Energy Intensity of Indian Manufacturing Firms: Effect of Energy Prices, Technology and Firm Characteristics

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Abstract

The energy intensity of Indian manufacturing has declined significantly since 1992. According to the estimates of Ray and Reddy (2007), energy intensity of Indian manufacturing declined from 787 TJ per billion Rupees of output in 1992 to 547 TJ per billion Rupees of output in 2002. A similar fall (at the rate of about 5% per annum) was there in the ratio of real value of energy consumption to the real value of output in Indian manufacturing (organized) in the period 1992-93 to 2007-08. Between 1992-93 and 1997-98, energy intensity fell by about 55 percent. However, there is scope for further substantial decline. *Annual Survey of Industries* (ASI) data reveal significant inter-state variation in the energy intensity of energy intensive industries, such as cement, paper and steel. Similarly, firm-level analysis brings out significant inter-firm variation in the ratio to energy cost to sales. Thus, it seems reasonable to assert that substantial reduction in energy use in Indian industries is possible, and the rate of fall in energy intensity in Indian industries can possibly be made faster.

The paper examines the factors that influence energy intensity in Indian industries. It has two parts. In the first part, trends in energy intensity are analysis and cross-industry panel data (taken from ASI) are used to estimate an energy demand function. The results show that energy demand responds negatively to a hike in energy prices and positively to a hike in real wages. There are indications from the results of the analysis that the post-1992 decline in energy intensity of Indian manufacturing is attributable mostly to an improvement in energy use efficiency of energy intensive industries, which in turn may be traced to hikes in the real price of energy paid by manufacturing firms. The results also show a significant impact of technological change (captured by Total Factor Productivity indices) on energy intensity. In the second part, cross-section data on industrial firms (taken from *Capitaline* for the years, 2006-7 to 2008-9) are used to investigate the firm-level determinants of energy intensity. Technology (captured by R&D intensity, materials import intensity and technology import intensity) is found to be an important determinant. Use of IT is found to help in improving energy use efficiency. Firms of bigger size are found to be more energy efficient, but not in energy intensive industries. Firms of older vintage are found to be less energy efficient. Location of plants is found to have a significant effect on energy intensity. An attempt is made in the paper, perhaps for the first time, to assess energy efficiency spillover from foreign firms to local firms. The econometric results indicate presence of significant spillover effects.

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1. Introduction

The concentration of carbon dioxide (CO_2) in the atmosphere has been increasing over the last two decades at the average rate of about 0.5 percent per year. In October 1989, the CO_2 concentration level in the atmosphere (Mauna Loa Observatory) was 350.1 ppm (parts per million), and in December 2009, it had risen to 387.3 ppm. Some recent studies have indicated that inconceivable catastrophic changes in the environment will take place if the global temperatures increase by more than 2° C (3.6° F). A warming of 2° C (3.6° F) corresponds to a carbon dioxide (CO_2) concentration of about 450 ppm in the atmosphere. CO_2 concentration, as noted above, has already crossed 380 ppm and it has been rising on average 2-3 ppm each year. Thus, the critical value will be reached in approximately 20 to 30 years from now. Hence, the serious adverse effect that the current rate of increase in CO_2 concentration, if maintained, can have on the global environment in course of time is a very important issue today.

If CO_2 emissions are halved by 2050 compared to the 1990 level, global warming can be stabilized below two degrees. This is shown by two recent studies published in the journal *Nature* (Allen et al., 2009; Meinshausen et al., 2009). This may be contrasted with the growth that has actually taken place in CO_2 emissions since 1990. Between 1991 and 2008, CO_2 emissions have grown from 21.6 billion tones to 31.5 billion tones, an increase by about 46 percent. The annual growth rate of emissions at the global level in the 1990s was about one percent per year, while that in period 2000 to 2008 was about more than 3 percent per year.

The CO_2 emissions from India and China have been growing faster than the growth rate at the global level. The CO_2 emissions from China increased by about 150 percent between 1990 and 2006. China's share in global CO_2 emissions increased significantly in this period and reached 21.5 percent in 2006. The CO_2 emissions from India grew by about 125 percent between 1990 and 2008. The share of India in global CO_2 emissions has increased over time, and it was about 5 percent in 2008. It may be mentioned in this connection that the CO_2 emissions from India are expected to grow three to five times by 2031 as the economy expands and population increases (Government of India, 2009). From 1.4 billion tones in 2008, the emission level is projected to increase to somewhere in the range of 4 to 7.3 billion tones in 2031. In spite of this increase in emissions, India's share in cumulative CO_2 emissions will remain relatively low. While China's share in cumulative CO_2 emissions in the period 1990 to 2030 is expected to be about 16 percent approaching the shares of US (25 percent) and EU (18 percent), India's share in cumulative emissions during 1990-2030 is projected at 4 percent.

In the United Nations Climate Change Summit in Copenhagen, held December 2009, the United States has agreed to cut its greenhouse gas emissions by roughly 17 percent by 2020, as compared to the 2005 levels. This is a major change from the trends in the past. The U.S. had not ratified the Kyoto Protocol, a regime that would have obliged it to reduce its emissions by a fixed percentage below 1990 levels. The U.S. has, in fact, increased its carbon dioxide emissions by 20 percent between 1990 and 2007.

China, which had a growth rate of CO_2 emissions of about 10 percent per annum and has recently taken over the US as the leading country in CO_2 emissions, has declared that it would bring down the carbon intensity of its economy by 40 to 45 percent below the 2005 level by 2025. India has similarly announced a unilateral climate mitigation measure to reduce its carbon intensity level by 20 to 25 percent over the next 11 years.[1] Of the various measures that could be taken for reducing carbon intensity, measures directed at improving energy use efficiency obviously occupy a very important place.[2] There is a proposal to specify optimum energy use norms for various industries to be coupled with a system of trading in energy efficiency certificates. This is likely to be introduced soon and, if successfully administered, is expected to save about 10,000 MW energy every year.

In the context of the government's emission intensity reduction plan for the non-agricultural sector by 20-25 percent in the course of next 11 years, a study of energy intensity of Indian manufacturing firms, especially what factors determine energy intensity, assumes considerable significance.[3] The paper makes an attempt in that direction.

The paper is organized as follows. The next section examines inter-industrial variation in energy intensity and how the energy intensity of Indian manufacturing at the aggregate level has changed over time. This is followed in Section 3 by an analysis of inter-state variation in energy intensity in energy intensive industries. In Section 4, the effect of energy prices and technological progress on energy use in industries is assessed by estimating an energy demand function for Indian manufacturing. Section 5 presents an analysis of inter-firm variation in energy intensity with the aim of assessing the effect of technology and some other firm characteristics (such as firm size, vintage and foreign equity) on energy intensity. Section 6 summarizes the main findings of the study and concludes.

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[1] In a statement submitted recently to the UN framework convention on climate change secretariat, the Government of India has declared that "India will endeavour to cut its emissions intensity by 20-25% by 2020 in comparison to the 2005 level through domestic mitigation actions." It has been emphasized that the actions will be entirely voluntary in nature, and will not have a legally binding character. It has been stressed further that the agricultural sector would not be a part of the mitigation actions and the emissions from agriculture would be excluded from the assessment of emission intensity.

[2] See *National Action Plan on Climate Change*, Prime Minister's Council on Climate Change, Government of India, 2008.

[3] Nearly a third of world energy consumption and about 36% of CO_2 emissions are attributable to manufacturing industries. According to an estimate, CO_2 emissions in India in 1999 was 883 million tons of which the contribution of manufacturing and construction was 205 million tons, i.e. a share of 23%.

2. Inter-industrial variation and trends in Energy Intensity in Manufacturing

Energy intensity (defined as the ratio of energy cost to the value of output) varies considerably across industries. A comparison of energy intensity across four-digit manufacturing industries for 2003-04 using *Annual Survey of Industries*[4] (ASI) data reveals that energy intensity is more than 10% in 17 industries (in 4 cases exceeding 20%), between 5 and 10% in 22 industries, between 2.5 and 5% in 45 industries and less than 2.5% in 44 industries (some cases less than 1%). Taking the industries in which the energy intensity is more than 10%, it is found that these industries accounted for about 57% of total energy consumption in organized manufacturing (in value) and about 25% in value added and 22% in value of output in 2003-04.

A similar analysis for three-digit industries (for 2005-06) reveals that energy intensity exceeds 10% in 6 industries out of 63 industries. Taking the industries in which the energy intensity is more than 10% along with those in which the energy intensity is between 9 and 10%, it is found that these three-digit industries, nine in number, accounted for about 67% of total energy consumption in organized manufacturing (in value) and about one third in value added in 2005-06.

