CO_2 Emission from Fossil Fuel Consumption and Firm Heterogeneity: A Study of Indian Manufacturing Industries*

Santosh Kumar Sahu
Doctoral Student in Economics
Department of Humanities & Social Sciences
Indian Institute of Technology Bombay
Powai, Mumbai, 400076, India
Mail: santoshkusahu@gmail.com

K. Narayanan
Institute Chair Professor and Head
Department of Humanities & Social Sciences
Indian Institute of Technology Bombay
Powai, Mumbai, 400076, India
Mail: knn@iitb.ac.in

Abstract
Industrial energy efficiency has emerged as one of the key issues in India. The increasing demand for energy that leads to growing challenge of climate change has resulted major issues. It is obvious that high-energy intensity leads to high carbon intensity of the economy. In this connection, this work is an attempt to compute CO_2 emission from fossil fuel consumption for firms in Indian manufacturing from 2000-2011 by adopting the IPCC reference approach and further relate with firm heterogeneity. The contribution of this chapter lies in estimating CO_2 emission at the firm level and analyzing the factors that explain inter-firm variation in CO_2 emission. The results indicate that there are differences in firm-level emission intensity and they, in turn, are systematically related to identifiable firm heterogeneity. This study found size, age, energy and technology intensity as the major determinants of CO_2 emission intensity of Indian manufacturing firms. In addition capital and labour intensity of the firms are also related to the firms' CO_2 emission intensity. We conclude the short run policy implications should be aimed at encouraging firms to invest more in R&D and technology sourcing and at long run firm should be able to adapt cleaner energy to reduce CO_2 emission from the fuel consumption.

Keywords: CO_2 emission, Technology intensity, Firm heterogeneity, Panel data, Indian manufacturing
JEL Classifications: Q4, B23

1 Introduction

Political efforts to address the concerns of climate change have developed greatly in the last twenty years. In 1992, at the Rio Summit, the United Nations Framework Convention on Climate Change (UNFCCC) was established. Then, in 1997, despite its flaws, the Kyoto Protocol set targets to curb greenhouse gas emissions on a number of industrialized countries emissions between 2008 and 2012. While natural scientists identified the relationship

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between greenhouse gas concentrations and climate change and highlighted many of the threats; social scientists, particularly economists played a crucial role in developing strategies for mitigating climate change (Nordhaus 1977, 1991; Cline 1992; IPCC 2007). Economists have been influential in arguing that the cost of mitigation may not be as great as many expected (Porter 1991, Fischer and Newell 2008) and there may be substantial benefits (Stern 2004, Sterner and Persson 2008). They have also proposed mechanisms for trading responsibilities and credits related to greenhouse gas emission reductions, which have been central tools to agreement on targets related to Kyoto Protocol and certain national climate policies (Dales 1968, Atkinson and Tietenberg 1991, Stavins 1995). At a national level, many governments have introduced taxes to discourage the consumption of high-carbon energy sources (Pearce 1991, Newbery 1992, Oates 1995, Parry and Small 2005, Nordhaus 2007, Sterner 2007). In other words, economists have become highly influential in the global efforts to achieve climate stability.

In a parallel line at macroeconomic perspective there is no consensus on the effect of international trade on the environment; and in particular on the effect of trade on global emissions. Neither theoretical nor empirical literature provides a clear cut answer to the link between trade and CO_2 emissions. In this context even fewer studies have attempted to estimate emission at firm level, however studies on eco-innovation have given much importance. Studies in eco-innovation can be broadly divided in to two categories. A first mainstream research deals with the drivers of eco-innovation strategies. The seminal work by Jaffe and Palmer (1997), that studies environmental innovation (R&D and patents) at industry level, was followed by Brunnermeier and Cohen (2003), that employs panel data on manufacturing industries to provide new evidences on the determinants of environmental innovation, measured by number of patents. The European setting has recently been the source of some interesting evidence for instance; Rennings et *al*., (2003) exploit OECD survey data in order to investigate whether environmental auditing schemes and pollution abatement innovation are correlated. Mazzanti and Zoboli (2008) present evidence for manufacturing sector at a district level, focusing on an extended set of drivers (environmental R&D, policy induced costs, industrial relations, and other innovations). Frondel et *al*. (2004) use an OECD survey data on manufacturing firms and focus on internal firm-based strategies, external policy variables and test the drivers for end-of-pipe measures or integrated cleaner production processes. However, the second stream of research is focused on environmental innovation and employment effects. The main contributions in this stream include Rennings and Zwick (2001) and Pfeiffer and Rennings (1999).

