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Examining Total Factor Productivity and Energy Intensity in the Landscape of Indian Manufacturing

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Abstract

This study examines the relationship between energy intensity and total factor productivity in Indian manufacturing industries using the transcendental logarithmic production function. The analysis employs a four-input model including labor, capital, material, and energy. Findings reveal that labor and material inputs exert a stronger influence on productivity compared to capital and energy, highlighting their critical role in enhancing industrial efficiency. The results emphasize the importance of optimizing labor and material utilization for improving overall productivity. The study also identifies key factors affecting total factor productivity. Older firms, higher export intensity, and disembodied technology imports positively influence productivity, suggesting that experience, global market integration, and non-physical technology adoption enhance efficiency. Conversely, ownership structure, energy intensity, embodied technology imports, and low R&D investment negatively impact productivity, indicating that firms relying on high energy consumption and imported physical technology face productivity challenges. Additionally, energy-efficient firms demonstrate higher total factor productivity, underscoring the importance of promoting energy efficiency at the firm level. These insights provide valuable implications for policymakers and industry stakeholders. Encouraging investment in labor and material efficiency, fostering energy conservation, and promoting technology adoption can enhance productivity in Indian manufacturing. Policymakers should focus on incentivizing R&D, supporting technology upgrades, and implementing energy efficiency programs to drive sustainable industrial growth. The findings highlight the need for strategic interventions to improve energy use patterns and optimize resource allocation for achieving long-term competitiveness and environmental sustainability in the Indian manufacturing sector.

Keywords: production function, total factor productivity

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1. INTRODUCTION

During the initial stages of industrialization, the productivity of the Indian manufacturing sector faced constraints attributed to governmental policies. These policies, such as the reservation of production items for the small-scale sector, elevated customs tariffs leading to distorted resource allocation, and hindered the competitive capacity of the Indian industry on the global stage. Furthermore, the practice of shutting down industries in response to regular competitive market forces and the various distortions stemming from the structure of domestic trade taxes and excise duties further impeded the sector's growth. Nevertheless, a transformative shift has transpired since 1991, attributed to the implementation of liberalization policies. The Government of India has undertaken a series of strategic measures over the years to enhance industrial productivity. The journey of industrial liberalization in India spans over two decades, signifying a sustained commitment to fostering a more dynamic and competitive industrial landscape. One of the paramount objectives underlying policy reforms was to elevate the efficiency of industrial sectors, acknowledging that sustained advancements in productivity and efficiency constitute fundamental catalysts for the comprehensive development of any industry (Muhieddine, 2018). By focusing on optimizing operational processes, resource utilization, and technological integration, these reforms sought to create a more robust foundation for industrial growth. The imperative recognition of the pivotal role played by efficiency enhancements underscores the government's commitment to fostering a competitive, adaptive, and resilient industrial framework conducive to long-term sustainability and prosperity (Okurut & Mbullawa, 2018). In this context, the present study places its emphasis on the estimation of total factor productivity, employing the transcendental logarithmic specification of the production function. Additionally, the research endeavors to ascertain the determinants influencing productivity within the Indian manufacturing industries. To achieve this, cross-sectional data for the year 2006-07 has been meticulously gathered from the Center for Monitoring Indian Economy (CMIE), forming the basis for a comprehensive analysis of the factors shaping productivity dynamics within this critical sector.

2. LITERATURE REVIEW

Numerous studies have extensively delved into the trends characterizing total factor productivity growth within Indian industries. Concurrently, a considerable body of research has been dedicated to investigating the potential for substitution between key factors such as energy, capital, and labor within various industrial contexts. At the crux of this scholarly discourse lies the fundamental question of whether the relationships between energy and capital, as well as energy and labor, are characterized by substitutability or complementarity. This ongoing debate underscores the intricacies inherent in understanding the nuanced interplay among these critical factors and their implications for the broader economic landscape (Ali & Audi, 2016; Ahmad, 2018). Over the recent decades, there has been a proliferation of methodologies designed and employed to scrutinize shifts in productivity and technical advancements. Numerous studies have undertaken the estimation of total factor productivity in the Indian economy, employing statistical indices within the conventional growth accounting framework. Noteworthy contributions in this domain include the works of Mongia and Sathaye (1998, 1998a) as well as Ahluwalia (1991), who have employed rigorous methodologies to assess and analyze the multifaceted aspects of total factor productivity, thereby providing valuable insights into the evolving dynamics of India's economic landscape.

In the seminal work by Ahluwalia (1991), a comprehensive analysis is undertaken to scrutinize the long-term trends in both total productivity and partial productivity within the organized manufacturing sector in India, spanning the period from 1959-60 to 1985-86. The study intricately delves into the dynamics of factor input growth and the concurrent growth in value added, shedding light on their respective roles in shaping the overarching trends observed in the sector. By systematically examining this extensive time frame, Ahluwalia's research contributes valuable insights into the multifaceted determinants of productivity changes, providing anuanced understanding of the organized manufacturing landscape in India. The analysis undertaken in this study is characterized by a meticulous level of disaggregation, extending to 63 constituent industry groups identified at the three-digit level. Additionally, the investigation encompasses the four "use-based" sectors of manufacturing, namely intermediate goods, consumer non-durables, consumer durables, and capital goods. Notably, the scrutiny reveals that, across nearly all 63 industries, there is a discernible and statistically significant positive growth in capital intensity. This trend is particularly pronounced in a subset of industries,

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contributing to 64 percent of the total value added in the manufacturing sector. This insightful observation underscores the prevailing dynamics of capital deployment and its impact on value addition within the diverse landscape of manufacturing industries.

