lack of data on these variables, we used agglomeration fixed effects to understand the benefits conferred by locating in particular regions. We find that the fixed effects are quite useful in explaining efficiency variations. For example, the leather industry in Calcutta is more efficient than in other parts of the country. This stems from the historic presence of the industry in this area leading to exchange of tacit knowledge and development of industry specific skill sets, thereby enhancing efficiency. This bears out the crucial importance of historical skill accumulation through clustered learning that has been studied in depth in recent years (Bell and Albu 1999, Lall 1999).

It is important to emphasize that significant liberalization of the Indian economy begins only in the early 1990s and it is still too early to observe major re-alignment of industry structure on account of competitive pressure. It is likely that most of the dynamism will be seen in the export-oriented sectors, as in the East Asian economies (Lall 1999, Kim and Nelson 2000). The methodology and findings reported here indicate that the study of industry-specific technical efficiency distributions, is a vital analytical tool for tracking the response of domestic firms to the advance of market forces.

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Table 1. *Maximum Likelihood Parameter Estimates for Selected Sectors*

VARIABLE	Leather Products	Motor Vehicles	Machine Tools	Electronics & Computers
Abbreviation	LP	MV	MT	EC
Constant	1.064	.931	2.724	.690
	(.50)	(.06)	(.09)	(.58)
Ln(k)	-.239	-.359	-.399	.044
	(.34)	(.00)	(.06)	(.82)
Ln(L)	.913	.853	.505	.796
	(.00)	(.00)	(.06)	(.00)
$Ln^2(k)$	.067	.642	.076	.017
	(.00)	(.00)	(.00)	(.09)
$Ln^2(L)$	-.043	-.300	-.015	-.032
	(.02)	(.00)	(.21)	(.00)
Ln(k).LnL	-.010	-.867	-.009	.002
	(.72)	(.48)	(.67)	(.00)
Lambda	1.435	1.135	1.567	.920
	(.00)	(.00)	(.00)	(.00)
Sigma	1.404	.927	.923	1.233
	(.00)	(.00)	(.00)	(.00)
Log-likelihood	-735.1	-530.7	-414.9	-1253
Technical efficiency				
Mean value	.44	.59	.57	.53
Standard dev.	.15	.12	.14	.11
Number of plants	500	475	405	862

Note: numbers within parentheses indicate the associated probability-value.

Table 2 *Sources of Technical Efficiency Variation: SET I*

VARIABLE	Leather Products	Motor Vehicles	Machine Tools	Electronics& Computers
Constant	2.501	.961	1.665	.517
	(.003)	(.000)	(.168)	(.000)
Ln (Age)	.000	-.003	.000	.000
	(.397)	(.709)	(.007)	(.387)
Ln (Location	-.004	0.01	.009	.007
Quotient)	(.304)	(0.15)	(.180)	(.032)
Ln(Urb.Pop)	-.293	-.248	-.150	-.003
	(.016)	(.114)	(.368)	(.667)
Ln^2 (Urb.Pop)	.011	.695	.578	.000
	(.010)	(.165)	(.315)	(.393)
EnergyShare	-.314	-.182	-.387	-.108
	(.000)	(.000)	(.000)	(.083)
Worker/Total	-1.45	-.187	-.169	-.000*
Empl. Ratio	(.000)	(.000)	(.000)	(.623)
Adj. R-squared	.1706	.1185	.0998	.0035
F-statistic	18.10	13.74	8.47	1.50
	(0.000)	(0.000)	(0.000)	(0.175)
Number of plants	500	475	405	862

Note: numbers within parentheses indicate the associated probability-value.