In the economic literature it is also argued that innovation through technological advancement makes firm/industries competitive and productive. In such reviews arguments are also attempted to link the complementarity of energy to capital, where energy is considered as an instrument to capture the technological indicator. This line of studies however follow a productivity framework and necessarily try to estimate the relationship of energy and non-energy inputs. In this attempt we focus on the bad output of industrial production particularly at firm level. Bad outputs of industrial production are in terms of pollution and emissions. We would like to link the bad output specifically Carbon Dioxide (CO_2) emission from the firms and firm characteristics. Given the reviews limited in this line of research this work aims at investigating the relationship from the structure conduct performance point of view, meaning apart from the CO_2 emission, most of the variables of choice are drawn from the SCP literature. In detail we would like to first estimate the CO_2 emission from fossil fuel consumption for the sample of manufacturing firms, and second we will try to understand the relationship between the CO_2 emission and firm heterogeneity.

The reminder of the paper is as follows. Section-2 of this paper discusses exiting literature; section-3 is dedicated to the conceptual framework, construction of CO_2 emission at firm level, model & variable construction. Section-4 presents the descriptive analysis of the sample. Section-5 is focused on the empirical results and section-6 concludes with policy implication of the study.

2. Review of literature

This section of the paper attempts to look at the mainstream research similar to the objectives of this work. To start with eco-innovation, the study carried out by Rennings and Zwick (2001) is based on a sample of eco-innovative firms for five European Union (EU) countries in manufacturing and service sectors. The result of the study indicates that in most of the firms employment does not change as a consequence of innovations. The econometric results show that, apart from some product innovations, eco-innovation typologies do not influence the level of employment, though as expected, according to their evidence environmentally oriented innovations seem to lead to a skill based effect. Also end-of-pipe innovations are related to a higher probability of job losses, while innovations in recycling have a positive effect on employment. Employment effects may thus be unevenly distributed with strong negative effects from environmental strategies/policies on low skills intensive industries and potentially positive effects on other industries. It could also be argued that product and process eco-innovation strategies may bring about (potentially negative) net effects on employment, attributable to a destruction of the low skilled labour force and a creation of high skilled positions (R&D).

There is a complementary stream of literature that has focused on the various static and dynamic relationships between eco-innovation, environmental performances and firm performances. Konar and Cohen (2001) investigated the effect on firms' market performance of tangible and intangible assets, including two environmental performance-related elements as explanatory factors. Cohen et *al*. (1997) also analyzed the relationship between environmental and financial performances. Overall, authors found that investing in a *green portfolio* did not incur a penalty and even produced positive returns. Gray and Shadbegian (1993) used total factor productivity and growth rates for firms over 1979-1990 as performance indicators to test the impact of environmental regulations and pollution abatement expenditures. They found that $1 more expenditure on abatement is associated with more than 1$ worth of productivity losses. Analysis on variations over time or growth rates, the relationship between abatement costs and productivity found not to be significant. Greenstone (2001) estimated the effects of environmental regulations, using data for 175 million observations of firms in the 1967-87 US censuses of manufacturers. According to the study environmental regulations negatively affect growth in employment, output and capital shipments.