Trends in Energy Intensity

Ray and Reddy (2007) have analyzed trends in energy intensity in Indian manufacturing in the period 1992 to 2002. Their estimates indicate that energy intensity of Indian manufacturing has declined from 787 TJ per billion Rupees of output in 1992 to 547 TJ per billion Rupees of output in 2002. The annual rate of fall in energy intensity was 3.6 percent. In CO_2 emission intensity (emission per billion of Rupees of output), there was a fall at the rate of about 3 percent per annum during this period.

In order to examine the sources of fall in energy intensity in the period 1992 to 2002, Ray and Reddy have carried out a decomposition analysis, which helps them to assess the relative sizes of energy intensity effect and structural effect. Based on their results, they conclude that most of the reduction in energy intensity observed at the aggregate level during 1992-2002 is attributable to the structural effect (i.e. change in relative shares of different industries in production) rather than the energy intensity effect.

Figure 1 shows the trends in energy intensity in Indian manufacturing (organized) during the period 1973-74 to 2007-08 (using *Annual Survey of Industries* data). Ratio of deflated value of energy cost to the deflated value of output is taken as the measure of energy intensity. For this purpose, a price index for energy used in manufacturing has been

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[4] Annual Survey of Industries, Central Statistical Organization, Government of India.

formed by taking a weighted average of the wholesale price indices of coal, oil and electricity. The weights are obtained from the input-output table for 1993-94.

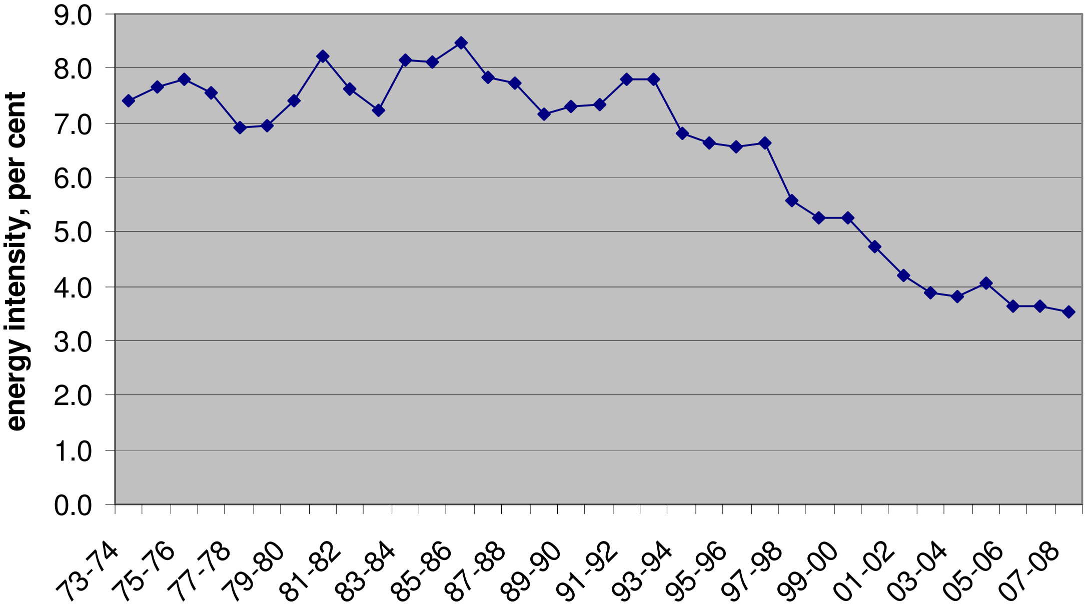
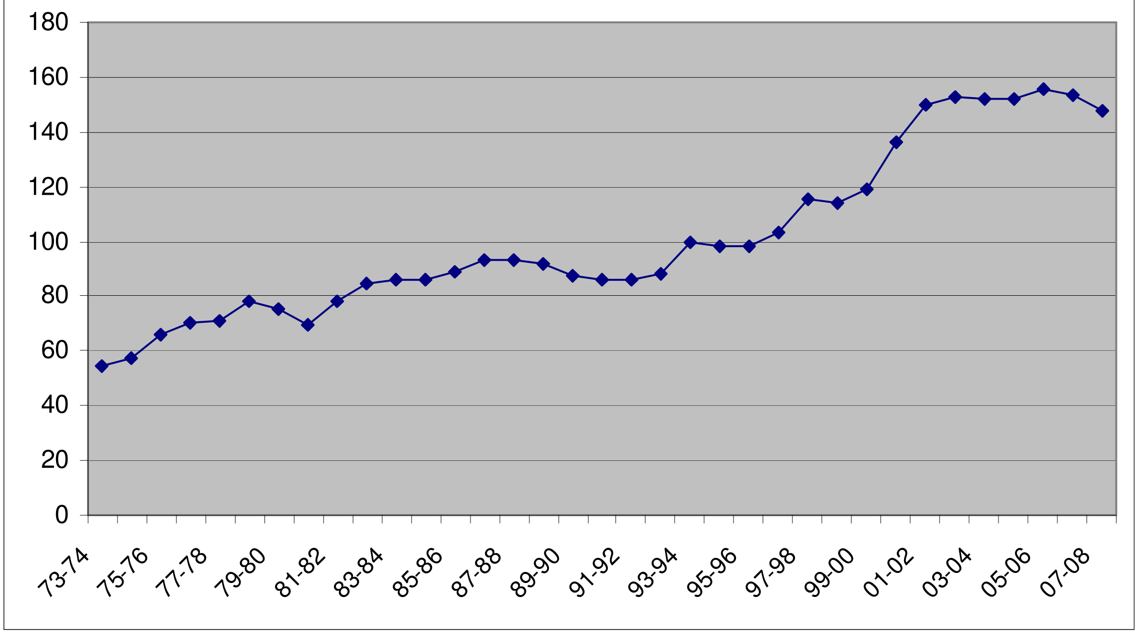


Fig. 1: Energy Intensity (ratio of energy cost to value of output, both deflated), Indian Manufacturing, 1973-74 to 2007-08

It is interesting to note from Figure 1 that between 1973-74 to 1992-93 (a twenty year period), energy intensity remained by and large within the range of 7 to 8 percent. There was no upward or downward trend. In the period after 1992-93, there was a clear downward trend in energy intensity. In the period 1992-93 to 2002-03 (which is comparable to the period considered by Ray and Reddy, 2007), the trend growth Rate was -6.3 percent per annum, and that in the period 1992-93 to 2007-08 was -5.4 percent per annum. Between 1992-93 and 2007-08, energy intensity fell by about 55 percent.

A matching pattern is observed in the movements of energy prices. There was acceleration in the growth of real price of energy to manufacturing (the price index for energy divided by the price index for manufactured articles) in the period after 1992-93. The index is depicted in Figure 2.

Fig. 2: Real Price of Energy (Index, 1993-94=100), Indian Manufacturing, 1973-74 to 2007-08



The trend growth rate in the real price of energy was 2.3 percent per annum in the period 1973-74 to 1992-93, which increased to 5.4 percent per annum during the period 1992-93 to 2002-03. The trend growth rate in the period 1992-93 to 2007-08 was 4.1 percent per annum.

Regressing logarithm of energy intensity (lnEI) on the logarithm of the real price of energy to manufacturing (lnRPE) and the trend variable (T) [also squared trend term to allow for non-linearity], the following equation is obtained (t-ratios in parentheses):

$$\begin{array}{lccc} \ln EI = 4.36 & -\ 0.59 \ln RPE & +\ 0.042\, T & -\ 0.0014\, T^2 \\ & (-5.5) & (10.3) & (-14.1) \end{array}$$

$n=35 \quad R^2= 0.97 \quad DW=1.09$

In view of the low value of DW statistic, the model has been re-estimated by applying the Prais-Winsten AR(1) regression. The results are shown below.

$$\ln EI = 4.52 - \underset{(-4.9)}{0.63 \ln RPE} + \underset{(7.1)}{0.043\, T} - \underset{(-9.8)}{0.0014\, T^2}$$