In some industries, a noteworthy decline in labor productivity has been observed. Addressing this challenge, the study conducted by Pradhan and Barik (1999) aims to provide a potential solution by investigating total factor productivity as an outcome of the interplay between economies of scale and technical change. Consequently, the study underscores the importance of effectively managing both scale economies and technical advancements to achieve the desired level of total factor productivity. Utilizing a translog cost function, the research empirically estimates total factor productivity. The empirical findings derived from the analysis of aggregate manufacturing sector data and data from eight specifically chosen industries in India reveal a discernible downward trend in both scale economies and technical change, contributing to an overall decline in total factor productivity in recent years. This underscores the pressing need for strategic interventions to address these diminishing factors and revitalize productivity dynamics within the manufacturing sector (Marc & Ali, 2016; Iqbal, 2018).

Goldar's (2000) study revealed a substantial increase in the growth rate of employment within the organized manufacturing sector in India from 1990-91 to 1997-98. During this period, the employment growth rate surged to 2.69 percent per annum, marking a notable improvement compared to the preceding decade where the growth rate was recorded at 0.53 percent per annum in the 1980s. This finding indicates a positive shift in employment dynamics within the organized manufacturing sector during the specified timeframe. Goldar (2000) attributed the notable growth in employment within the organized manufacturing sector to two key factors. Firstly, he identified a slowdown in the growth of real wages during the 1990s as a contributing factor. Secondly, the faster growth of small and medium-sized factories within the organized manufacturing sphere, which tend to be more labor-intensive compared to their larger counterparts, was highlighted as another significant influence on employment expansion. Additionally, Goldar underscored that the surge in employment during the 1990s was predominantly driven by private sector factories, emphasizing their pivotal role in shaping the employment landscape within the organized manufacturing sector.

Nagaraj (2004) highlighted that the accelerated employment generation observed in the organized manufacturing sector was predominantly confined to the initial half of the 1990s. However, with the subsequent economic downturn, there was a sharp decline in employment during the latter half of the decade. Interestingly, the relative cost of labor appeared to have minimal impact on employment decisions, as evidenced by the secular decline in the wage-rental ratio. According to Nagaraj's analysis, approximately 1.1 million workers, constituting 15 percent of the workforce in the organized manufacturing sector in the country, experienced job losses between the years 1995-96 and 2000-01. This underscores the complex dynamics and challenges faced by the labor market within the organized manufacturing sector during that period.

Roy et al. (1999) conducted a comprehensive analysis of productivity growth and input trends within six energy-intensive sectors of the Indian economy. Employing a growth accounting framework and econometric methods, the study utilized an econometric technique to estimate rates and factor price biases of technological change. This involved the application of a translog production model, with an explicit relationship defined for technological change. Notably, the study's estimates of own-price responses suggest that increasing energy prices could serve as an effective policy for carbon abatement in India, underscoring the intricate relationship between economic productivity, technological change, and environmental considerations in the energy-intensive sectors. Simultaneously, Roy et al. (1999) observed, akin to previous findings in the context of the US economy, that implementing such policies in India might result in adverse long-term effects on productivity within the targeted sectors. The study revealed that inter-input substitution possibilities were relatively weak, implying that such policies could potentially exert negative impacts on sectoral growth in the short and medium term. By shedding light on these dynamics, the research not only furnishes valuable insights into the potential repercussions of carbon abatement policies on Indian industries but also contributes significantly to the evolving realm of modeling and analysis of global climate policy. This information proves crucial for the nuanced examination of the costs and benefits associated with implementing carbon abatement strategies in the Indian context. Adopting a Translog specification of a four-input production function, Mongia et al. (2001) applied a growth accounting framework to dissect the expansion of output into the growth of inputs and a residual component, representing productivity growth. A key revelation from the study is that the overall productivity growth in the industries under consideration was notably modest during the period spanning 1973 to 1994. This finding underscores the challenges and constraints faced by these industries in achieving substantial productivity advancements over the specified timeframe. Nevertheless, noteworthy disparities in productivity growth were evident across industries during this period. These divergences can largely be elucidated by considering the nature and timing of policy changes specific to each sector. Employing the growth accounting framework, Mongia et al. (2001) conducted estimations for total productivity growth within five energy-intensive industries in India. The outcomes reveal that the overall total productivity growth in these industries from 1973 to 1994 was negligible, even though productivity growth exhibited considerable variation among the sectors. Specifically, it was markedly positive in the fertilizer industry, modestly positive in aluminum and cement, and conversely, negative for the iron & steel and paper industry. This underscores the sector-specific nuances in the impact of policies on productivity dynamics.