The EU based study by Ziegler et *al*., (2008), focused on the effects of environmental strategies on the stock performances of corporations using standard cross section/panel approaches and event studies that analyze whether there are exogenous unexpected policy effects on the short term performance of environmentally minded firms. The latter are criticized for their intrinsic very short term focus. Based on official datasets they conclude that the evidence focusing on stock market performance is limited since the majority of firms especially in Italy are of medium or small sized and do not appear in stock market data. Innovation dynamics are close to productivity trends which in the end are the main engines of firm performance.

Doonan et *al*. (2005) examined the role of communities to create incentives for local industrial facilities to reduce pollution. They found that firms face both internal and external pressures to improve their environmental performance. Using primary data collected for 750 pulp and paper industries in Canadian pulp and paper industries during 1992 they found that the Government policies are much of a barrier for the Canadian pulp and paper industries. However, financial and consumer markets are not most important barriers. They found that education status of employee is one of the important determinants of environmental performance. The regulatory intervention is also found as the major determinants of environmental performance of the pulp and paper industries. Unlike other industrial sectors the pulp and paper industries produce energy as by-products.

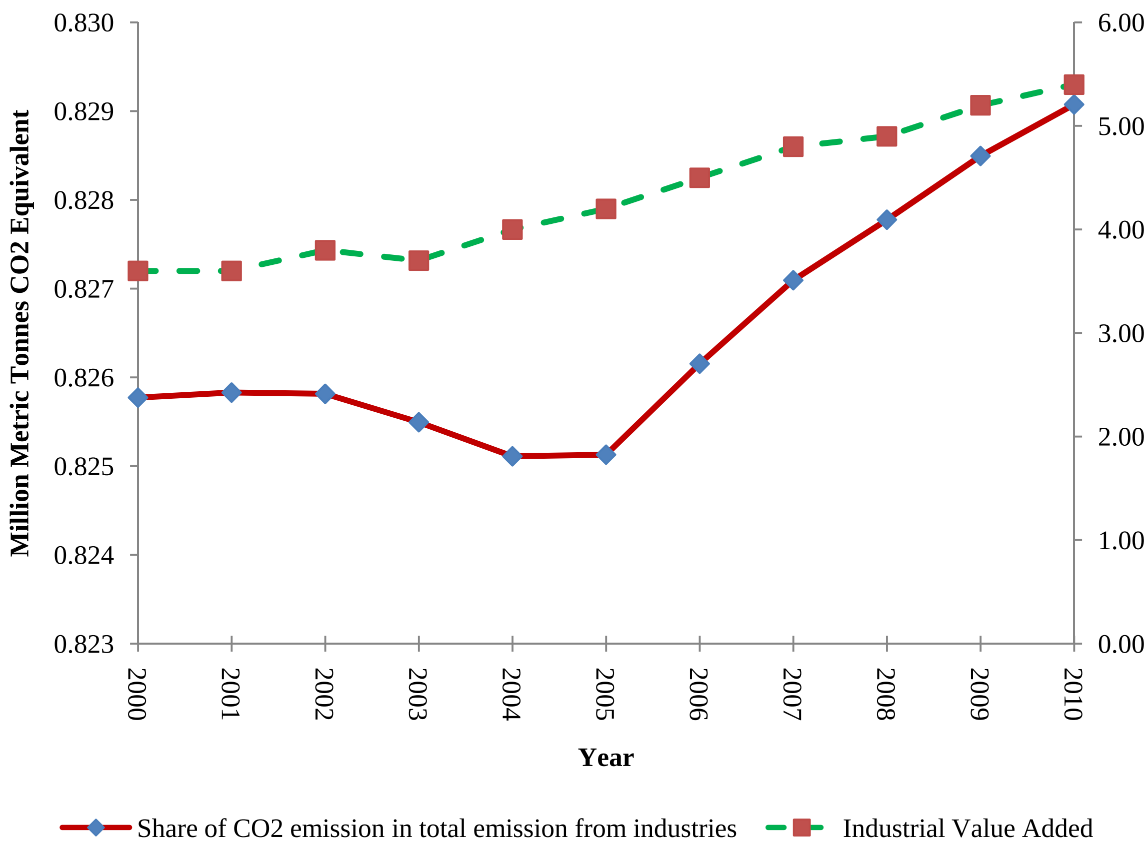
In case of the Indian manufacturing industries firm level energy intensity and their determinants has been studied majorly by Goldar (2011) and Sahu & Narayanan (2011). Both the studies use Indian manufacturing data from CMIE PROWESS online database and follow structure-conduct-performance theory of the firm and analyzed the determinants of energy intensity at firm level. In both of the studies energy intensity is considered as a proxy for energy efficiency of firm. However, what is relevant to our study is the main hypothesis that increasing environmental efficiency by environmental innovations strengthens competitiveness and the firm heterogeneity. In the above discussion on the exiting review of literature concludes that environmental performance has direct or indirect relationship with the firm performance; in terms of employment or in terms of growth of productivity. However, none of them have linked negative externality such as CO_2 emission as a byproduct of the firm to firm heterogeneity. Hence, the motive of the paper is to focus on emission (CO_2) intensity with the firm heterogeneity.