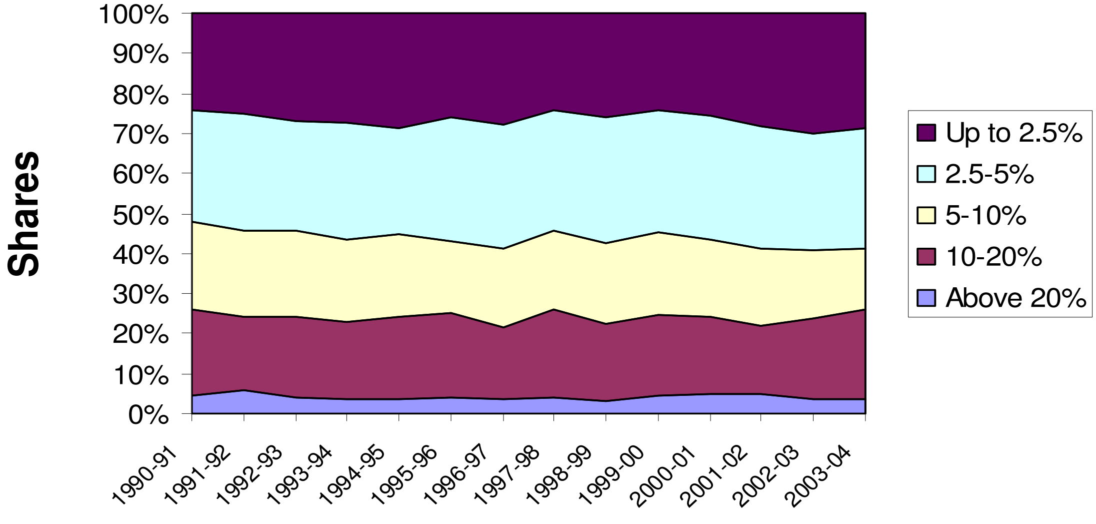
$n=35 \quad R^2 = 0.96 \quad DW=1.79$

The results indicate a significant (negative) effect of energy price on energy intensity in manufacturing. The price elasticity of demand for energy is indicated to be about 0.6.

Contribution of Structural Changes

The analysis carried out by Ray and Reddy (2007) bring them to the conclusion that the observed decline in energy intensity in Indian manufacturing is mostly attributable to structural changes. This aspect has been re-investigated using data on energy cost, value of output and value added from the *Annual Survey of Industries* (ASI). Four-digit industries have been classified into the following five groups according to their energy intensity (in 2003-04): (a) above 20%, (b) 10 to 20%, (c) 5 to10%, (d) 2.5 to 5%, and (e) below 2.5%. The shares of these five groups in deflated gross value added in the period 1990-91 to 2003-04 are shown in Figure 3.[5]

Fig. 3: Value added share of industries classified according to energy intensity



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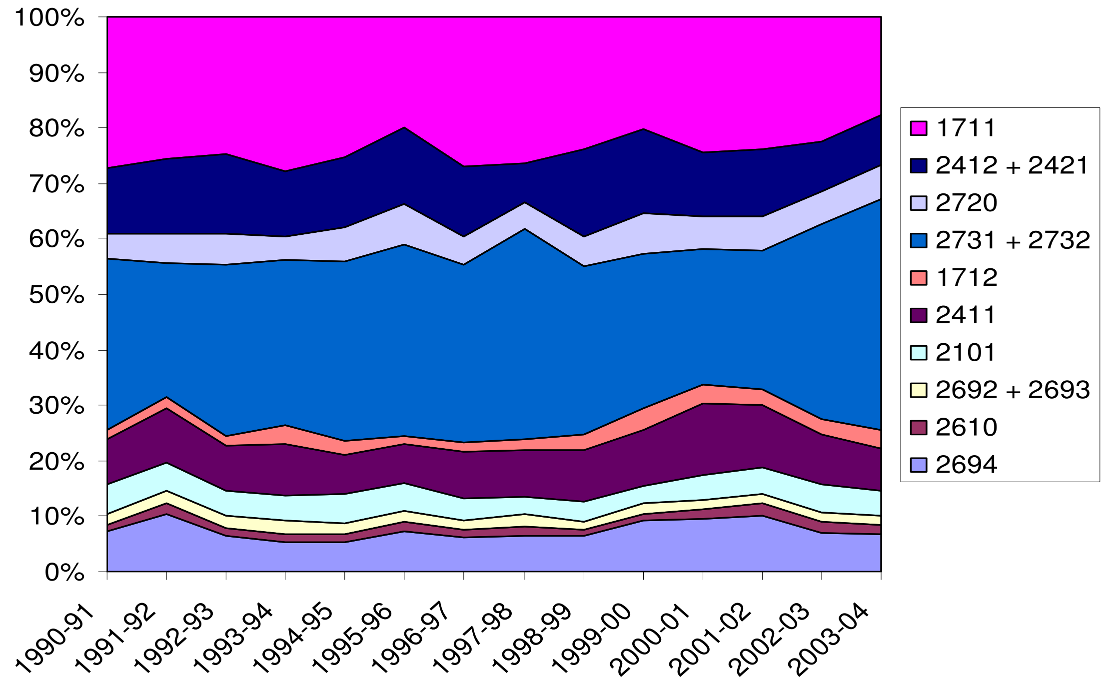
[5] This analysis makes use of a dataset on real value added at four-digit level that was prepared for a study undertaken at the ICRIER. See Das et al. (2009).

The shares of the five industry groups in real gross value added have not changed much in the period 1990-91 to 2003-04. A slight increase seems to have taken place in the share of industries in which energy intensity is less than 5%. This would contribute of a fall in energy intensity at the aggregate level. The change in shares is small, however, and therefore the effect of this change in industrial structure on aggregate energy intensity will be small too.

To examine this aspect further, ten industries (or combinations) have been chosen which rank high in terms of energy intensity (about 10% or more) as well as value added (their combined share in the value of energy consumption in manufacturing was 45% in 2003-04). The relative shares of these ten industries in real value added are depicted in Figure 4. No clear pattern is visible from the figure. But, there is an indication that the combined shares of industries1711, 2412, 2421 and 2720 have gone down over time. These industries rank relatively low in energy intensity among the ten industries selected, and the fall in their share will not contribute to a fall in energy intensity at the aggregate level. It seems therefore that changes in industrial structure would not provide adequate explanation for the observed decline in energy intensity in Indian manufacturing in the period since 1992, and the main explanation probably lies in improvement in energy use efficiency in energy intensive industries.

Fig. 4: Value added shares of high energy intensive industries (4-digit NIC)



3. Energy Intensity Variation between Plants Located in Different States

It has been noted above that energy intensity varies significantly from industry to industry. There is also plant to plant variation in energy intensity. Indeed, an examination of data on energy intensity of energy intensive industries from ASI reveals significant variation in the energy intensity at the plant level.[6] This is brought out by a state-wise comparison of energy intensity of plants of energy intensive industries located in different states. Table 1 presents such a comparison for nine three-digit industries for which the ratio of energy cost to the value of output is nearly 10% or more than 10% (in 2005-06). For each industry, an index of energy intensity has been formed by taking the energy intensity at the All-India level as 100. Then the index computed for the nine industries have been combined into an overall index by taking a simple average. The index is shown for 18 states.

It is evident from Table 1 that plants belonging the same three-digit industry vary widely in terms of the value of energy used per Rupee of output. In Metal casting industry, for instance, energy intensity is in the range of 21 to 23% in Uttaranchal and Jharkhand, while it in the range of 6 to 9% in Haryana, Chattisgarh and Uttar Pradesh. Such variation is noted also in other industries. Another point worth noting from Table 1 is that the ranking of states in terms of energy efficiency differs from industry to industry. For Metal casting industry, the energy intensity of plants located in Uttar Pradesh is 18% less than that at the All-India level, but for Non-ferrous basic metals industry, the energy intensity of plants located in Uttar Pradesh is over three times that at the All-India level.

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[6] This is corroborated by a study of inter-firm variation in energy intensity using company level data. A large variation in energy intensity is found across companies belonging to the same industry. Among cement firms, median energy intensity is about 19%. But, about a quarter of the firms have energy intensity of less than 8%. In metal casting, similarly, the median energy intensity is 11% and about a quarter of firms have energy intensity less than 6%.

Table 1: Energy intensity of plants of energy intensive industries located in different states

Code	Indicator	State							
		All India	AP	GUJ	HAR	KAR	KER	MP	MAH
171	Energy int(%)	10%	10%	10%	12%	8%	11%	10%	10%
	Index	100	99.3	104.3	119.7	77.7	112.1	99.7	97.1
210	Energy int(%)	12%	12%	13%	12%	15%	16%	13%	11%
	Index	100	98.0	103.9	97.2	123.8	130.5	106.5	85.9
241	Energy int(%)	10%	10%	8%	20%	14%	15%	13%	11%
	Index	100	104.4	80.5	204.5	142.4	156.3	132.0	109.3
243	Energy int(%)	10%	0%	11%	11%	8%	0%	0%	10%
	Index	100	0	106.2	109.8	82.3	0.0	0.0	97.1
261	Energy int(%)	20%	27%	14%	20%	13%	29%	18%	19%
	Index	100	135.4	71.0	98.2	62.2	141.5	87.1	95.4
269	Energy int(%)	23%	29%	26%	20%	25%	21%	31%	14%
	Index	100	126.3	113.2	86.8	109.2	90.9	137.8	63.2
271	Energy int(%)	11%	9%	13%	6%	7%	17%	6%	8%
	Index	100	87.8	122.6	55.4	65.5	154.8	58.3	75.5
272	Energy int(%)	9%	10%	5%	5%	14%	10%	3%	5%
	Index	100	106.7	52.7	52.3	151.3	112.7	33.3	52.5
273	Energy int(%)	11%	12%	12%	6%	10%	16%	12%	10%
	Index	100	101.1	103.0	55.8	84.2	136.4	104.9	85.3
	Overall index	100	107.4	95.3	97.7	99.8	129.4	95.0	84.6

Note: Energy intensity = ratio of cost of energy to the value of output. Overall index is a simple average of indices for different industries.