Table 3 *Sources of Technical Efficiency Variation: SET 2*

VARIABLE	Leather Products	Motor Vehicles	Machine Tools	Electronics & Computers
Constant	.563	-0.52	.726	.523
	(.000)	(0.000)	(.000)	(.000)
Delhi	.016	0.025	.048	.018
	(.528)	(0.44)	(.019)	(.072)
Bangalore	.024	0.016	.031	.008
	(.293)	(0.63)	(.151)	(.546)
Calcutta	.069	-0.06	-.148	-.003
	(.007)	(0.39)	(.000)	(.885)
Madras	-.030		-.029	-.024
	(.061)		(.357)	(.103)
Bombay	.041	0.043	.087	.028
	(.208)	(0.26)	(.002)	(.009)
Ln (Age)	.000	-0.007	.000	.000
	(.038)	(0.677)	(.730)	(.408)
Ln (Location	-.010	0.001	.002	.003
Quotient)	(.0040)	(0.60)	(.769)	(.312)
EnergyShare	-.313	0.008	-.420	-.098
	(.000)	(0.19)	(.000)	(.115)
Worker/Total	-.114	-0.01	-.187	-.000*
Empl. Ratio	(.002)	(0.79)	(.000)	(.750)
Adj. R-squared	.1812	0.006	.1549	.0105
F-statistic	13.27	0.49	9.23	2.01
	(0.000)	(0.20)	(0.000)	(0.035)
Number of plants	500	465	405	862

Note: numbers within parentheses indicate the associated probability-value.

Figure 1: Distribution of Technical in-efficiency (TIE)

