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Technological Advancements and Energy Efficiency in Indian Firms

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Abstract
This study examines the impact of various technology sources on the energy intensity of firms. Utilizing data from the Center for Monitoring Indian Economy, we model the relationship between energy intensity and the use of different technologies. The primary objective is to identify which technological practices contribute to lower energy consumption within firms. Our analysis reveals several key findings. Firstly, firms that import disembodied technology are less energy-intensive. Disembodied technology, which refers to innovations and improvements that are not tied to physical equipment but rather to knowledge and processes, significantly reduces the energy consumption of firms that adopt it. This suggests that knowledge-based technological advancements play a crucial role in enhancing energy efficiency. Secondly, the study finds that firms engaging in research and development activities also exhibit lower energy intensity compared to firms without such activities. Research and development efforts lead to the development and implementation of new technologies and practices that optimize energy usage and improve overall efficiency. This highlights the importance of continuous innovation and investment in research and development for achieving sustainable energy consumption. Additionally, our study uncovers an inverted 'U' shaped relationship between energy intensity and the age of the firm. This relationship indicates that both younger and older firms tend to be more energy-efficient than those at the intermediate stages of their lifecycle. Younger firms might benefit from newer technologies and processes, while older firms may have accumulated experience and incremental innovations that enhance their energy efficiency. Firms in the middle age range, however, might face challenges in upgrading their technology or optimizing their operations, leading to higher energy intensity. The findings underscore the significant role of technological adoption and innovation in reducing energy intensity. Policymakers and business leaders can leverage these insights to promote practices that foster energy efficiency. Encouraging the import of disembodied technology, supporting research and development initiatives, and facilitating technological upgrades across the firm lifecycle can drive substantial improvements in energy consumption patterns.
Keywords: Energy Intensity, Technological Innovation, Firm Lifecycle
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1. INTRODUCTION

India, as a developing nation with a population exceeding a billion, has witnessed significant shifts in its energy consumption patterns and consequent greenhouse gas emissions over the past several decades. The country's energy mix has increasingly leaned towards coal, primarily due to its relative abundance compared to oil and natural gas resources. This shift has led to higher energy intensity, reflecting how efficiently energy is utilized within the economy, which historically has been higher compared to more developed OECD member countries (International Energy Agency [IEA], 2007). Since the late 1990s, however, India has experienced a decline in energy intensity. This reduction can be attributed to several factors shaping its energy landscape. Firstly, demographic shifts from rural to urban areas have altered consumption patterns and demand for energy. Secondly, structural changes in the economy, including the growth of less energy-intensive industries and a significant expansion in the services sector, have contributed to lowering overall energy intensity. Moreover, India has made strides in improving energy efficiency across sectors such as industry, transportation, and residential buildings. These efforts have been pivotal in mitigating the environmental impact of energy consumption (IEA, 2007). Additionally, there has been a gradual transition towards cleaner energy sources like renewable energy, which has further supported efforts to reduce greenhouse gas emissions. Looking ahead, India continues to prioritize sustainable development goals, aiming to further decrease energy intensity and enhance environmental sustainability. Policies promoting energy efficiency, technological advancements, and the continued adoption of renewable energy sources are expected to play a crucial role in achieving these objectives. This trajectory underscores India's commitment to balancing economic growth with environmental stewardship in the global fight against climate change.

In Indian industries, energy intensity ranks among the highest globally. The manufacturing sector stands out as the largest consumer of commercial energy within India's industrial landscape. Despite contributing approximately one-fifth of the nation's GDP, this sector accounts for nearly half of all commercial energy consumed industrially across the

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country. This disparity highlights the significant energy demands associated with manufacturing activities in India, particularly in key sectors such as steel, aluminum, cement, paper, textiles, and others (IEA, 2007). The energy consumption per unit of production in these industries is notably higher in India compared to many other developing nations. This high energy intensity underscores the challenges and opportunities for improving energy efficiency and reducing environmental impact within India's industrial sector. Efforts to enhance energy efficiency through technological advancements, adoption of cleaner production methods, and policy measures aimed at promoting sustainable industrial practices are crucial in addressing these challenges. As India continues to pursue economic growth and industrial development, optimizing energy use in manufacturing remains a critical priority for enhancing competitiveness and achieving sustainable development goals.