Industry codes: 171(Spinning, weaving and finishing of textiles), 210 (Manufacture of paper and paper products), 241 (Manufacture of basic chemicals), 243 (Manufacture of man-made fibers), 261 (Manufacture of glass and glass products), 269 (Manufacture of non-metallic mineral products n.e.c. [includes cement]), 271 (Manufacture of Basic Iron & Steel), 272 (Manufacture of basic precious and non-ferrous metals), and 273 (Casting of metals).

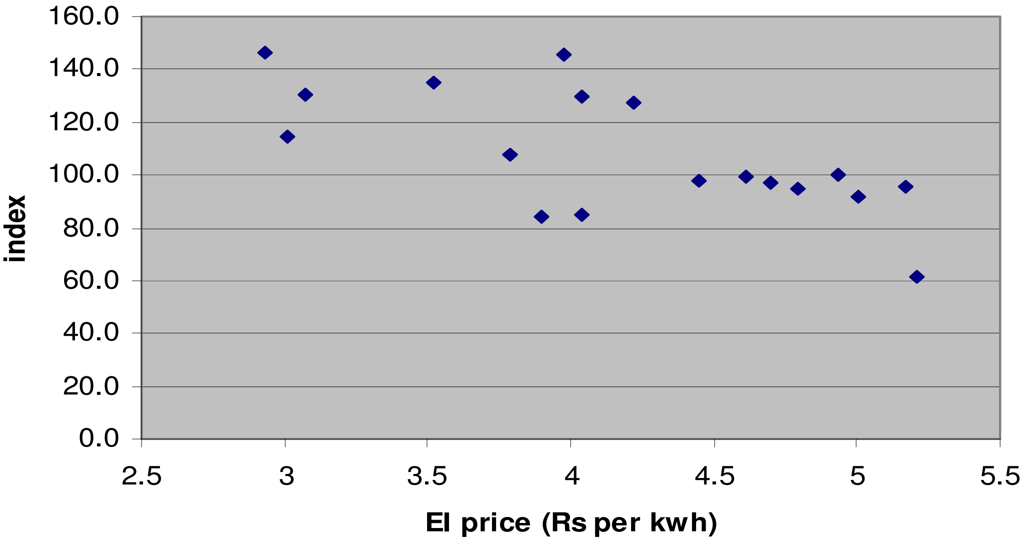
(Table 1 continued)

Code	Indicator	State										
		BHR	CHTT	DLH	JHAR	ORSS	PNJB	RAJ	TN	UP	UA	WB
171	Energy int(%)	9%	16%	6%	16%	8%	10%	8%	14%	11%	5%	8%
	Index	86.5	156.4	64.2	158.5	83.5	101.4	78.3	139.7	109.9	54.5	76.6
210	Energy int(%)	4%	20%	3%	4%	11%	17%	6%	10%	16%	15%	15%
	Index	32.3	164.3	21.3	34.2	88.1	138.4	51.5	77.9	127.2	124.1	119.9
241	Energy int(%)	8%	6%	2%	35%	4%	29%	17%	14%	12%	22%	6%
	Index	77.7	66.0	18.2	361.3	41.3	299.2	170.4	140.1	121.1	224.5	62.4
243	Energy int(%)	0%	0%	0%	0%	0%	0%	0%	9%	12%	0%	0%
	Index	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.8	117.5	0.0	0.0
261	Energy int(%)	9%	0%	13%	15%	0%	14%	11%	15%	30%	40%	27%
	Index	45.3	0.0	65.4	74.5	0.0	67.2	56.0	75.5	146.3	197.6	133.4
269	Energy int(%)	26%	35%	13%	12%	14%	18%	23%	18%	13%	9%	11%
	Index	116.9	153.7	55.5	53.4	60.6	77.5	101.7	78.6	58.6	38.8	49.7
271	Energy int(%)	17%	13%	14%	11%	22%	12%	11%	10%	11%	21%	10%
	Index	163.7	117.3	133.2	101.6	205.3	110.0	106.5	89.6	98.5	197.4	92.2
272	Energy int(%)	16%	26%	4%	8%	17%	9%	8%	7%	29%	0%	5%
	Index	169.8	284.3	38.1	89.4	178.7	92.6	83.5	72.2	315.1	0.0	52.0
273	Energy int(%)	5%	9%	11%	23%	16%	15%	15%	15%	9%	21%	10%
	Index	42.6	79.1	93.6	204.3	141.8	133.9	128.0	128.9	82.0	186.3	84.9
	Overall index	91.8	145.9	61.2	134.6	114.2	127.5	97.0	99.0	130.7	146.2	83.9

Note: States: AP (Andhra Pradesh), BHR (Bihar), CHTT (Chattisgarh), DLH (Delhi), JHAR (Jharkhand), GUJ (Gujarat), HAR (Haryana), KAR (Karnataka), KER (Kerala), MAH (Maharashtra), MP (Madhya Pradesh), ORSS (Orissa), PNJB (Punjab), RAJ (Rajasthan), TN (Tamil Nadu), UA (Uttaranchal), UP (Uttar Pradesh), WB (West Bengal).

The inter-state variation in energy intensity of plants belonging to an industry could be attributed to differences in plant size, technology, vintage, product composition and other factors. The overall index shown in Table 1 indicates that energy productivity or energy use efficiency is relatively higher in Maharashtra, Madhya Pradesh, West Bengal and Delhi (the index is less than one), and energy productivity is relatively lower in Chattisgarh, Jharkhand, Kerala, Punjab, Uttar Pradesh and Uttaranchal. One question that presents itself here is whether the observed inter-state variation energy productivity is connected with inter-state variation in the energy prices. Indeed, a significant negative correlation (-0.68) is found between electricity price (unit price paid for electricity purchased) and the overall index of energy intensity. A graphical presentation is made in Figure 5.

Fig. 5: Electricity Price and Energy Intensity (oveall index), Across 18 States



The energy intensity index bears a negative correlation also with coal price (unit value of coal used).[7] However, the correlation coefficient is lower in this case (-0.30). In view of the observed negative correlation between the index of energy intensity and prices of electricity and coal, it may be inferred that inter-plant variation in energy intensity is attributable partly to differences in the energy prices faced by firms – a firm facing higher prices tend to be more energy efficient. This aspect is analyzed further in the next section.

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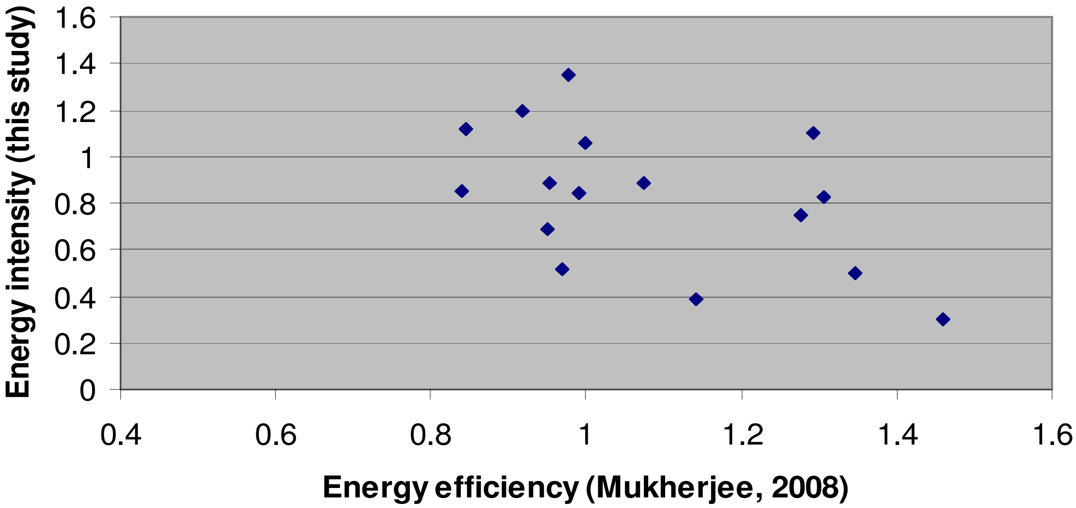
[7] Unit values computed from quantity and value of coal used by plants may not properly reflect the regional variation in prices due to differences in the quality (calorific value) of coal used.