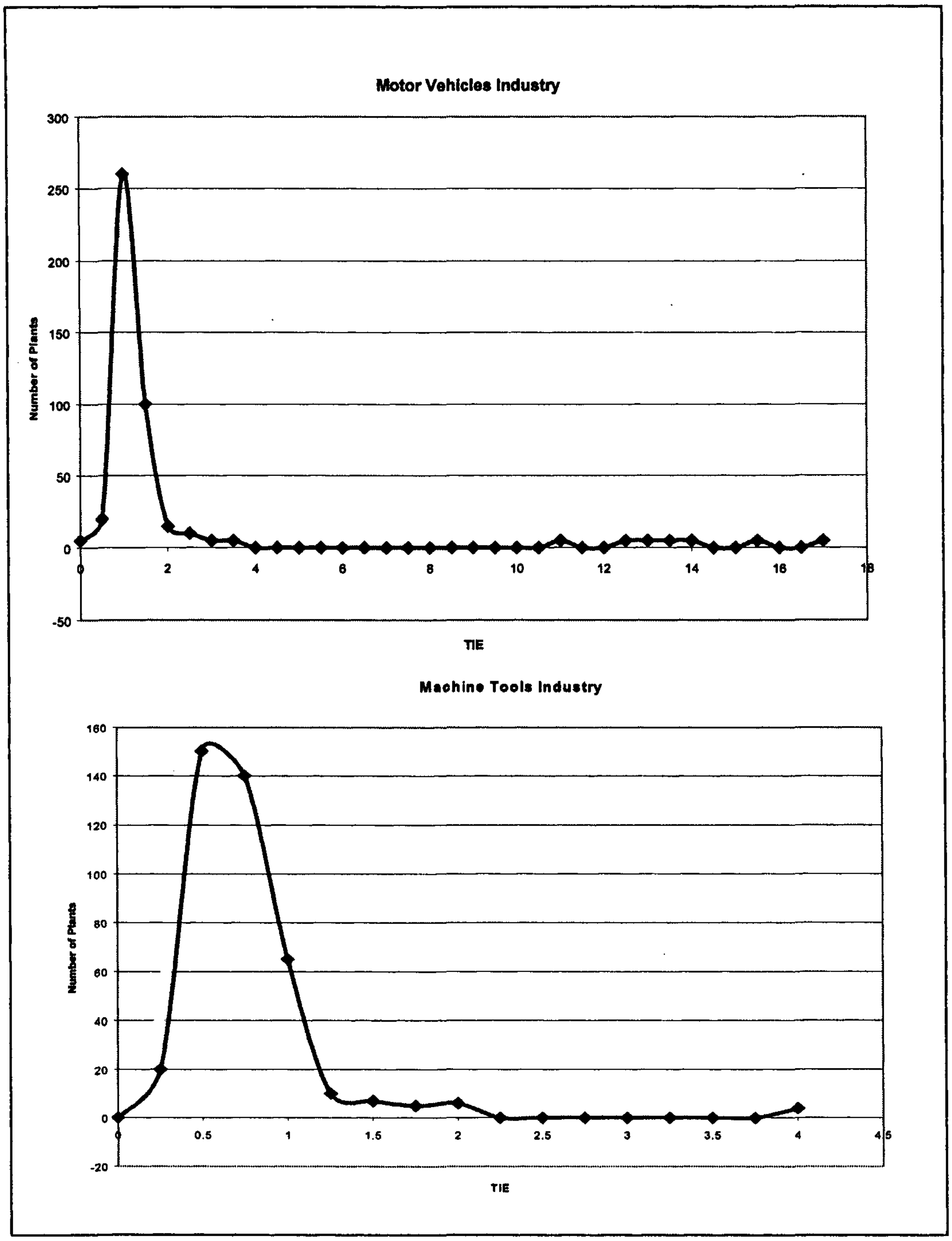


Figure 2: Distribution of Technical Efficiency

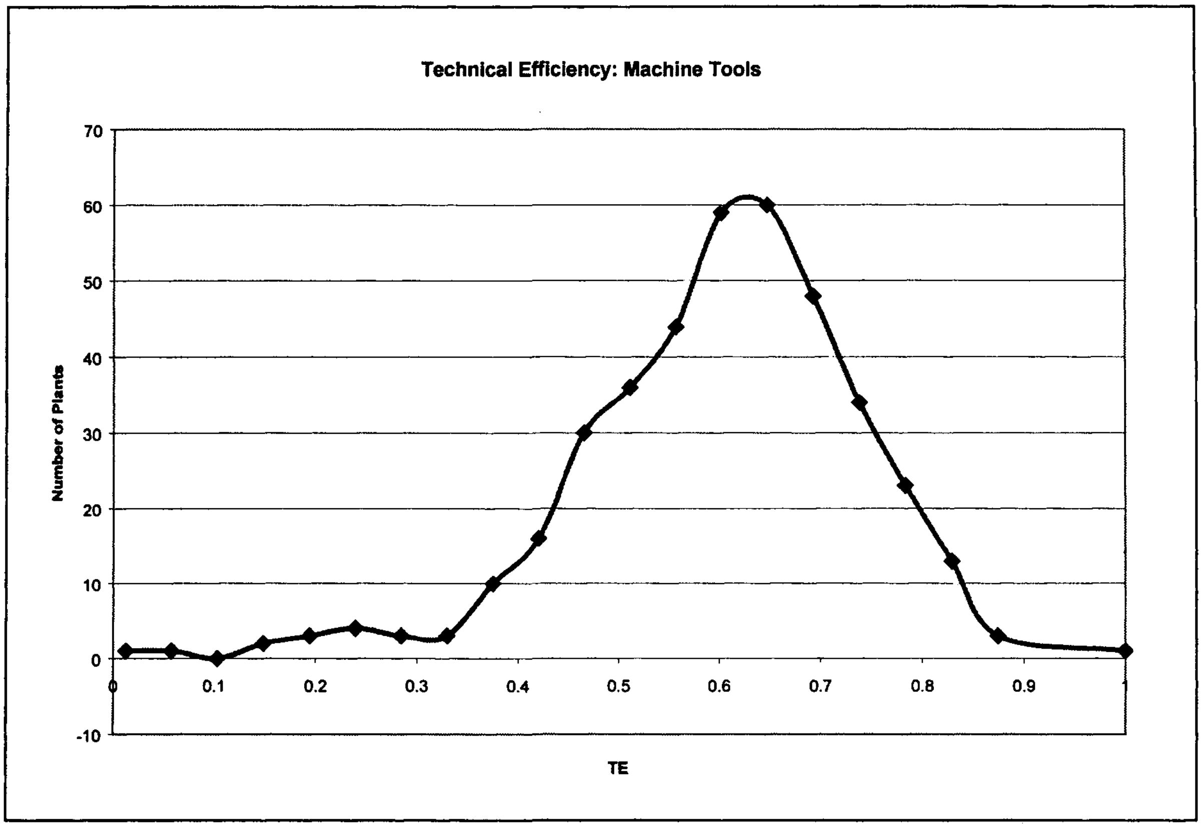
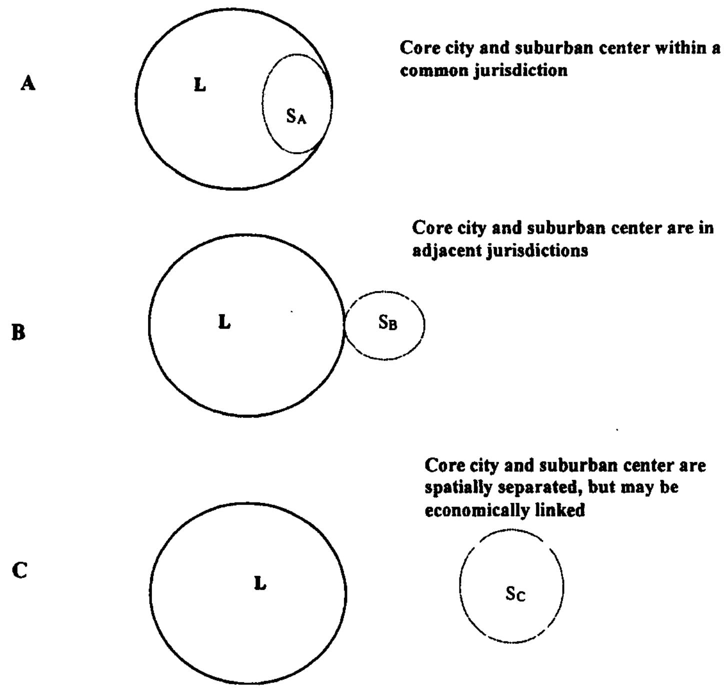