Several studies have examined various aspects of productivity, technical efficiency, and research and development (R&D) intensity within the Indian manufacturing sector. Mitra, Varoudakis, and Veganzones (1998) provided estimates of Total Factor Productivity (TFP) and Technical Efficiency in Indian Manufacturing, shedding light on the efficiency and performance of the sector. Additionally, studies such as Puran and Jayant (1998) have specifically focused on estimating TFP in energy-intensive industries within Indian manufacturing, highlighting the productivity challenges and potential improvements in these sectors. Research on R&D intensity in Indian manufacturing has also been extensive. Kumar (1987) and Narayanan & Banerjee (2006) conducted studies examining variations in R&D intensity at both aggregate and disaggregate levels, providing insights into how different industries allocate resources towards innovation and technological advancement. Studies by Kumar & Saqib (1996) and Siddharthan & Agarwal (1992) explored the determinants of R&D investments in Indian industries, offering perspectives on the factors influencing innovation within the manufacturing sector. Furthermore, the demand for energy in Indian manufacturing industries has been a significant area of research interest. Saumitra & Rajeev (2000) and other energy researchers have studied energy consumption patterns at both aggregate and specific industry levels, aiming to understand the drivers of energy demand and opportunities for enhancing energy efficiency across the sector.

Over the past two decades, the manufacturing sector has witnessed substantial advancements in technology adoption, including computer-aided design and manufacturing, as well as integrated information networks within manufacturing plants. These technological innovations represent embodied technical change, influencing manufacturing operations in two primary ways: first, by altering the production function itself, and second, by modifying the mix of inputs used in production processes. A notable study by Bhat and Narayanan (2009) explored how technological efforts and firm size influence the export behavior of firms in India's basic chemical industry. This research delved into the dynamics of technological adoption within firms of varying sizes, examining how these factors interact to shape firms' capacities and strategies in international markets. By analyzing these relationships, Bhat and Narayanan contributed valuable insights into the role of technology as a driver of export competitiveness, highlighting its implications for firm-level performance and industry dynamics in the Indian manufacturing landscape. Their findings underscored the importance of technological investments and capabilities in enhancing firms' ability to compete globally, thereby linking technological advancements directly to economic outcomes in the manufacturing sector.

In their research, Bhat and Narayanan (2009) employed three distinct econometric models—the Tobit model, the two-part model (comprising Probit and Truncation), and the Heckman sample selection model—to analyze the determinants of firms' export behavior within India's basic chemical industry. Their study highlighted the significant roles played by technological efforts, firm size, and other specific characteristics of firms in shaping their export activities. However, there has been relatively less emphasis in economic research on exploring how technology influences factors such as input choices and, notably, its impact on the energy intensity at the plant level within industries or firms. Most studies in the field of energy economics traditionally use aggregate or industry-level data and often model technology as a linear time trend (Berndt, 1990). This approach has limitations in capturing the nuanced effects of technological change on energy use efficiency within specific manufacturing plants or sectors. By focusing on technology sourcing and its influence on factors like input choices, future research could delve deeper into understanding how these technological advancements specifically affect energy intensity levels in manufacturing facilities. Such investigations could provide crucial insights into optimizing energy use and enhancing sustainability in industrial operations, thereby contributing to both economic efficiency and environmental sustainability goals.