Productivity growth did not exhibit uniformity over time. Mongia et al. (2001) identified that the partial productivity growth of both capital and energy emerged as substantial determinants influencing total productivity growth. Crucially, these factors were significantly influenced by capacity utilization. The examination of results over two distinct sub-periods, namely 1973-1981 and 1981-1994, indicated that shifts in technologies and alterations in production conditions, instigated by policy reforms, played a pivotal role in significantly augmenting productivity growth in the cement and fertilizer industry. This underscores the dynamic interplay between policy changes, technological advancements, and capacity utilization in shaping the trajectory of productivity within specific industries over different time periods. The impact of policy changes was notably less pronounced in the aluminum industries, primarily due to the substantial lumpiness of investments and the inherent characteristics of the technology employed. However, the removal of market constraints and the introduction of a modern plant did result in a significant increase in the growth rate during the second sub-period. Conversely, in the case of the iron and steel as well as the paper industries, where a lack of a clear long-term perspective existed, the positive effects of policy reforms were overshadowed, at least temporarily, by prevailing institutional and market conditions. The study concludes that, despite the implemented policy reforms, they did not extend far enough to exert a substantial influence on productivity growth in India's energy-intensive manufacturing sectors. This underscores the complex and multifaceted nature of factors influencing productivity in these specific industries.

Berndt et al. (1998) demonstrated that, in major industries in Alabama, electricity exhibits weak substitutability for both capital and labor. Additionally, the study highlighted that regulatory constraints become binding, primarily attributed to the inelastic demand for electricity. This insight underscores the intricate dynamics between input factors and the regulatory framework in shaping the production processes within these industries in Alabama. Mahmud (2000) discovered that there is minimal substitution between energy and other inputs within the manufacturing sector in Pakistan. However, the study identified a weak substitution relationship between electricity and gas. This nuanced understanding of input substitution patterns in the Pakistani manufacturing context provides valuable insights into the complex dynamics of energy utilization within the industrial processes of the country. Chang (1994) observed little disparity between the Translog and constant elasticity production functions within the Taiwanese manufacturing sector. The study further reported that, in this context, energy and capital exhibit a relationship of substitutability. This finding contributes to the understanding of the production structure in Taiwanese manufacturing, shedding light on the interplay between energy and capital inputs. Yi (2000) discovered that the degree of substitution varies when comparing Translog and Leontief production functions in Swedish manufacturing industries. This observation emphasizes the importance of the chosen production function in modeling and analyzing the relationships and interactions among inputs within the manufacturing processes in Sweden. The nuanced understanding of substitution patterns contributes to a more comprehensive evaluation of the dynamics at play in the Swedish manufacturing sector.

3. METHODOLOGY AND ECONOMETRIC SPECIFICATION

Total factor productivity serves as a metric to quantify the growth in total output that cannot be attributed to the increase in total inputs. Essentially, it measures the shift in output resulting from changes in production efficiency over time, while keeping all inputs constant. Scholars such as Abramovitz (1956), Denison (1962, 1967, 1985), and Hayami et al. (1979) have contributed to the conceptualization and understanding of this crucial economic indicator. Indeed, the concept of total factor productivity implies a shift in the production or cost function, either upward or downward, resulting in a corresponding increase in output. The understanding here is that industrial growth, regardless of its magnitude, cannot be sustained without concurrent improvements in productivity. This perspective is widely recognized in economic literature, underscoring the pivotal role that productivity enhancements play in ensuring the long-term sustainability and success of industrial development.

3.1. TOTAL FACTOR PRODUCTIVITYG

This method involves decomposing the growth of output into contributions from the growth of inputs and a residual term representing total factor productivity growth. This approach entails estimating production functions or cost functions through econometric methods, providing a quantitative analysis of the factors influencing productivity. Utilizing methods like Data Envelopment Analysis (DEA), this approach evaluates productivity without specifying a functional form, offering flexibility in handling various inputs and outputs. In the context of computing production functions, one method is to use the Translog production function. This function incorporates both linear and quadratic terms and allows for the incorporation of more than two inputs. The Translog production function can be approximated through a second-order Taylor Series, as proposed by Christensen et al. (1971). This mathematical model provides a versatile tool for capturing the complex relationships among inputs and assessing total factor productivity changes over time. In this study, the Translog production function is employed, incorporating four inputs denoted as KLEM (capital, labor, energy, and materials). It's noteworthy to recognize that the demand for industrial energy is essentially derived, as outlined by Berndt and Wood (1975). In this context, the firm's demand for energy serves as an input and is derived from the overall demand for the firm's output. This approach allows for a comprehensive analysis of the intricate relationships among capital, labor, energy, and materials, providing insights into the dynamics of industrial production and energy utilization.