3. Conceptual framework and variable construction

One of the objectives of this work is to estimate the CO_2 emission at firm level. Further, we econometrically model the factors explaining determinants of inter-firm differences in the CO_2 emission. We begin explaining the construction of the firm level CO_2 emission for the Indian sample of firms in manufacturing industries. From figure-1 we can see that share of CO2 emission of the manufacturing industries (at aggregate level) is higher as compared to other emission. This information is collected from the Long-range Energy Alternatives Planning (LEAP)[†] India Starter data base.

[†] The Long-range Energy Alternatives Planning system (LEAP) is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed at the *Stockholm Environment Institute (SEI).*

Figure 1: Share of CO_2 emission in total emission from Manufacturing Industries



From this figure we can see that industrial value added is increasing over the time from 2000-2010 with little fluctuation. In addition from a decrease of emission till 2005, the share of CO_2 emission has increased from 2005-2010. The growth of industrial value added has directly related to emission of the manufacturing industries at aggregate level. This emission is from the output of firm. Hence, this emission is output related not input related. However, data on emission from output of Indian manufacturing firms are not available. Hence, we are focused on estimating the emission from the input use i.e. energy use. This is an indirect measure based on the scientific approach, however is closely related to the emission generated from firm according to the IPCC. The estimation of emission from the fossil fuel consumption is based on the IPCC reference approach that refers as a top-down approach using aggregate information of fossil fuel consumed, to calculate the emissions of CO_2 from combustion of mainly fossil fuel. However, the study has few data limitations such as quality of coal used is not considered mainly because the calculation is carried out for the first time at firm level in Indian manufacturing firms using PROWESS data base. Data is collected from the Center for Monitoring Indian Economy data-base PROWESS 4.0. This data is a combination of the annual audited balance sheet (that gives information of the firm characteristics) and energy consumption at firm level. Therefore, firms that don't report energy consumption are dropped from the active data sheet. Also, since we are adopting the IPCC reference approach, we have considered only fossil fuels consumed by the firms. The IPCC reference approach of estimating emissions from fossil fuels is as follows:

$$CO_2 = \sum_{i=n} \left[\left(\left(ac_f \times cf_f \times cc_f \right) \times 10^{-3} - ec_f \right) \times cof_f \times \frac{44}{12} \right] \quad (1.1)$$

Where, ac_f = apparent consumption fuel, cf_f = conversion factor for the fuel to energy units (TJ) on net caloric value basis, cc_f = carbon content (tonne C/TJ i.e. to kg C/GJ), ec_f = excluded carbon defined as carbon in feed-stocks and non-energy use excluded from fuel combustion emissions (Gg C), cof_f = carbon oxidation factor defined as fraction of carbon oxidized. Usually the value is 1, reflecting complete oxidation. Lower values used only to account for carbon retained indefinitely in soot, and $\left(44/12\right)$ is the molecular weight ratio of CO_2 to Carbon (C).