It may be mentioned here that inter-state differences in energy efficiency in organized manufacturing has been studied by Mukherjee (2008). She has used industry level data for different states for the period 1998-99 to 2003-04 (taken from ASI), and has applied Data Envelopment Analysis (DEA) technique to assess energy efficiency. She has presented three alternate estimates of energy efficiency. Of the three, the estimates based on cost minimization match to some extent the estimates obtained in this study. Figure 6 shows the energy efficiency estimates of Mukherjee (2008) plotted against the overall energy intensity index given in Table 1 above. The correlation coefficient is -0.50.[8]

Fig. 6: Energy Efficiency of Manufacturing Firms in Different States, Comparison with the Estimates of Another Study



Two points emerge from the analysis presented above in this section. First, energy intensity varies significantly from plant to plant which implies that some plants are much less efficient in the use of energy than others. Secondly, variation in energy use efficiency among plants belonging to different states can be explained to some extent by inter-state variation in the price paid for energy by manufacturing plants.

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[8] Since energy intensity should bear an inverse relationship with energy efficiency, a negative correlation coefficient is expected.

4. Energy demand function

To probe further the effect of input prices on energy demand, an energy demand function has been estimated for Indian manufacturing (organized) using cross-industry panel data for the period 1980-81 to 2003-04. The KLE production function specification is utilized for this purpose. Capital, labour and energy are taken as three inputs. Output is accordingly defined as total value of output minus the value of materials.[9]

Let the production function be:

$Y = f(K, L, E; t)$ … (1)

where K denotes capital, L labour, E energy and Y net output (value of output minus value of materials). In this equation, t denotes time and represents technological change. Given the production function, the demand function for energy may be derived under the assumption of competitive markets. This may be written as:

$E = g(Y, P_K, P_L, P_E, t)$ … (2)

where P_K, P_L and P_E are the prices of capital, labour and energy respectively. Since the cost function associated with the production function in (1) is homogeneous of degree one in input prices, the demand function for energy should be homogenous of degree zero in input prices.

For applying the above equation empirically, it has been taken as log linear. The ratios of P_E and P_L to the output price index P_Q have been taken as explanatory variables, and the price of capital input has been excluded. The Model has thus been specified as:

$$\ln E = \beta_0 + \beta_1 \ln(P_E / P_Q) + \beta_2 \ln(P_L / P_Q) + \beta_3 \ln(Y) + \beta_4 t + u \quad ...(3)$$

where u is the random error term.

In an alternative specification of the model, instead of using the time variable to represent technology, total factor productivity index has been introduced as an explanatory variable. This has the advantage that the use of TFP index instead of a time variable allows the effect of technological change on energy demand to vary over time as well as across industries. The modified model may be written as:

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[9] For studying energy demand in industries, the KLE specification is better than the KLEM (capital, labour, energy and materials) specification. It may be argued in this context that economic output is created by capital, labour and energy. Materials used are a passive partner in the production process and do not contribute to value addition which is the essence of economic output (Lindenberger and Kummel, 2002). It may be added that a number of earlier studies have used the KLE specification. These include Goldar and Mukhopadhyay (1991), Kemfert and Welscth (2000) and Klacek et al. (2007). See also Pindyck (1979) who assumes that labour, capital and energy are as a group weakly separable from material input.

$$\ln E = \beta_0 + \beta_1 \ln(P_E / P_Q) + \beta_2 \ln(P_L / P_Q) + \beta_3 \ln(Y) + \beta_4 \ln A + u \quad ...(4)$$

where A denotes total factor productivity index.

The models in equations (3) and (4) above are based on the assumption that the firms are able to adjust their input use to the equilibrium level instantaneously following a change in input prices. This is obviously not a realistic assumption to make. It seems reasonable to argue that the firms may take time to adjust capital stock and employment to the desired level. Indeed, in employment function studies, lagged employment is commonly taken as an explanatory variable to incorporate the fact that firms need time to adjust their employment to the desired employment level (see, for example, Hasan et al., 2007; and Goldar, 2009). Since the firms need time to adjust labour and capital inputs to the desired level, the other inputs will also be in disequilibrium, and will require time to adjust to the desired level. To incorporate this issue in model specification, the energy demand models given above in equations (3) and (4) have been modified as:

$$\ln E = \beta_0 + \beta_1 \ln(P_E / P_Q) + \beta_2 \ln(P_L / P_Q) + \beta_3 \ln(Y) + \beta_4 t + \beta_5 \ln E_{-1} + u \quad ...(3a)$$
$$\ln E = \beta_0 + \beta_1 \ln(P_E / P_Q) + \beta_2 \ln(P_L / P_Q) + \beta_3 \ln(Y) + \beta_4 \ln A + \beta_5 \ln E_{-1} + u \quad ...(4a)$$

In these two equations, E_{-1} denotes energy input with one year lag.

Data and Variables

The Economic and Political Weekly Research Foundation has formed an electronic database combining the ASI results of different years. Drawing on this source, a panel dataset for 22 two-digit industries of ASI for the period 1980-81 to 2003-04 has been prepared which has been used to estimate the energy demand function specified in equations (3), (4), (3a) and (4a).

The variables have been constructed as follows. Number of employees is taken as the measure of labour input (L). Emoluments per employee is taken as the price of labour input (P_L). A price index of energy input (P_E) has been formed for each two-digit industry by taking a weighted average of price indices of coal, oil and electricity. The weights are based on the input-output matrix for 1993-94. The reported figures on value of fuel consumption in ASI are deflated by the energy price index to derive a measure of energy input (E). Fixed capital at constant prices is taken as the measure of capital input (K). This series has been formed by the perpetual inventory method.

From the value of output reported in ASI, the value of materials has been subtracted and then the series so obtained has been deflated. This provides the measure of output (Y). For each two-digit industry, the best available price index has been taken from the official wholesale price indices series as the deflator or the output price index (P_Q).

The Translog index of total factor productivity has been used to compute the growth rate in TFP and thus form the TFP index (A) (an index for each industry, taking value one for

1980-81). The income share of labour is computed as $(P_L.L)/(P_Q.Y)$ and that for energy is computed as $(P_E.E)/(P_Q.Y)$. The income share of capital is taken one minus income shares of labour and energy. The computed growth rates in TFP for select periods are reported in Annex A.

Energy demand function estimates

The estimates of energy demand function are presented in Tables 2, 3 and 4. The estimates of equations (3) and (4) are presented in Table 2. These estimates have been made by the random effects model. The estimates of equations 3a and 4a are presented in Tables 3 and 4. In these cases, the estimation of parameters has been done by the General Method of Moments Instrument Variable (GMM-IV) estimator.[10]

It is seen from Tables 2-4 that the coefficient of the energy price variable is negative and statistically significant in all cases. The long term elasticity of energy demand with respect to energy price is about 0.6 to 0.7.[11] The ratio of energy price to the price index for manufactured products has grown at the rate of about 5.3% per annum during 1992-93 to 2003-04. Thus, a sizeable part of the declined in energy intensity in Indian manufacturing in the post-1992 period may be attributed to hikes in the real price of energy.[12]

Table 2: Energy Demand Function, Indian Manufacturing Industries, random effects model

Explanatory variables	Regressions	
	(1)	(2)
$\ln(P_E/ P_Q)$	-0.640 (-8.3)	-0.565 (-7.7)
$\ln(P_L/ P_Q)$	0.119 (1.5)	0.184 (2.5)
ln(Y)	0.757 (22.4)	0.903 (34.0)
t	0.015 (5.5)	
ln (A)		-0.336 (-9.4)
constant	0.586	-1.058
R^2	0.834	0.865
No of observations	528	528

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[10] Because of the inclusion of lagged energy input variable in the equation, random or fixed effects model will not be appropriate.

[11] This is consistent with the estimate presented in Section 2.

[12] Similar findings have been reported in the studies undertaken by Fisher-Vanden et al. (2004) for China and by Metcalf (2008) for the US. Fisher-Vanden et al. find that rising relative price of energy was one of key factors responsible for China's declining energy intensity. Three other factors noted are R&D, ownership reforms and shifts in industrial structure.