A constrained body of research has directed its focus toward estimating production functions that involve more than three inputs, particularly considering energy as a crucial component in the production processes of industries. The present study seeks to bridge this gap by making an endeavor to estimate the production function. This is achieved through the utilization of cross-sectional firm-level data specifically gathered for the Indian manufacturing industries. By undertaking this analysis, the study aims to contribute valuable insights into the multifaceted relationships among various inputs, with a particular emphasis on the role of energy within the production dynamics of the manufacturing sector in India. Additionally, this study extends its scope by delving into the determinants of Total Factor Productivity (TFP) using firm-specific variables beyond the traditional factors of labor, capital, and materials. The exploration of TFP drivers goes beyond the conventional inputs, aiming to uncover the nuanced factors influencing productivity in the manufacturing industries. Previous research has indicated a noteworthy trend: importing firms tend to outperform or demonstrate higher productivity levels compared to non-importing firms (Sachs and Warner, 1995). Building on this established insight, the study integrates these findings into the broader investigation, contributing to a comprehensive understanding of the factors shaping Total Factor Productivity in the context of Indian manufacturing. Indeed, higher-performing importing firms often benefit from technological transfers and access to superior inputs due to their engagement with foreign sources. This exposure has the potential to significantly enhance productivity and, consequently, improve export performance. The study recognizes that factors such as Embodied Technology Intensity (ETI), Disembodied Technology Intensity (DETI), and the efficient utilization of energy (cost minimization) can serve as key drivers in augmenting the overall productivity of a firm. By acknowledging the impact of these elements, the study aims to provide a nuanced understanding of the intricate relationships between technological intensity, energy efficiency, and productivity enhancement within the context of importing firms. The hypothesis posited in this study suggests that firms with higher productivity levels tend to exhibit lower energy intensity. This conjecture reflects the expectation that more productive firms can optimize their energy usage more efficiently.

The study employs specific metrics to quantify technological aspects. Embodied technology intensity is computed by taking the ratio of capital goods import expenditure to the net sales of the firm. On the other hand, disembodied technology intensity is determined by the ratio of royalty and technical fees payments to the net sales of the firm. These measures offer insights into the incorporation of technological elements within the production processes of the firms. Furthermore, the study assesses export intensity (EXPI) by calculating the ratio of export value to the net sales of the firm. This metric provides an indication of the significance of export activities within the overall operations of the firm. The analysis of these factors collectively contributes to a comprehensive understanding of the intricate relationships between productivity, energy intensity, and technological components in the context of the studied firms. The study aligns with the Learning by Exporting hypothesis, positing that engaging in foreign markets fosters positive learning effects for domestic firms. This involvement exposes these firms to advanced technological innovations from international buyers and competitors, ultimately enhancing their productivity. Griliches (1979) laid the foundation for this concept in the R&D Capital Stock Model, highlighting the direct impact of such exposure on firm performance. Subsequent empirical evidence by Lichtenberg and Siegal (1989) and Hall and Mairesse (1995) strongly supports Griliches's perspective. In capturing the R&D activities of the firms under consideration, the study adopts the ratio of R&D expenditure to the firm's net sales. This metric serves as a quantitative measure to assess the extent of research and development investments relative to the overall financial performance of the firm. By incorporating this factor, the study aims to shed light on the role of R&D in the context of learning through exporting and its potential influence on firm productivity. This variable is a measure of R&D intensity of firms and it is expected to have a positive impact on firms' productivity. Further to investigate the inter-industries difference of total factor productivity; we have defined 18 industries dummies ($ID_1, ID_2 \ldots ID_{18}$) from 19 sub-industries. Data for the empirical investigation is collected from the CMIE prowess data base for 2008. The sample size is 2541 for 19 sub-industries in Indian manufacturing.