Further, following Chen et *al*. (2010) we construct the firm level emission as:

$$C_t = \sum_{i=1}^{3} C_{i,t} = \sum_{i=1}^{3} E_{i,t} \times NCV_i \times CEF_i \times COF_i \times \left(44/12\right) \quad (1.2)$$

Where, C_t = flow of carbon dioxide with unit of 10,000 tons, NCV_i = net calorific value provided by IEA energy statistics for India, 2011, CEF_i = carbon oxidization factor provided by 2006 National Greenhouse Gas Inventories in IPCC, COF_i is the carbon oxidization factor set to be one in this study. Therefore, following equation (1.2) in manufacturing industries the calculated CO_2 emission coefficient for coal is 2.0483 (kg CO_2/ kg coal), for oil 3.272 (kg CO_2/ kg oil) and for natural gas 2.819 (kg CO_2/m^3 natural gas).

Following Copeland and Taylor (1995) and assuming each firm produces two outputs: a manufactured good (*x*) and emission (*e*), the testable implication of the study follows a log linear relation of the following type:

$$\ln \frac{e}{x} = \left(\vec{fh} \right) \quad (1.3)$$

Where, $\ln \frac{e}{x}$ =Natural log of firm level emission intensity and $\vec{fh}$ is a vector representing firm characteristics. We use an unbalanced panel data for the estimation of equation (1.3). Following similar framework as in Goldar (2011) and Sahu & Narayanan (2011) for the

Indian manufacturing industries, the general form of equation (1.3) is estimated with the following econometric specification:

$$\ln\frac{e}{x_{it}} = \alpha_{it} + \beta_1 ci_{it} + \beta_2 li_{it} + \beta_3 ei_{it} + \beta_2 s_{it} + \beta_2 s_{it}^2 + \beta_2 ag_{it} + \beta_2 ag_{it}^2 + \beta_2 t_{it} + \beta_2 rd_{it} + \beta_2 mne_{it} + \varepsilon_i + \mu_{it} \quad (1.4)$$

Where ci: capital intensity, li: labour intensity, ei: energy intensity, s: firm size, s^2: Square of firm size, ag: age of the firm, ag^2: Square of age of firm, t: technology import intensity, rd: research and development intensity and mne: multinational affiliation

Now we describe the sample and the variable construction to estimate the model. Different empirical works that study reasons for energy (in)efficiencies pay attention to the market share or value added to the industry output and find the evidence that it can make a contribution to the explanation of inefficiencies as the factor of market power (Hrovatin and Urib, 2002). It is worth mentioning, that fossil energy resources are characterized by the considerable undesirable outcome (such as CO_2 emissions) and still their share in total energy generation is dominant, while the role of renewable energy sources is comparatively low, though extended recently. We have selected the following variables those influence the emission intensity of firms.

Output is deflated net sales adjusted for change in inventory and purchase of finished goods. In PROWESS database the purchase of finished goods is defined as finished goods purchased from other manufacturers for resale. Hence, we subtracted purchase of finished goods from sales to arrive at the firms manufactured output. A positive increase in inventory is added to sales to arrive at output and a decrease subtracted.

Firms can gain technological advancement not only through their own innovations but also through purchases of new capital or intermediate goods from other sectors. Capital is measured as defined in Srivastava (1996) for the measurement of capital stock, which revalues the capital given at historical cost to a base year. Actual invest for the present period is estimated by taking the difference between Gross Fixed Asset (GFA) for current year and that of last year. The real investment value is expressed in the base price of 1993-1994=100. This enables us to use the perpetual inventory method to construct capital stock. In estimating the capital stock we first revalue the GFA at historical cost to a particular base year value. We have used GFA, after deflating it with the wholesale price index for machinery and machine tools, as plant and machinery accounts for 71 percent of the GFA (RBI Bulletin, 1990). Firms can gain a technological advancement not only through their own innovation but also through purchases of new capital or intermediate goods from other sectors. Capital intensity, measured in terms of deflated GFA as a proportion of output. Further, capital intensity is defined as ratio of capital to output.