Figure 3: Administrative Boundaries and Economic Linkages



NOTES

[1] For example in India, the leather industry is highly concentrated in a few clusters -- Agra has 66 times the national representation of leather products workers.

[2] Goldar (1997) notes that factories are classified into industries according to their principal products. In some cases this causes reclassification of factories from one class to another in successive surveys, making inter-temporal comparisons difficult.

[3] While the ASI data structure allows the identification of the firm at the block level, and the firm addresses are reported in the survey, these data were not made available for confidentiality concerns.

[4] Ahluwalia, Mohan, and Goswami (1996); Joshi and Little (1994); World Bank (1996 and 1999).

[5]This description is based on material taken from http://leather.webindia.com/overview.htm, Austin and Kohn (1990: pp. 249-267) and Knorringa (1999).

[6] Information culled from http://auto.indiamart.com/auto-industry/index.html and Kathuria (1996).

[7] A website devoted to machine tool suppliers turned up many hundred company listings. See http://www.indiamart.com/indianexporters/m_matool.html

[8] See http://www.hmti.com/profile.html.

[9] Agarwal 1985; Wogart et al 1993; IEEE Spectrum 1994; Sridharan 1996; Joseph 1997.

[10] IEEE Spectrum 1994; Joseph 1997; Business Week March 6, 2000; pp:82-7.

[11] In related specifications using labor productivity as the dependent variable, agglomeration fixed effects for the Electronics and Computer Industry are significant and positive for the Bangalore agglomeration (estimated at 15 percent). These are available on request from the authors.

[12] Since productivity is the result of physical and non-physical accumulations of capital, the "software" of production refers to non-physical factors such as managerial competence, which bear on productive efficiency (see Rodrigo, 2000).

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