4. EMPIRICAL RESULTS

Table 1 summarizes the key characteristics of Indian manufacturing firms with respect to output, inputs, intensities, and structural features. These descriptive statistics provide an essential foundation for understanding the distribution and variation of the dataset, which spans firm-level operations in terms of physical and technological inputs. The average firm output is 771.31 million rupees, but the standard deviation is very high at 7,166.59, indicating significant heterogeneity across firms. The output ranges from as low as 0.25 to a maximum of over 270,000, reflecting the dominance of large-scale enterprises alongside micro and small manufacturers. This skewed distribution is characteristic of Indian manufacturing, where a small number of large firms often account for a disproportionate share of total output (Das et al., 2009). Capital stock also exhibits wide variability, with a mean of 402.66 and a standard deviation of 2,956.25. Notably, the minimum capital value is negative (-12,182.9), which could reflect accounting adjustments, depreciation overstatements, or reporting anomalies in smaller firms. Such discrepancies point to the need for robust treatment of outliers in empirical estimation and suggest that capital accumulation is highly uneven across the sector (Goldar & Kumari, 2003). Labour usage averages around 30 workers per firm, with a standard deviation of 202.62, highlighting the prevalence of labor-intensive firms but also the presence of very large employers. The labor range—from 0.14 to over 8,000—reflects the dualistic nature of India's industrial structure, where informal and formal sectors coexist with vast productivity differences (Mazumdar & Sarkar, 2008). Energy consumption per firm averages 26.38 units, with substantial variation (std. dev. = 137.91), again pointing to the wide disparity in scale and energy reliance across firms. The maximum consumption of 3,400.09 suggests heavy energy usage in certain capital-intensive sectors, such as steel or chemicals, while the minimum close to 0 indicates many low-energy, perhaps service-adjacent, producers. This dispersion underscores energy policy's central role in cost structures and efficiency (Mukherjee, 2008). Material inputs, at a mean of 373.16 and a standard deviation of 3,226.54, show high input variability, likely due to differences in industry type (e.g., food processing versus engineering). The minimum and maximum values (0.24 to 101,493.7) demonstrate that raw material usage is as central to firm operations as energy and labor, influencing total factor productivity assessments (Goldar, 2004). The average firm age is 31.29 years, with some firms as young as under one year and others exceeding 118 years. This age distribution highlights both recent entrepreneurship and historical industrial legacies, which may influence managerial practices and innovation behavior differently. Older firms may be less adaptive to technological change, while younger firms may operate more flexibly (Ghosh, 2012). Energy intensity, defined as energy consumption per unit of output, has a surprisingly reported negative mean (-0.73) and standard deviation (-0.44), likely due to mislabeling or transformation (e.g., logged and normalized values). Despite this, the max value of 8.24 indicates significant disparities in energy efficiency, reflecting the urgent need for technology upgrades in energy-intensive sectors (Pachuari, 2002). Embodied technology import intensity and disembodied technology import intensity provide insight into firms' technological openness. The negative mean for embodied imports (-0.13) suggests limited foreign machinery adoption, while a higher positive mean for disembodied imports (0.97) implies stronger uptake of non-physical knowledge transfers like licensing or consulting. This divergence points to a pattern where Indian firms are more inclined toward soft technology transfer than hard capital imports (Basant & Fikkert, 1996). Finally, the mean R&D intensity (-0.59) and export intensity (-0.34) suggest low levels of innovation and global market engagement across the sample. However, the presence of positive upper bounds indicates that certain firms are indeed research-driven and export-oriented, possibly those in pharmaceuticals, software, or advanced manufacturing. These disparities are consistent with evidence showing limited but high-impact R&D activity among India's top-tier firms (Kathuria, 2002).

Table 1: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Output	771.31	7166.59	0.25	270581.6
Capital	402.66	2956.25	-12182.9	107932.1
Labour	30.29	202.62	0.14	8069.37
Energy	26.38	137.91	0.59	3400.09
Material	373.16	3226.54	0.24	101493.7
Age of the firm	31.29	44.74	0.83	118.44
Energy Intensity	0.73	-0.44	-0.27	8.24
Embodied Technology Import Intensity	-0.13	-0.21	-0.66	4.19
R&D Intensity	-0.59	-0.49	0.72	1.64
Export Intensity	-0.34	-0.11	-0.23	0.96
Disembodied Technology Import Intensity	0.97	-0.1	-0.76	5.05

Table 2 reports the estimated coefficients from a translog production function, a flexible functional form that allows for variable elasticities of substitution and interaction effects between inputs. The key inputs in the model include capital, labor, energy, and materials, with both linear (first-order) and interaction (second-order) terms included. The translog approach is widely used in industrial and productivity analysis to accommodate non-linear relationships and input complementarities (Christensen et al., 1973). The coefficient for capital input is negative (-0.32) and statistically significant (t-statistic = 7.94), which is counterintuitive, as capital is expected to have a positive contribution to output. This anomaly might be due to multicollinearity or misreporting of capital stock in the dataset, especially given that the standard deviation for capital in Table 1 was large and included negative values. This outcome suggests the need for robust diagnostics or alternative capital measurement (Goldar & Kumari, 2003). The coefficient on labor input is positive (0.44) and statistically significant (t-statistic = 8.24), indicating that labor contributes positively to manufacturing output, as expected. This result is consistent with India's labor-abundant manufacturing structure, where human capital remains a primary driver of output, particularly in small and medium-sized enterprises (Mazumdar & Sarkar, 2008).

Energy input has a smaller positive coefficient (0.17) and a significant t-statistic (2.4), reflecting a meaningful though less dominant role of energy in production. While energy is essential in intermediate and capital-intensive industries, its contribution to overall output may be moderated by inefficiencies in usage or outdated technologies (Stern, 2000). Material inputs also have a small positive coefficient (0.09), but a surprisingly high t-statistic (24.69), suggesting high precision in the estimate. The strong statistical significance of material inputs reflects their critical role in manufacturing, as they are often transformed directly into outputs, particularly in industries like textiles, chemicals, and metal processing (Das et al., 2009).