The PROWESS database provides information on wages and salaries of the firm and provides no information on the number of employees. Therefore, we need to use this information to arrive at the number of person engaged in each firm. Number of persons engaged in a firm is arrived at by dividing the salaries and wages at the firm level by the average wage rate of the industry (at the three digit level) to which firm belongs. Hence, *Number of persons engaged per firm =Salaries and Wages/Average Wage Rate*. To arrive at the average wage rate we make use of the Annual Survey of Industries (ASI) data on Total Emoluments as well as Total Persons Engaged for the relevant industry. And *Average Wage Rate = Total Emoluments/Total persons engaged.*

In most of the productivity studies of four factors of production, energy consumption is considered as one of the indicator for innovation. This implies that in cost minimization a firm can shift from one source to the other and it has been observed that firms do shift from energy intensive to efficient. Hence, it will be of interest to check the relationship between energy efficiency and emission at the firm level. Size of the firm is the proxy for several effects as observed by Bernard and Jensen (2004). Size of firm is one of the components of firm heterogeneity. Because of scale economics bigger firms might use the efficient fuel and emit less. In the present study, firm size is measured by the natural log of total sales. There could be a non-linear relationship between emission intensity and firm size. Age of the firm is calculated as the deference between years of the study to year of the incorporation of the firm as reported in the CMIE database.

Technology import intensity is defined as the expenses on import of capital goods and royalty and technical fees payments in foreign currency, to net sales of the firm. Higher the technology import it is assumed that firm might be emitting less as technology advancement of the firm might enable the firm to be energy efficient and emit less. R&D intensity is also one of the innovation strategies that might help firms in emitting less. Here, we define R&D intensity as the ratio of R&D expenditure to net sales. There is empirical evidence that foreign-owned companies tend to be more efficient in energy conservation (Faruq and Yi, 2010) and, at the same time, there is also evidence in Zelenyuk and Zheka (2006) that reveals a negative correlation between foreign ownership and firm's environmental efficiency level. We have created a dummy to capture the MNE affiliation, where firm belonging to foreign affiliation takes a value 1 and the domestic firms takes a value of 0.

4. Descriptive analysis

This section of the study depicts the descriptive analysis of the sample. We have estimated CO_2 emission based on equation 1.2, from fossil fuel consumption of Indian manufacturing sample of firms from 2000-2011. Figure 2 presents the aggregate mean annual average CO_2 emission of the full sample. From the figure we can observe that the aggregate CO_2 emissions of the sample of Indian manufacturing firms are fluctuating over the period with an increasing trend from 2000-2011.

Emission intensity is considered as better measurement as compared to emission in absolute form as it is normalized with the output of the firm. Emission intensity is drawn in figure 3. The standard deviation between the average emission and emission intensity are however different. We can observe that for emission intensity, the standard deviations across years are quite fluctuating as compared to the standard deviation of aggregate emission for the sample figure-2). If we compare between the distributions of both the series we can observe that emission of the sample are more stable as compared to emission intensity. However, the trend is quite similar for both the distributions. One of the interesting findings of this comparison is that the trend in average annual emission is more flatter then the emission intensity over the years, which is due to the structure and production of the firms. Hence, when we normalize the emission with output we can get a different movement as compared to the absolute level of emission due to fossil fuel consumption.

From this discussion, we can assume that increase in emission of firms is related to the output which is definitely related to the technology in use for the production process. To check this let us plot technology intensity of firm with the emission intensity for the same period. Figure-3 presents this exercise. From this figure we can observe that from 2000 to 2008 the emission intensity is fluctuating while technology intensity was increasing. However, from 2009 even technology intensity continued to increase, emission intensity has started declining. For a few years such as 2001, 2003 and 2008 emission intensity has seen higher and for rest of the years the intensity has been less.