In developing countries, firms often adopt imported technological strategies to enhance their capabilities. These technologies are acquired through various channels, including direct imports, in-house research and development (R&D), and collaborations with foreign equity partners. The imported technologies can be classified into embodied, where physical equipment or machinery is imported, and disembodied, which involves the transfer of knowledge and organizational practices. This study specifically investigates both embodied and disembodied technical changes and their impact on the energy intensity of firms in the Indian manufacturing sector. The central question addressed is whether plants that adopt embodied technology sourcing are more energy-efficient compared to those employing disembodied technology sourcing. Embodied technical change typically involves the acquisition of new equipment or machinery that may inherently incorporate energy-saving features or more efficient production processes. In contrast, disembodied technical change focuses on knowledge transfer and organizational improvements that may lead to operational efficiencies but might not directly influence energy consumption in the same tangible manner. By examining these dynamics, the study aims to contribute to a better understanding of how different forms of technological adoption influence energy intensity levels in manufacturing plants. This research could potentially inform policies and strategies aimed at promoting sustainable industrial development and improving energy efficiency practices within the manufacturing sector in India and similar developing economies.

The paper is structured as follows: The next section provides a comprehensive review of the existing literature on technology efforts, innovation, and firm characteristics, focusing specifically on their implications for energy intensity in industrial settings. This review aims to establish a theoretical foundation and contextual background for understanding how technological advancements and firm-specific factors influence energy consumption levels. Following the literature review, the third section outlines the methodology employed in this study, detailing the construction of variables used to measure technology sourcing, innovation activities, firm characteristics, and energy intensity. This section clarifies the approach taken to analyze the relationships between these variables and provides insights into the empirical framework adopted. In the fourth section, the paper presents the empirical model developed to assess energy intensity within manufacturing plants. This model is structured to examine the impacts of embodied and disembodied technological changes, alongside other firm-specific characteristics, on energy efficiency outcomes. The model formulation includes econometric techniques tailored to capture the complexities of energy consumption patterns across different types of technological adoption. The fifth section summarizes the findings derived from the energy intensity regressions. It highlights key empirical results and discusses their implications for understanding the role of technology in shaping energy efficiency practices in the manufacturing sector. Finally, the paper concludes with a synthesis of the main findings and offers concluding remarks on the implications for policy, practice, and future research directions in the domain of energy efficiency and technological adoption in industrial settings.

2. ENERGY CONSUMPTION AND TECHNOLOGY SOURCING

Two primary approaches have been employed to investigate the correlation between energy consumption and technology sourcing. The first approach involves conducting case studies that focus on energy-saving technology innovations or the adoption of new technologies. Researchers such as Ayres (1991), Joyce (1991), Schmidt (1987), and Sparrow & Schmidt (1993) have utilized this method, which entails analyzing specific production processes from an engineering standpoint. These studies typically delve into the technical details of how particular technologies affect energy use within production systems. In contrast, the second approach utilizes econometric modeling of production functions to explore how technology influences overall production and its subsequent energy consumption. Pioneered by scholars like Berndt and Wood (1975), this approach examines how changes in technology alter the relationships between inputs (such as capital and labor) and outputs (goods or services). By modeling these production functions, researchers can quantify the impact of technological advancements on energy efficiency and understand the broader implications for industrial energy consumption patterns.

In their study, Sahu and Narayanan (2010) aimed to identify the factors influencing energy intensity in Indian manufacturing industries. They focused on variables such as capital intensity, firm size, firm age, and labor intensity as significant determinants of energy intensity. Using econometric methods, they estimated energy-factor demand equations based on data from Indian manufacturing firms. The current paper extends this research by investigating the relationship between technology sourcing and energy intensities within Indian manufacturing firms. The hypothesis posits that increased automation and adoption of advanced manufacturing technologies may affect overall energy consumption in several ways. While these technologies may not be explicitly designed to reduce energy consumption, they could lead to indirect reductions in energy intensity through efficiency improvements and technological spillovers in energy use efficiency across production processes. This study aims to empirically explore how different forms of technology sourcing—both embodied and disembodied—impact the energy profiles of manufacturing firms in India, contributing to the understanding of energy management strategies and technological influences on industrial energy consumption patterns.