Table 3: Energy Demand Function, Indian Manufacturing Industries, dynamic model, one step method

Explanatory variables	Regressions	
	(1)	(2)
$\ln(P_E/P_Q)$	-0.458 (-6.6)	-0.405 (-9.6)
$\ln(P_L/P_Q)$	0.120 (1.6)	0.116 (1.6)
ln(Y)	0.509 (14.9)	0.630 (17.8)
t	0.009 (3.5)	
ln (A)		-0.185 (-5.8)
$\ln(E_{-1})$	0.334 (10.1)	0.309(9.6)
constant	0.306	-0.775
Wald chi-square (prob.)	4315.9 (0.000)	4021.9(0.000)
Sargan test, Chi-sqr and probability	472.4 (0.003)	523.5(0.000)
No of observations	528	506

Table 4: Energy Demand Function, Indian Manufacturing Industries, dynamic model, two step method

Explanatory variables	Regressions	
	(1)	(2)
$\ln(P_E/P_Q)$	-0.465 (-11.1)	-0.410 (-12.2)
$\ln(P_L/P_Q)$	0.092 (1.4)	0.079 (1.9)
ln(Y)	0.523 (11.1)	0.675 (15.5)
t	0.009 (1.4)	
ln (A)		-0.205 (-2.6)
$\ln(E_{-1})$	0.330 (13.4)	0.276 (8.2)
constant	0.227	-0.901
Wald chi-square (prob.)	1813.5 (0.000)	4247.0(0.000)
Sargan test, Chi-sqr and probability	21.5 (1.0)	20.5(1.0)
Arellano-Bond test for zero autocorrelation in first-differenced errors, order 2, Chi-sqr and probability	0.411 (0.68)	0.209 (0.83)
No of observations	528	506

The coefficient of real wages is consistently positive and is statistically significant in some cases. This suggests that a hike in real wages tends to reduce demand for labour and increase energy intensity of production.

The coefficient of ***t*** is positive and statistically significant in the results presented in Tables 2 and 3. It is positive but statistically insignificant in the results presented in Table 4. This would give the impression that technological change did not contribute much towards lowering of energy intensity. This inference does not seem right. There is a possibility that the coefficient of time variable is found to be positive because the results are affected by a high correlation of the trend variable with other explanatory variables. Interestingly, the coefficient of the TFP index is negative and statistically significant in the results presented in all three tables. This would imply that technological change to the extent it gets reflected in the TFP index contributed to the fall in energy intensity of Indian manufacturing.

A methodological issue one may raise here is that E enters the computation of TFP growth and hence enters the construction of TFP index, A. This may give rise to a two-way relationship between E and A, and thus the econometric estimates of the energy demand function may be affected. This is particularly an issue with the estimate of equation (3) by the random effects model presented in Table 2. To address this issue, A has been replaced by its lagged value in the equations and then the equation has been re-estimated. The coefficient of the TFP index is found be negative and statistically significant. It seems reasonable to conclude therefore that technological advance did help industrial firms in India to reduce energy consumption, and the observed decline in energy intensity in Indian manufacturing in the post-1992 period is attributable in part to technological improvement.

5. Determinants of Energy Intensity in Industrial Firms

Earlier Studies

Determinants of energy intensity in industrial firms in India have been investigated earlier by Kumar (2003) and Sahu and Narayana (2009). Both studies applied multiple regression analysis to identify the important factors influencing energy intensity in industrial firms.

Kumar has used *Prowess* data for his study. Data for 1342 firms for a period of eight year (panel data) have been used. The explanatory variables considered include firm size, age of the firm, wages, R&D intensity, technology import intensity, profit margin, capital intensity, repair intensity, degree of vertical integration, and the pattern of ownership (particularly foreign ownership of the firm). A negative relationship is found between firm size and energy intensity, which is attributed to economies of scale. Energy intensity is found to be positively related to repair intensity (ratio of expenditure incurred on repairs of plant and machinery to sales). A positive relationship is found between energy intensity and technology import intensity (defined as the expenditure in foreign exchange incurred on imports of capital goods, raw materials, royalty, and purchase of technical know-how as a ratio to sales), which is contrary to the expected relationship. The results of the analysis indicate that the type of ownership has an important influence on energy intensity. Foreign ownership is found be associated with lower energy intensity, while state ownership is found to be associated with higher energy intensity.

Sahu and Narayanan use data for 2350 firms for the year 2008 for their analysis, drawn from *Prowess*. The explanatory variables considered include firm size (logarithm of sales), labour intensity, capital intensity, repair intensity and age of the firm. Other variables considered include R&D intensity (ratio of R&D expenditure to sales), technology import intensity (definition similar to that adopted by Kumar), foreign ownership (dummy variable for foreign owned firms), export intensity (exports to sales ratio) and profit margin. Thus, many of the explanatory variables considered by Sahu and Narayanan are the same as those used by Kumar in his analysis.

Sahu and Narayanan include both firm size and square of size as explanatory variables. The advantage of including the squared term is that the relationship between firm size and energy intensity need not be monotonically increasing or decreasing. Indeed, the coefficient of size is found to be positive and that of the squared term negative. Accordingly, Sahu and Narayanan infer an inverted-U shaped relationship between energy intensity and firm size.

A negative relationship is found between energy intensity and export intensity (implying that export oriented firms are more efficient in use of energy) and also between energy intensity and profit margin. A positive relationship of energy intensity is found with capital intensity and repair intensity, which is in agreement with the findings of Kumar (2003). The results indicate that foreign firms are more efficient in the use of energy, which is again in agreement with the findings of Kumar. Another similarity between the findings of the two studies is that both find a significant positive relationship between energy intensity and technology import intensity. This, as noted above, is contrary to expectations.

Sahu and Narayanan find a positive relationship between energy intensity and the age of the firm. Such a relationship is expected because older firms will have plant and machinery of older vintage which are likely to be less energy efficient as compared with the plant and machinery of more recent vintage. In this regard, the results of Kumar differ from that of Sahu and Narayanan. Kumar finds a negative insignificant coefficient of the age variable.

For this study, an analysis of firm level variation in energy intensity has been undertaken similar to the analysis undertaken by Kumar (2003) and Sahu and Narayanan (2009). The construction of variables and the results of analysis are discussed below.

Data and Variables for this Study

Data for the firm level analysis presented in this paper have been taken from *Capitaline*. The data relate to 2008-09 or to 2007-08 if data for 2008-09 are not available. In those cases where data for both 2007-08 and 2008-09 are not available, data for 2006-07 have been used, if available.

From *Capitaline*, data for about 2800 manufacturing companies could be obtained. These companies have been divided into two groups: firms belonging to energy intensive industries and other firms. One regression equation has been estimated for all firms and another one for firms belonging to energy intensive industries. In both regressions, eight dummy variables for eight groups of energy intensive industries have been included. This helps in capturing inter-industry differences in energy intensity. In addition to industry dummies, state dummies have been introduced to take into account the location of plants of the companies. It has been noted above that there are significant differences in energy intensity across states and this could be a result of state specific factor, including availability and price of electricity. This is incorporated into the model by the state dummies. These dummy variables take value one if the company in question has its plant(s) located in that state and zero otherwise. A company may have multiple plants located in a number of states. For such a company, the corresponding state dummies take value one and other state dummies take value zero.

The list of variables used for the analysis, the definition of the variables and their expected relationship with energy intensity are given in Table 5.

Table 5: Definition of variables and their expected sign in the regression equation

Sr. no.	Variable	Definition/Description	Expected sign
1	Energy intensity	Ratio of power and fuel expenses to sales	
2	Firm size	Logarithm of sales	-ve
3	Age of the firm	Obtained by subtracting the year of incorporation from the year of the study i.e. the year the data relate to. This is capped at 50 years.	+ve
4	Export intensity	Ratio of exports to sales	+ve/-ve
5	Import of finished goods intensity	Ratio of imports of finished goods to sales	-ve
6	Raw materials import intensity	Ratio of imports of raw materials to sales	-ve
7	Capital goods import intensity	Ratio of imports of capital goods to sales	-ve
8	Technology import intensity	[Forex expenditure on royalty and technical fees + forex expenditure on items other than those listed above]/sales	-ve
9	R&D intensity	R&D expenditure to sales ratio; this is converted into a dummy variable taking value one if the ratio in question is 1% or higher, zero otherwise	-ve
10	IT use intensity	Investment in computers as a ratio to gross block (fixed assets)	-ve
11	Advertisement intensity	Ratio of advertisement expenditure to sales	+ve/-ve
12	Repairs intensity	Expenditure on repairs to sales	+ve
13	Foreign firm	Dummy variable for foreign firms (the cut off in equity holding is taken as 10%)	-ve
14	Output-capital ratio	Ratio of sales to gross block (inverse of capital intensity)	-ve

The estimated regression equations are presented in Table 6. Regression (1) is for all firms, and regression (2) is for firms belonging to energy intensive industries (textiles, paper, basic chemicals, fertilizers, glass, cement, steel, non-ferrous basic metals, and metal casting).