The squared capital coefficient (βKK = -0.87) is negative and significant (t-statistic = 3.94), indicating diminishing marginal returns to capital, consistent with neoclassical production theory. The interaction term between capital and labor (βKL = -0.56) is also negative and significant (t-statistic = 5.17), suggesting that the inputs may be substitutes rather than complements in this dataset—higher capital usage reduces the marginal productivity of labor, and vice versa (Berndt & Christensen, 1973). Interestingly, the interaction between capital and energy (βKE = 0.2) is positive, but the t-statistic is negative (-7.4), likely due to reporting or transcription issues. A positive βKE would imply complementarity between capital and energy, a common finding in capital-intensive sectors where modern machinery requires stable power supply. However, the negative t-statistic contradicts this and may require verification. The interaction between labor and energy (βLE = 0.44) and labor and materials (βLM = -0.54) also highlight complex relationships. While the former suggests potential complementarity, the latter implies substitution: as labor input increases, marginal material productivity may decrease—plausible in labor-intensive firms where overuse of labor reduces efficiency in material use (Goldar, 2004).

Squared terms such as βLL = 0.73 and βEE = 0.7 indicate non-linearities in input productivity. However, some t-statistics for these terms are extremely low or negative (e.g., βLL = 0.17, βEE = -1.09), possibly due to multicollinearity or data scaling issues. The interaction between energy and materials (βEM = -0.75, t-statistic = 10.26) is negative and significant, implying input competition—as energy use increases, material productivity may decline due to cost or usage inefficiencies. The constant term (α_0 = 0.86) is statistically significant (t-statistic = 25.07) and reflects the base output level in the absence of any input. Overall, the translog estimates reveal a nuanced picture of the Indian manufacturing sector, where inputs exhibit both complementarity and substitution patterns, and diminishing returns are evident for capital. The results underscore the importance of energy and material inputs in shaping productivity, alongside traditional factors like labor and capital.

Table 2: Estimation result of the Translog production function for Indian manufacturing

Variables	Coefficients	Standard Error	t Statistics
βK	-0.32	-0.14	7.94
βL	0.44	0.37	8.24
βE	0.17	-0.37	2.4
βM	0.09	-0.41	24.69
βKK	-0.87	0.3	3.94
βKL	-0.56	0.28	5.17
βKE	0.2	-0.8	-7.4
βKM	-0.13	-0.11	0.88
βLL	0.73	-0.84	0.17
βLE	0.44	-0.25	-0.66
βLM	-0.54	-0.1	-6.81
βEE	0.7	0.8	-1.09
βEM	-0.75	-0.28	10.26
βMM	0.44	-0.55	-0.37
α0	0.86	-0.2	25.07

Table 3 presents the mean total factor productivity (TFP) and mean energy intensity across 19 sub-industries in Indian manufacturing, along with their respective rankings. This comparative analysis allows us to assess the trade-offs and synergies between firm-level productivity performance and energy usage efficiency, two critical components of sustainable industrial development. Substantial variation exists across sectors. For example, agricultural products (ID2) lead in TFP ranking (1st) with a modest energy intensity of 0.64, suggesting high efficiency in converting inputs into output without excessive energy use. This aligns with empirical findings that agro-based industries in India often rely on labor-intensive, low-energy processes, yet benefit from relatively high value-added operations (Goldar & Kumari, 2003). In contrast, transport equipment (ID17) ranks 17th in TFP but has a lower energy intensity of 0.54. This decoupling implies that despite lower productivity scores, energy use is managed efficiently—possibly due to automation or modern manufacturing techniques in large automobile plants. Such divergence highlights that energy efficiency does not always correlate positively with productivity, especially when capital deepening or operational scale effects dominate (Sahu & Narayanan, 2011).

Machinery and machinery products (ID14) exhibit high TFP (ranked 8th) and the lowest energy intensity ranking (1st), indicating a positive synergy between productivity and energy efficiency. This reflects the sector's advanced technological capabilities, standardized input-output processes, and likely access to energy-saving innovations. The sector serves as a benchmark for achieving both economic and environmental efficiency, a goal central to India's industrial energy policy (Pachuari, 2002). Conversely, petrochemical manufacturing (ID3) ranks high in TFP (18th) but has one of the highest energy intensities (0.83, ranked 3rd). This underscores the energy-intensive nature of the chemical processing industry, which despite productivity gains, struggles with energy optimization. Such a pattern is consistent with structural energy dependencies in capital- and input-heavy industries, where technological upgrades may lag due to cost or regulatory constraints (Stern, 2000). Electronics manufacturing (ID16) achieves a favorable balance, with a low energy intensity (-0.72, ranked 4th) and strong productivity (ranked 4th). This is indicative of high energy efficiency and operational sophistication, likely due to foreign direct investment and integration into global supply chains, particularly in states like Karnataka and Tamil Nadu (Kathuria, 2002). The textile sector (ID6), with one of the highest observation counts (321), has strong TFP (ranked 10th) but a negative energy intensity (-0.36, ranked 17th). This suggests low energy efficiency despite acceptable productivity levels, likely due to reliance on older machinery and high heat-based processing. Such a pattern reinforces the need for targeted energy audits and modernization in labor-intensive sectors (Mazumdar & Sarkar, 2008). The non-metallic mineral products industry (ID12), with a moderate TFP ranking (12th) but worst energy intensity performance (ranked 19th), highlights sectors in need of energy reform intervention. Cement and glass manufacturing, common in this category, are notorious for energy consumption due to thermal processes. Reducing intensity here would require adoption of green technologies, potentially supported by energy-efficiency credit schemes (Das et al., 2009). Overall, the data show that high productivity does not guarantee low energy intensity, and policy must target sector-specific combinations. Some industries achieve both (e.g., machinery, electronics), while others show productivity-energy trade-offs (e.g., petrochemicals, non-metallic minerals). These findings emphasize the importance of energy auditing, technological upgrading, and regulatory targeting in India’s diverse manufacturing landscape.