In addition to exploring the impact of advanced manufacturing technologies on energy usage, this paper delves into whether older manufacturing firms exhibit higher energy intensity compared to younger firms. Several mechanisms might explain how plant age influences energy efficiency and energy consumption patterns. Firstly, there's a technological effect: older firms may not have initially adopted the latest energy-saving technologies available to newer plants. This technological lag could lead older firms to rely on outdated equipment and processes that are more energy-intensive compared to modern counterparts benefiting from newer, more efficient technologies. Secondly, age can influence energy intensity through economic considerations, as highlighted in models by economists like Abel (1983) and Lambson (1991). These models emphasize the role of expected relative prices in shaping firms' choices regarding technology adoption. Older firms, due to historical investments and operational practices, may face higher costs in transitioning to newer, more energy-efficient technologies, thereby maintaining higher energy intensity levels compared to younger firms that can start with more efficient infrastructure from inception. By examining these dynamics, the study aims to contribute to a deeper understanding of how firm age interacts with technological adoption to shape energy consumption patterns in the manufacturing sector, offering insights into strategies for enhancing energy efficiency and sustainability across different stages of industrial development.

The models discussed suggest that firms tend to choose less energy-intensive production methods when expected energy prices are high. This hypothesis implies that plants constructed during periods of high expected energy prices may have opted for less energy-intensive production facilities. Furthermore, plant survival can serve as an indicator of plant efficiency. Older plants that survive over the long term may generally be more efficient than younger plants. This longevity could stem from their ability to adapt and innovate in response to changing economic and technological landscapes, including advancements in energy efficiency. The third objective of the paper focuses on examining the relationship between R&D expenses and energy intensity in manufacturing firms. R&D expenditures are critical because they signify investments in developing new technologies and processes that can enhance production efficiency and reduce energy consumption. Higher R&D spending may lead firms to innovate and adopt less energy-intensive technologies, thereby lowering their overall production costs. In essence, the study aims to explore how firms' strategic decisions, influenced by expected energy prices and investment in R&D, shape their energy intensity levels. By analyzing these relationships, the paper seeks to provide insights into how firms can optimize their energy use and enhance their competitiveness in the manufacturing sector.

3. AN EMPIRICAL MODEL OF ENERGY INTENSITY

To construct an empirical model of energy consumption incorporating technological factors, we draw on the framework established by Doms and Dunne (1995), which utilizes an energy factor demand equation derived from a cost minimization perspective. The dependent variable in our model is the total energy consumed by the firm, measured in Indian Rupees (INR), divided by net sales, which serves as a proxy for industrial output. This ratio helps normalize energy consumption relative to the scale of production output, providing a clearer measure of energy intensity. The first set of independent variables in our model captures factor prices at the plant level, including the labor rate specific to each plant. This variable accounts for labor costs, which can influence energy consumption patterns through their impact on production processes and workforce efficiency. The subsequent set of independent variables focuses on plant-specific measures of fixed capital. This inclusion is crucial as it helps control for variations in energy intensity across plants of different sizes. Larger plants, for example, may exhibit different energy consumption patterns compared to smaller facilities due to economies of scale or different production technologies. The vector "z" encompasses a series of production process variables that further refine our understanding of energy consumption dynamics within each plant. These variables encompass technological inputs and operational processes that directly influence how energy is utilized in production activities.

By structuring our model in this manner, we aim to elucidate the role of technological factors, labor costs, and capital investments in shaping energy consumption patterns in manufacturing firms. This approach allows us to explore how firms' strategic decisions regarding technology adoption and production processes impact their overall energy efficiency and operational costs. To model the technology factor in our empirical analysis, we incorporate two distinct sets of variables. Firstly, we include plant age variables to capture the overall lifespan of the plant and its relationship to the energy intensity of the firm. This allows us to assess how older versus newer plants may differ in their energy consumption patterns, considering technological advancements over time. In an enhancement to previous research, we also introduce the size of the firm as a crucial variable. Firm size is measured here in terms of total energy consumption. This variable helps account for differences in energy usage between firms within and across industries, providing insights into inter-industry variations in energy intensity. Larger firms, for example, may have different energy consumption profiles compared to smaller firms due to economies of scale or differing production technologies.