Table 6: Determinants of Energy Intensity, Manufacturing Firms, 2006-07/2008-09

Explanatory variables	Regression 1	Regression 2	Regression 3
	All firms	Firms belonging to energy intensive industries	Domestic firms@ belonging to energy intensive industries
Firm size	-0.002 (-1.65)*	0.0003 (0.13)	0.0008 (0.32)
Export intensity	-0.006 (-1.10)	-0.023 (-1.97)**	-0.021 (-1.57)
Import of finished goods intensity	-0.020 (-1.16)	-0.049 (-2.27)**	-0.058 (-2.30)**
Raw materials import intensity	-0.025 (-2.13)**	-0.022 (-0.83)	-0.014 (-0.43)
Capital goods import intensity	0.036 (0.82)	0.027 (0.56)	0.029 (0.43)
Technology import intensity	-0.083 (-3.75)***	-0.135 (-2.29)**	-0.100 (-1.35)
R&D dummy (R&D intensity 1% or more)	-0.011 (-2.46)**	0.001 (0.06)	0.006 (0.23)
IT investment intensity	-0.148 (-5.80)***	-0.267 (-1.71)*	-0.491 (-1.42)
Expenditure on repairs to sales ratio	0.778 (4.67)***	0.726 (3.00)***	0.909 (2.63)***
Ratio of sales to fixed capital (gross block)	-0.005 (-11.33)***	-0.008 (-7.09)***	-0.007 (-4.41)***
Age of the firm	0.0002 (2.05)**	0.0008 (3.25)***	0.0007 (2.43)***
Foreign firm (dummy)	-0.002 (-0.45)	-0.014 (-2.03)**	
Advertisement intensity	-0.156 (-3.11)***	-0.189 (-0.56)	-0.207 (-0.55)
Energy intensity of foreign firms in the industry and state			0.246 (1.82)*
Industry dummies	Yes	Yes	Yes
State dummies	Yes	Yes	Yes
R^2	0.317	0.279	0.277
No. of observations	2775	1074	813

@ Analysis confined to domestic firms having plants in one or more of 17 selected states.

Note: The t-ratios are shown in parentheses. The standard errors are corrected for heteroscedasticity.

From the results (regressions 1 and 2) presented in Table 6, a positive relationship is found between energy intensity and repair intensity and a negative relationship between energy intensity and output-capital ratio. There results are consistent with the results reported by Kumar (2003) and Sahu and Narayanan (2009). The results indicate a positive relationship between age of the firm and energy intensity. This is in agreement with the findings of Sahu and Narayanan who found a significant positive coefficient for this variable. The results suggest an inverse relationship between export-orientation of a firm and its energy intensity. This is again in agreement with the findings of Sahu and Narayanan.

For the technology related variables, technology import intensity, R&D expenditure, investment in IT, and use of imported raw materials, the coefficient is negative and statistically significant in regression (1) which covers all firms. The coefficients of technology import intensity and investment in IT are negative and statically significant also in regression (2), which covers the firms belonging to energy intensive industries. Thus, there is evidence to indicate that acquisition and application of advanced technology helps in cutting down energy intensity. This finding is at variance with the findings of Kumar (2003) and Sahu and Narayanan (2009) who did not find a negative coefficient for the technology import variable. Rather, both studies found a significant positive coefficient, which is contrary to expectations.

A negative relationship is found between firm size and energy intensity in the sample of all firms but not in the sample of firms belonging to energy intensive industries. The finding of a negative relationship between energy intensity and firm size is in agreement with the results of Kumar (2003) who found a significant negative coefficient for firm size. The results obtained in this study do not match with the results of Sahu and Narayanan (2009) who report an inverted-U relationship between firm size and energy intensity. [13] As regards to be finding that a negative relationship between firm size and energy intensity does not hold for energy intensive industries, similar finding has been reported in a study undertaken for Hellenic manufacturing. Papadogonas et al. (2007) in their study of manufacturing firms in Greece find that large firms have an energy cost advantage in relation to small firms only in low energy consuming industries.

The coefficient of the foreign firm dummy variable is negative in both regressions (1) and (2), and it is statistically significant in regression (2). It seems from the results that in energy intensive industries where energy efficiency is critical for competitiveness, the foreign firms have a significant advantage over domestic firms in terms of energy use efficiency. These results are broadly in agreement with the results obtained by Kumar (2003) and Sahu and Naryanan (2009). At the same time it may be noted that these two studies found a significantly lower energy intensity in foreign firms compared to domestic firms in the all industry sample, while in this study this is found only for energy intensive industries sample.

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[13] Regression (1) was modified by introducing the squared size variable. The coefficient of the squared term was, however, found to be statistically insignificant, and hence the variable was dropped.

The imports of finished goods variable has been introduced in the regression equation to capture the fact that a large increase in imports of finished goods by a firm may enable it to hike the value of sales without a significant increase in manufacturing activity. The ratio of energy use to sales may therefore fall without an improvement in the energy use efficiency in the production process. Clearly, a negative coefficient is expected for this variable. In the results obtained, the variable has a negative coefficient and in regression (2), the coefficient is statistically significant.

The coefficient of advertisement intensity is found to be negative and statistically significant in regression (1). This probably captures, at least to some extent, the technological differences among industries. The finding of a negative coefficient perhaps indicates that, ceteris paribus, energy intensity tends to be relatively lower in consumer goods industries, especially consumer durables.

The coefficients of the state dummy variables (not reported in the table) reflect the influence of state specific factors on energy intensity. The results indicate that after controlling for a host of factors such as firm size, vintage of plant and machinery, and technology acquisition efforts, there are significant differences in energy intensity of industrial firms across states. It seems state specific factor cause the energy intensity to relatively higher in Kerala, Punjab, and Rajasthan, and relatively lower in Chattisgarh, Gujarat, Karnataka, Maharashtra, and West Bengal. It is heartening to note that this list has some degree of similarity with the index of energy intensity shown in Table 1, which is based on a different data set and a different approach.

Energy Efficiency Spillover

There is a huge literature on productivity spillovers from multinational enterprises to local firms. A number of studies on this issue have been undertaken for Indian manufacturing firms.[14] In the context of the present study, it is interesting to examine if there are energy efficiency spillovers from foreign firms to local firms. This issue is examined here perhaps for the first time. The framework used for the study is similar to that adopted by Siddharthan and Lal (2004). Energy intensity of ith firm in jth industry in state r (denoted by E_{ijr}) is taken to be a function of the characteristics of the firm, denoted by a vector X_{ijr}, the energy intensity of foreign firms in jth industry in state r, denoted by E^*_{jr} and industry and state dummy variables picking up the influence of industry specific and state specific factors. Thus, the equation to be estimated is:

$$E_{ijr} = \alpha + \beta' X_{ijr} + \gamma E^*_{jr} + \sum \mu_j N_j + \sum \eta_r S_r + u_{ijr} \quad ..(5)$$

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[14] Studies on productivity spillover in Indian manufacturing firms have been undertaken by Vinish Kathuria; Rashmi Banga; Susan E. Feinberg and Simit K. Manumdar; N. S. Siddharthan and K. Lal; G. Chidabaran Iyer; Subahs Sasidharan; Jaya Prakash Pradhan; Mita Bhattacharya, Jong-Rong Chen and V. Pradeep; David M. Kemme, Volodymyr Lugovskyy and Deepraj Mukherjee.

In this equation N denotes the industry dummies and S the state dummies. The parameters to be estimated are: α. β (vector), γ, η (vector) and μ (vector).

The estimate of equation (5) is given as regression (3) in Table 6. The equation is estimated using data for domestic firms belonging to the energy intensive industries. Also, the analysis has been restricted to 17 selected states (major states, 17 out of the 18 in Table 1, Uttaranchal is excluded). For each state and industry group the average energy intensity of foreign firms has been computed. This enters the regression equation as an explanatory variable. Where there are no foreign firms in a particular industry in a particular state, the average of energy intensity of foreign firms of that industry in the states for which such data are available has been used.

Comparing the results of regressions (2) and (3), it is seen that the sign of the coefficients remain the same. But, fewer coefficients are statistically significant in regression (3). What is important to note is that the coefficient of energy intensity of foreign firms is positive and statistically significant. One may accordingly infer that there is significant energy efficiency spillover from foreign firms to domestic firms.

6. Concluding Remarks

The analysis presented above brings out clearly that there was a marked fall in energy intensity of Indian manufacturing (organized) since 1992. The fall seems to have occurred mainly because the energy intensive industries became more efficient in energy use, which in turn may be traced in part to increases in the real price of energy faced by manufacturing. Significant contribution was also made by technological improvement whether induced by energy price hikes or otherwise. The proposal for introducing in energy intensive industries a system of trading in energy efficiency certificates will raise the effective price of energy to energy inefficient firms and thus induce them the reduce energy intensity.