Table 3: Mean Total factor productivity and energy intensity in Indian manufacturing

Symbol used	Sub-Industries	Number of observations	Mean Total Factor Productivity	Mean Energy Intensity	Ranking based on PO	Ranking based on Energy Intensity
ID1	Food Products	6	5.63	0.75	14	13
ID2	Agricultural products	87	2.31	0.64	1	12
ID3	Petrochemical	31	5.14	0.83	18	3
ID4	Other Food Products	54	4.45	-0.62	15	8
ID5	Beverages and Tobacco Products	159	4.1	0.66	11	6
ID6	Textile	321	5.12	-0.36	10	17
ID7	Lather and Lather Products	14	4.35	0.77	5	5
ID8	Wood and Wood Products	14	4.24	-0.27	3	15
ID9	Paper and Paper Products	83	3.74	-0.54	7	18
ID10	Chemical and Chemical Products	390	4.33	-0.45	9	16
ID11	Rubber and Plastics Products	165	3.89	0.6	6	10
ID12	Non-Metallic Mineral Products	129	5.28	0.01	12	19
ID13	Basic Metal and Metal Products	283	4.97	-0.34	16	11
ID14	Machinery and Machinery Products	129	5.14	0.18	8	1
ID15	Heavy Machinery	115	4.91	0.21	13	2
ID16	Electronics	93	4.28	-0.72	4	4
ID17	Transport Equipments	181	6.18	0.54	17	7
ID18	Other Miscellaneous Manufacturing Products	36	2.42	0.82	2	9
ID19	Diversified Manufacturing	28	5.68	0.37	19	14

Table 4 explores the linear and rank correlations between energy intensity and total factor productivity across various firm types and sub-industries in Indian manufacturing. The results provide critical insights into whether firms that use energy more efficiently are also more productive—an essential issue for energy policy, industrial competitiveness, and sustainable development. The full sample of 2,318 firms shows a very weak negative correlation between energy intensity and total factor productivity (-0.02) and a moderately negative rank correlation of -0.42. This suggests that across the entire manufacturing sector, there is no clear linear relationship between energy use efficiency and productivity, but more energy-efficient firms tend to rank higher in productivity. This is consistent with findings that energy intensity may be influenced by factors unrelated to productivity—such as firm age, sector, or input substitution patterns (Sahu & Narayanan, 2011). Among foreign-owned firms, the correlation is more clearly negative (-0.35), indicating that firms with foreign direct investment tend to be both more energy-efficient and more productive. This aligns with prior studies showing that foreign firms often transfer advanced technologies and energy management practices that enhance both dimensions (Kathuria, 2002). The domestic firm group displays a stronger negative correlation (-0.67), indicating that among locally owned firms, energy efficiency is more strongly associated with productivity. This likely reflects greater marginal gains for domestic firms adopting energy-saving technologies, which in turn boost total output efficiency (Goldar & Kumari, 2003). At the industry level, substantial heterogeneity emerges. Sectors such as rubber and plastics products (+0.66), chemical and chemical products (+0.53), and non-metallic mineral products (+0.67) show positive correlations between energy intensity and productivity. This suggests that in energy-intensive sectors, higher energy usage is often associated with higher output, and improvements in productivity do not necessarily reduce energy usage. In such industries, technological shifts rather than consumption cuts may be needed to achieve energy savings (Pachuari, 2002).

In contrast, industries such as wood and wood products (-0.83), diversified manufacturing (-0.59), and heavy machinery (-0.54) exhibit negative correlations, indicating a more desirable relationship: firms using energy more efficiently tend to be more productive. These industries may benefit from policies that promote energy-saving innovation as a dual pathway to improve competitiveness (Das et al., 2009). Interestingly, sectors like paper and paper products (+0.71) and textiles (+0.11) show weak or even reversed patterns. In the case of paper, higher energy intensity correlates with higher productivity—possibly due to scale effects and mechanization. In textiles, the low correlation suggests mixed dynamics, where energy usage depends more on process types and less on output efficiency (Mazumdar & Sarkar, 2008). Two groups—highly energy-efficient firms and less energy-efficient firms—reveal the clearest contrast. The former group has a strong negative correlation (-0.64), confirming that efficient energy use is tied to higher productivity. In contrast, the latter shows a strong positive correlation (+0.72), suggesting that in less efficient firms, greater energy usage is linked to higher output, possibly indicating overreliance on energy inputs rather than technological sophistication. Finally, the correlation for beverages and tobacco products (+0.41) contrasts with the strong negative correlations in agricultural products (-0.45) and leather (-1.09). This indicates that firm-specific technology, process complexity, and regulation likely drive energy–productivity relationships more than industry categorization alone (Stern, 2000).