Energy efficiency improvements can occur through various means, such as reducing energy inputs while maintaining service levels or enhancing services with the same amount of energy inputs. In the context of developing countries like India, technology imports play a pivotal role as a source of knowledge acquisition for enterprises. The adoption of imported technologies can significantly influence energy intensity. Whether these imported technologies lead to product innovations or process improvements, their adoption is likely to have measurable effects on energy efficiency within manufacturing industries. Given the challenges in accessing detailed technological data at the firm level in Indian manufacturing, we categorize technology sourcing into two components. The first component focuses on embodied technology interventions, where physical technologies or equipment are imported or adopted within the production processes. The second component addresses disembodied technologies, encompassing knowledge transfers, training, and organizational changes that enhance operational efficiency without necessarily changing physical production equipment. By categorizing technology sourcing in this manner and integrating these variables into our model, we aim to explore how different technological strategies impact energy intensity in Indian manufacturing firms. This approach allows us to discern the specific contributions of embodied and disembodied technologies to overall energy efficiency, thereby informing strategies for enhancing energy performance across the sector.

The reason for considering age of the firm is the firms having long span of years in production would likely incur relatively more expenditure on R and D compared to younger firms and hence age of the firm may affect the energy intensity of the firm. We have used the OLS regression model to analyze equation 1.4. The study uses the following definitions of variables. Data used in this analysis were collected from the Center for Monitoring Indian Economy (CMIE) database from 2000 to 2022.

The general form of regression equation takes the following functional form:

lnEI=f(lnCI, WI, AGE, SIZE, RI, ETI, DTI, MNE)

4. EMPIRICAL RESULTS

Table 1 provides a comprehensive overview of various descriptive statistics pertaining to firm characteristics. These statistics are crucial for understanding the distribution and central tendencies within the dataset. The Energy Intensity variable shows a mean of -3.330 and a standard deviation of 1.317. This metric ranges widely from -10.833 to 2.639, indicating significant variability in how firms consume energy resources. Such variation suggests diverse energy management strategies among the sampled firms. Capital Intensity exhibits a mean of 3.311 with a standard deviation of

1.762, spanning from -4.605 to 11.754. This highlights the diverse levels of capital investment across firms, impacting their operational scale and financial structure. Labour Intensity has a mean of 0.733 and a standard deviation of 1.802, ranging from -4.605 to 8.250. This variability reflects differences in employment practices and workforce utilization strategies among the firms analyzed. The Age of the Firm statistics reveal an average establishment age of 30 years, with a standard deviation of 19 years. The firms' ages range widely from 1 year to 184 years, indicating a mix of relatively young and long-standing enterprises in the dataset. In terms of Size of the Firm, the mean is 1.642 with a standard deviation of 0.810, ranging from -2.000 to 5.439. This metric underscores the varying scales of operations among firms, influencing their market presence and economic footprint. Embodied Technology Intensity shows a mean of 2.166 and a remarkably high standard deviation of 26.452. This variable spans from 0.000 to 2553.870, indicating substantial differences in the integration of technological assets across firms. Disembodied Technology Intensity is characterized by a mean of 0.059 and a standard deviation of 1.822, ranging from 0.000 to 223.880. This metric reflects the diverse impact of technology on firms beyond physical assets, influencing operational efficiencies and innovation capabilities. The MNE Affiliation of the Firm shows a high mean of 0.982 with a standard deviation of 0.133, indicating prevalent multinational enterprise influence among the sampled firms. This binary variable underscores the international connectivity and strategic partnerships within the dataset. Finally, the dataset comprises a substantial Number of Observations, totaling 33,496 entries. This large sample size enhances the statistical robustness and reliability of the findings, providing a comprehensive basis for analyzing firm characteristics and behaviors. In summary, Table 1's descriptive statistics offer valuable insights into the diverse economic, technological, and organizational attributes of firms, crucial for understanding their operational dynamics and strategic orientations within the broader economic context.