The firm level analysis of energy intensity revealed that energy intensity is relatively lower in bigger firms. But, this relationship does not hold in energy intensive industries. Technology is found to be an important factor in determining energy intensity. Technological advance helps in improving energy use efficiency. A significant positive relationship is found between energy intensity and repair intensity and also between energy intensity and age of the firm. This is indicative of energy efficiency being relatively lower in plants of older vintage, and signifies that to reduce energy intensity and hence CO_2 emission intensity, old plants need to be replaced by new ones. Suitable policies are therefore needed to facilitate such replacement.

The econometric results indicated that foreign firms in energy intensity industries have lower energy intensity than their domestic counterparts. The results also indicated presence of significant energy efficiency spillover from foreign firms in such industries to local firms. Evidently there are externalities from foreign investment in energy intensive industries, and such investment therefore needs encouragement and policy support.

References

Allen, Myles R., Allen, David J. Frame, Chris Huntingford, Chris D. Jones, Jason A. Lowe, Malte Meinshausen and Nicolai Meinshausen (2009), Warming caused by cumulative carbon emission: the trillionth tone**.** *Nature*, 458 (7242): 1163-1166.

Das, Deb Kusum, Deepika Wadhwa and Gunajit Kalita (2009), The Employment Potential of Labor Intensive Industries in India's Organized Manufacturing, Working Paper No. 236, Indian Council for Research on International Economic Relations, New Delhi.

Fisher-Vanden, K., Gary H. Jeferson, Hangmei Liu., and Quan Tao (2004), "What is Driving China's Decline in Energy Intensity," Resources and Energy Economics, 26: 77-97.

Goldar, Bishwanath (2009), "Trade Liberalization and Labour Demand Elasticity in Indian Manufacturing," *Economic and Political Weekly*, 44 (34): 51-57.

Goldar, Bishwanath and Hiranya Mukhopadhyay (1991), "Substitution among Labour, Capital and Energy in Indian Industries: An Application of the Cost-Price Approach," *Journal of Quantitative Economics*, 7(1): 65-78.

Government of India (2009), *India's GHG Emissions Profile: Results of Five Climate Modelling Studies*, Ministry of Environment and Forests, Government of India, September.

Hasan, Rana, Debashish Mitra and K. Ramaswamy (2007), "Trade Reforms, Labour Regulations and Labour-Demand Elasticities – Empirical Evidence from India," *Review of Economics and Statistics*, 89(3): 466-81.

Kemfert, Claudia and Heinz Welsch (2000), "Energy-Capital-Labor Substitution and the Economic Effects of CO2 Abatement: Evidence for Germany," *Journal of Policy Modeling* 22(6):641–660.

Klacek, Jan, Miloslav Vošvrda and Štefan Schlosser (2007), "KLE Translog Production Function and Total Factor Productivity" *Statistika*, no.4, 261-74.

Kumar, Alok (2003), "Energy Intensity : A Quantitative Exploration for Indian Manufacturing," Working Paper, Indira Gandhi Institute of Development Research, Mumbai.

Lindenberger, Dietmar and Reiner Kummel (2002), "Energy-Dependent Production Functions and the Optimization Model "PRISE" of Price-Induced Sectoral Evolution," *International Journal of Applied Thermodynamics*, 5(3):101-07.

Meinshausen, Malte, Nicolai Meinshausen, William Hare, Sarah C. B. Raper, Katja Frieler, Reto Knutti, David J. Frame and Myles R. Allen (2009), "Greenhouse-gas emission targets for limiting global warming to 2°C," *Nature*, 458 (7242): 1158-1162

Metcalf, Gilbert E. (2007), "An empirical analysis of energy intensity and its determinants at the state level," *Energy Journal*, 29(3):1-26.

Mukherjee, Kankana (2008), "Energy use efficiency in the Indian manufacturing sector: An interstate analysis," *Energy Policy* 36: 662–672.

Papadogonas, Theodore, John Mylonakis and Demosthenes Georgopoulos (2007), "Energy Consumption and Firm Characteristics in the Hellenic Manufacturing Sector," *International Journal of Energy, Technology and Policy*, 5(1) 89-96.

Sahu, Santosh and K Narayanan (2009), "Determinants of Energy Intensity: A Preliminary Investigation of Indian Manufacturing," Indian Institute of Technology, Mumbai, MPRA Paper no. 16606.

Pindyck, R, S, (1979), "Interfuel substitution and the industrial demand for energy: an international comparison," *Review of Economics and Statistics*. 61(2): 169–179.

Siddharthan, N.S. and K. Lal (2004), "Liberalization, MNE and Productivity of Indian Enterprises", *Economic and Political Weekly*, 39 (5), January 31, pp. 448-52.

Ray, Binay Kumar and B. Sudhakara Reddy (2007), "Decomposition of Energy Consumption and Energy Intensity in Indian Manufacturing Industries," Working Paper, Indira Gandhi Institute of Development Research, Mumbai.

Annex A

Total Factor Productivity Growth in Two-Digit Industries, 1980-81 to 2003-04

Industry code	1980-81 to 1985-86	1985-86 to 1990-91	1990-91 to 1995-96	1995-96 to 2003-04	**1980-81 to 1990-91**	**1990-91 to 2003-04**	**1980-81 to 2003-04**
15	13.907	0.914	0.975	-0.224	7.411	0.237	3.356
16	3.371	3.106	0.386	0.032	3.239	0.168	1.503
17	2.506	5.511	-3.536	5.090	4.008	1.772	2.744
18	5.979	10.423	-3.902	-5.577	8.201	-4.933	0.778
19	4.428	2.782	-2.383	1.583	3.605	0.057	1.600
20	-0.902	9.487	-14.218	0.030	4.293	-5.450	-1.214
21	0.800	4.973	-3.506	4.004	2.886	1.116	1.886
22	1.229	-0.226	3.839	-4.888	0.501	-1.532	-0.648
23	9.203	5.461	1.789	-5.947	7.332	-2.971	1.509
24	6.541	4.799	3.291	0.611	5.670	1.641	3.393
25	6.420	0.514	0.367	4.521	3.467	2.923	3.160
26	4.272	2.851	-0.040	2.911	3.562	1.776	2.552
27	1.512	1.226	3.090	3.392	1.369	3.276	2.447
28	2.857	-1.058	5.506	3.037	0.900	3.986	2.644
29	3.714	1.183	5.487	-0.561	2.449	1.765	2.062
30	7.306	4.172	14.756	2.677	5.739	7.323	6.634
31	1.823	9.462	3.177	0.864	5.643	1.754	3.445
32	13.820	2.479	3.039	6.512	8.149	5.176	6.469
33	11.370	-1.814	6.985	5.926	4.778	6.333	5.657
34	4.266	4.038	7.379	-0.240	4.152	2.690	3.326
35	0.684	8.676	5.353	6.257	4.680	5.909	5.375
36	21.547	-14.083	15.223	0.064	3.732	5.895	4.954

Industry codes and description

15	**Manufacture of Food Products and Beverages**
16	**Manufacture of Tobacco Products**
17	**Manufacture of Textiles**
18	**Manufacture of Wearing Apparel Dressing and Dyeing of Fur**
19	**Tanning and Dressing of Leather Manufacture of Luggage, Handsbages, Saddlery, Harness and Footwear**
20	**Manufacture of Wood and Products of Wood and Cork, Except Furniture, Manufacture of Articles of Straw and Plating Materials**
21	**Manufacture of Paper and Paper Products**
22	**Publishing, Printing and Reproduction of Recorded Media**
23	**Manufacture of Coke, Refined Petroleum Products and Nuclear Fuel**
24	**Manufacture of Chemicals and Products**
25	**Manufacture of Rubber and Plastic Products**
26	**Manufacture of Other Non-Metallic Mineral Products**
27	**Manufacture of Basic Metals**
28	**Manufacture of Fabricated Metal Products, Except Machinery and Equipments**
29	**Manufacture of Machinery and Equipments N.E.C**
30	**Manufacture of Office, Accounting and Computing Machinery**

31	Manufacture of Electrical Machinery and Apparatus N.E.C.
32	Manufacture of Radio, Television and Communication Equipments and Apparatus
33	Manufacture of Medical, Precision and Optical Instruments, Watches and Clocks
34	Manufacture of Motor Vehicles, Trailers and Semi-Trailers
35	Manufacture of Other Transport Equipment
36	Manufacture of Furniture; Manufacturing N.E.C.