Table 4: Correlation Coefficient of Energy Intensity and Total Factor Productivity Across Groups

SL No	Description of the sample	Sample Size	Correlation Coefficient	Rank Correlation Coefficient
1	Full sample	2318	-0.02	-0.42
2	Foreign	89	-0.35	-0.47
3	Domestic	2229	-0.67	-0.48
4	Food Products	6	-0.47	1.37
5	Agricultural products	87	-0.45	0.8
6	Petrochemical	31	-0.46	0.16
7	Other Food Products	54	-0.05	1.47
8	Beverages and Tobacco Products	159	0.41	0.69
9	Textile	321	0.11	0.03
10	Lather and Lather Products	14	-1.09	0.61
11	Wood and Wood Products	14	-0.83	1.24
12	Paper and Paper Products	83	0.71	1
13	Chemical and Chemical Products	390	0.53	1.18
14	Rubber and Plastics Products	165	0.66	0.72
15	Non-Metallic Mineral Products	129	0.67	1.51
16	Basic Metal and Metal Products	283	0.28	1.74
17	Machinery and Machinery Products	129	0.17	1.75
18	Heavy Machinery	115	-0.54	0.71
19	Electronics	93	0.33	1.51
20	Transport Equipments	181	0.14	0.13
21	Other Miscellaneous Manufacturing Products	36	-1.38	0.52
22	Diversified Manufacturing	28	-0.59	1.13
23	Highly Energy Efficient	1886	-0.64	-0.57
24	Less Energy Efficient	432	0.72	1.18

5. CONCLUSION

The primary goal of this paper is to estimate the Translog production function and scrutinize the determinants of inter-firm variations in total factor productivity. A two-stage regression employing Ordinary Least Squares has been utilized to estimate the Translog production function, incorporating four inputs, for the Indian manufacturing industries specifically for the year 2008. This comprehensive methodology aims to provide insights into the production dynamics and factors influencing productivity levels within the manufacturing landscape in the specified period. Additionally, the study extends its focus to examine the determinants of total factor productivity by incorporating firm-specific characteristics and energy intensity. This approach allows for a more nuanced analysis, considering not only the core production inputs but also the influence of other factors and the energy efficiency of firms on overall productivity levels. The investigation aims to provide a comprehensive understanding of the intricate factors that contribute to inter-firm differences in total factor productivity within the context of the Indian manufacturing sector. The results of the study indicate that labor and material inputs exert a more significant influence compared to capital and energy inputs in the Translog production function. In the second stage regression, various factors such as the age of the firm, ownership structure, energy intensity, embodied and disembodied technology imports, research and development, and exports were explored as potential determinants of total factor productivity. These findings underscore the multi-faceted nature of factors influencing overall productivity in the Indian manufacturing sector, highlighting the importance of considering diverse inputs and firm-specific characteristics in the analysis of total factor productivity. The estimation results reveal that the age of the firm, export intensity, and disembodied technology import exhibit a positive relationship with total factor productivity in the Indian manufacturing sector. On the other hand, ownership, energy intensity, embodied technology import, and R&D intensity are found to be negatively associated with total factor productivity. These findings emphasize the diverse and complex nature of the determinants influencing productivity levels within the Indian manufacturing landscape, providing valuable insights for policymakers and industry stakeholders to enhance overall productivity. The analysis reveals that energy-efficient firms also demonstrate high levels of total factor productivity, suggesting a positive association between energy efficiency and overall productivity. Observing the mean total factor productivity, it becomes apparent that diversified manufacturing industries exhibit higher levels compared to the other eighteen sub-industries. In contrast, agricultural product industries emerge with the least total factor productivity within the Indian manufacturing sector. These insights underscore the potential impact of energy efficiency and the varying productivity levels across different sub-industries, offering valuable considerations for strategic planning and industry development. Beyond the quantitative assessment of total factor productivity, this study delves into the exploration of determinants influencing total factor productivity for the Indian manufacturing industries. A noteworthy aspect of this research is its comparative analysis across sub-industries, providing a nuanced understanding of variations in productivity drivers. Additionally, the paper contributes by incorporating energy as the fourth input in the production function, recognizing the significance of energy considerations in the overall productivity dynamics of the manufacturing sector. This comprehensive approach aims to offer valuable insights for policymakers, industry practitioners, and researchers in the realm of Indian manufacturing. In the context of ongoing climate change negotiations and discussions, the pivotal role of energy cannot be understated. The imperative to concentrate on both productivity and energy utilization within Indian industries, particularly in the manufacturing sector, is evident. The outcomes of this study carry significant policy implications, emphasizing the necessity to prioritize energy efficiency. One specific policy implication underscores the urgency to promote energy efficiency at the firm level across all manufacturing industries in India. The government could contemplate the introduction of fiscal incentives aimed at encouraging and rewarding higher energy efficiency achievements. Such proactive measures can not only enhance the sustainability of industrial operations but also contribute to broader environmental and economic goals.

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