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
Energy Intensity	-3.330	1.317	-10.833	2.639
Capital Intensity	3.311	1.762	-4.605	11.754
Labour Intensity	0.733	1.802	-4.605	8.250
Age of the Firm	30	19	1	184
Size of the Firm	1.642	0.810	-2.000	5.439
Embodied Technology Intensity	2.166	26.452	0.000	2553.870
Disembodied Technology Intensity	0.059	1.822	0.000	223.880
MNE Affiliation of the Firm	0.982	0.133	0.000	1.000
Number of Observations	33496			

Table 2 presents a correlation matrix detailing the relationships among various variables in the dataset. The matrix is symmetric, with variables both in rows and columns, displaying Pearson correlation coefficients between each pair of variables. Energy Intensity (EI) shows a positive but weak correlation with Capital Intensity (CI) (0.111) and a negative but also weak correlation with Workforce Intensity (WI) (-0.060). These correlations suggest subtle relationships between energy consumption and capital investment and a slight inverse relationship with labor utilization. Capital Intensity (CI) exhibits moderate positive correlations with Workforce Intensity (WI) (0.805), Size of the Firm (SIZE) (0.809), Age of the Firm (AGE) (0.199), and Embodied Technology Intensity (ETI) (0.203). These correlations indicate stronger connections between capital investment and workforce utilization, firm size, age, and technological integration. Workforce Intensity (WI) correlates positively with Size of the Firm (SIZE) (0.827) and Age of the Firm (AGE) (0.374), indicating that larger firms and those of older age tend to employ more labor-intensive practices.

Table 2: Correlation Matrix

	EI	CI	WI	AGE	SIZE	RD	ETI	DTI	MNE
EI	1.000								
CI	0.111	1.000							
WI	-0.060	0.805	1.000						
AGE	0.076	0.199	0.374	1.000					
SIZE	-0.219	0.809	0.827	0.193	1.000				
RD	-0.030	0.125	0.133	0.039	0.124	1.000			
ETI	0.004	0.203	0.185	0.076	0.188	0.113	1.000		
DTI	-0.034	0.077	0.075	0.027	0.081	0.082	0.239	1.000	
MNE	0.001	-0.164	-0.203	-0.084	-0.146	-0.071	-0.173	-0.107	1.000

Age of the Firm (AGE) shows a positive correlation with Size of the Firm (SIZE) (0.193), reflecting that older firms are generally larger in size. Size of the Firm (SIZE) also correlates positively with Capital Intensity (CI) (0.809), reinforcing that larger firms tend to make greater capital investments. Research and Development (RD) expenditures correlate positively with Size of the Firm (SIZE) (0.124) and Embodied Technology Intensity (ETI) (0.113), suggesting that larger firms and those with higher technological integration tend to invest more in research and development. Embodied Technology Intensity (ETI) shows positive correlations with Capital Intensity (CI) (0.203) and Disembodied Technology Intensity (DTI) (0.239), indicating that firms with higher physical technology assets also tend to have higher capital investments and utilize more non-physical technological assets. Disembodied Technology Intensity (DTI) has a positive correlation with Embodied Technology Intensity (ETI) (0.239), reinforcing the association between physical and non-physical technological investments. MNE Affiliation (MNE) shows negative correlations with several variables: Capital Intensity (CI) (-0.164), Workforce Intensity (WI) (-0.203), Age of the Firm (AGE) (-0.084), Size of the Firm (SIZE) (-0.146), Research and Development (RD) (-0.071), Embodied Technology Intensity (ETI) (-0.173), and Disembodied Technology Intensity (DTI) (-0.107). This indicates that firms affiliated with multinational enterprises tend to have lower levels of these characteristics compared to non-affiliated firms. Overall, Table 2 provides a detailed view of how various firm characteristics are interrelated, offering insights into their mutual dependencies and strategic implications within the dataset.

Table 3 presents the results of regression analyses across two models, Model 1 and Model 2, examining the coefficients, standard errors (SE), and t-values for various variables. In Model 1, several variables show significant relationships with the dependent variable. Capital Intensity exhibits a highly significant positive relationship (Coefficient = 0.630, SE = 0.008, t = 80.830***), indicating that firms with higher capital intensity tend to have higher values of the dependent variable. Labour Intensity demonstrates a significant negative relationship (Coefficient = -0.038, SE = 0.009, t = -4.300***), suggesting that firms with higher labour intensity tend to have lower values of the dependent variable. Age of the Firm shows a significant positive impact (Coefficient = 0.017, SE = 0.001, t = 16.480***), indicating that older firms tend to have higher values of the dependent variable. The squared Age of the Firm exhibits a significant negative relationship (Coefficient = -0.008, SE = 0.000, t = -11.210***), implying a non-linear relationship with the dependent variable. Size of the Firm demonstrates a highly significant negative relationship (Coefficient = -1.427, SE = 0.019, t = -76.590***), indicating that larger firms tend to have lower values of the dependent variable. Research and Development (RandD) Intensity of the Firm shows a significant negative relationship (Coefficient = -0.001, SE = 0.001, t = -2.450**), suggesting that firms with higher R&D intensity tend to have lower values of the dependent variable. Embodied Technology Intensity exhibits a significant positive relationship (Coefficient = 0.004, SE = 0.000, t = 3.250***), indicating that firms with higher embodied technology intensity tend to have higher values of the dependent variable. Disembodied Technology Intensity demonstrates a highly significant negative relationship (Coefficient = -0.020, SE = 0.004, t = -5.010***), suggesting that firms with higher disembodied technology intensity tend to have lower values of the dependent variable. MNE (Multinational Enterprise) Affiliation of the Firm shows a marginally significant positive relationship (Coefficient = 0.098, SE = 0.056, t = 1.730*), indicating that firms affiliated with multinational enterprises tend to have higher values of the dependent variable. The constant term in Model 1 is significantly negative (Coefficient = -3.531, SE = 0.062, t = -57.110), suggesting a baseline value for the dependent variable when all predictors are zero.

Table 3: Results of Regression Analysis

Variables	Coefficient	RSE	t Value	Coefficient	RSE	t Value
		Model 1			Model 2	
Capital Intensity	0.630	0.008	80.830***	0.880	0.045	19.590***
Labour Intensity	-0.038	0.009	-4.300***	-0.012	0.057	-0.210
Age of the Firm	0.017	0.001	16.480***	0.003	0.001	2.400**
Square of Age of the Firm	-0.008	0.000	-11.210***	NA	NA	NA
Size of the Firm	-1.427	0.019	-76.590***	-1.126	0.218	-5.170***
Square of the Size of the Firm				-0.207	0.044	-4.600***
RandD Intensity of the Firm	-0.001	0.001	-2.450**	0.077	0.000	-0.720
Embodied Technology Intensity	0.004	0.000	3.250***	0.004	0.001	2.860***
Disembodied Technology Intensity	-0.020	0.004	-5.010***	-0.014	0.003	-4.010***
MNE Affiliation of the Firm	0.098	0.056	1.730*	0.177	0.161	1.100
Constant	-3.531	0.062	-57.110	-4.289	0.262	-16.380

N	33496	N	748
F(9, 33486)	1037.53	F(9, 738)	62.1
Prob > F	0.000	Prob > F	0.000
R^2	0.30		0.43

In Model 2, Capital Intensity maintains a highly significant positive relationship (Coefficient = 0.880, SE = 0.045, t = 19.590***), reinforcing its impact on the dependent variable. Labour Intensity shows no significant relationship (Coefficient = -0.012, SE = 0.057, t = -0.210), indicating that in this model, labour intensity does not influence the dependent variable significantly. Age of the Firm continues to have a significant positive impact (Coefficient = 0.003, SE = 0.001, t = 2.400**), similar to Model 1. The Size of the Firm remains significantly negatively related (Coefficient = -1.126, SE = 0.218, t = -5.170***), suggesting that larger firms continue to have lower values of the dependent variable. The squared Size of the Firm also shows a significant negative relationship (Coefficient = -0.207, SE = 0.044, t = -4.600***), reinforcing the non-linear relationship observed in Model 1. Embodied Technology Intensity maintains its significant positive relationship (Coefficient = 0.004, SE = 0.001, t = 2.860***), indicating its ongoing impact on the dependent variable. Disembodied Technology Intensity remains highly negatively related (Coefficient = -0.014, SE = 0.003, t = -4.010***), similar to Model 1. MNE Affiliation of the Firm shows no significant relationship (Coefficient = 0.177, SE = 0.161, t = 1.100), indicating that in Model 2, this variable does not influence the dependent variable significantly. The constant term in Model 2 remains significantly negative (Coefficient = -4.289, SE = 0.262, t = -16.380), providing a baseline value for the dependent variable when other predictors are zero. Additional statistical details provided are the number of observations (N), with Model 1 based on 33,496 observations and Model 2 on 748 observations. The F-statistics indicate Model 1 (F = 1037.53, Prob > F = 0.000) and Model 2 (F = 62.1, Prob > F = 0.000) are both statistically significant. The R-squared values for Model 1 (R2 = 0.30) and Model 2 (R2 = 0.43) indicate the proportion of variance in the dependent variable explained by each model. These regression results offer comprehensive insights into how various firm characteristics influence the dependent variable across two models, highlighting significant relationships, model fit statistics, and the overall explanatory power of each model.

5. CONCLUSIONS

This paper utilizes firm-level data spanning from 2000 to 2022 sourced from the Center for Monitoring Indian Economy to examine the impact of technology sourcing and other plant-level characteristics on energy consumption in Indian manufacturing plants. The study's primary finding suggests that the use of disembodied technology by firms contributes to a reduction in energy intensity across both models analyzed. However, in contrast, the import of embodied technology shows a positive relationship with the energy intensity of firms in both models. These results underscore the importance of distinguishing between embodied and disembodied technology when assessing their impact on energy efficiency in manufacturing. Disembodied technologies, such as knowledge transfers and organizational improvements, appear to lead to more efficient energy use. In contrast, embodied technologies, which involve physical equipment and machinery imports, may increase energy intensity, possibly due to initial setup costs, operational inefficiencies, or the nature of the technologies themselves. By highlighting these distinctions, the study contributes to understanding how different forms of technology adoption influence energy consumption patterns in the manufacturing sector.

This insight can inform policymakers and industry stakeholders aiming to promote sustainable practices and enhance energy efficiency in India's manufacturing industries. The study underscores that embodied technology imports tend to increase the energy intensity of firms, possibly due to the higher energy consumption involved in importing capital goods. This finding suggests that initial setup costs, operational inefficiencies, or the nature of the technologies themselves contribute to higher energy demands. Moreover, the results indicate that differences in plant-level energy demand are consistently influenced by identifiable plant characteristics. Even when controlling for the technology import variable, factors such as production process differences, plant age, technological effects, and firm size exhibit significant impacts on energy intensity. These consistent findings across different studies underscore the robustness of these factors in shaping energy consumption behavior at the plant level, providing valuable insights for both industry practitioners and policymakers interested in promoting energy efficiency initiatives. The concern over climate change, greenhouse gas emissions, and sustainable energy usage is increasingly pertinent not only for developed nations but also for developing and underdeveloped countries like India. As the largest and rapidly growing developing country, India faces significant challenges regarding energy intensity. It is crucial to delve beyond aggregate national-level discussions and focus specifically on sub-sectors within the economy. Energy intensity in Indian manufacturing firms is particularly concerning due to the substantial burden of crude petroleum imports. The global and local environmental impacts stemming from the extensive use of fossil fuels highlight the urgent need to foster economic growth in a sustainable manner. By examining how different technology sourcing strategies impact energy intensity at the firm level, this research seeks to provide insights into potential pathways for enhancing energy efficiency and mitigating environmental impacts within the Indian manufacturing sector. Such efforts are crucial for aligning economic development with sustainable practices and addressing the pressing challenges posed by climate change and energy security.

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