Figure-2: Annual CO_2 emission of the full sample (MT CO_2)

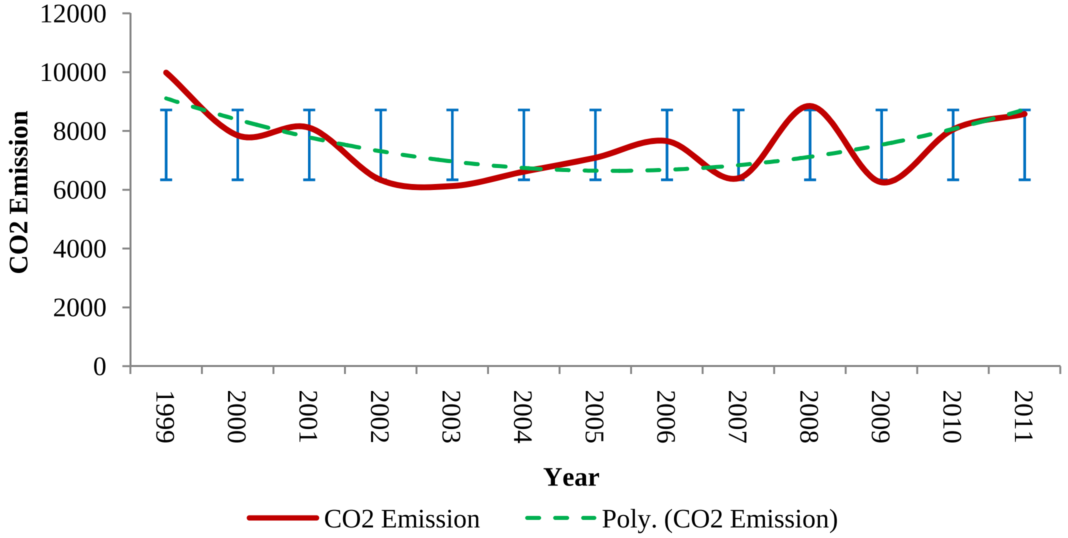


Figure-3: CO_2 emission intensity of the full sample

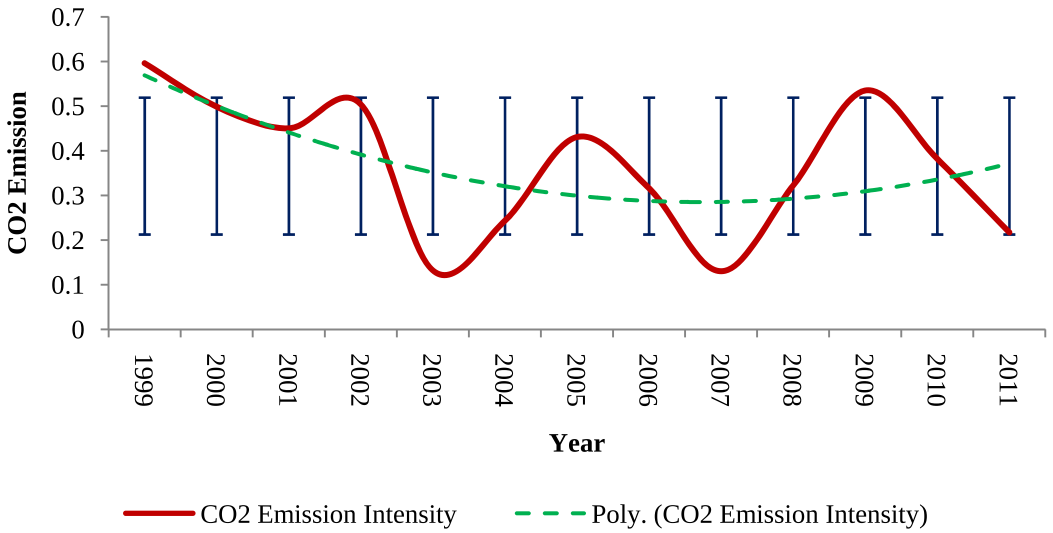


Figure-4: Comparison of CO_2 emission and technology intensity (full sample)

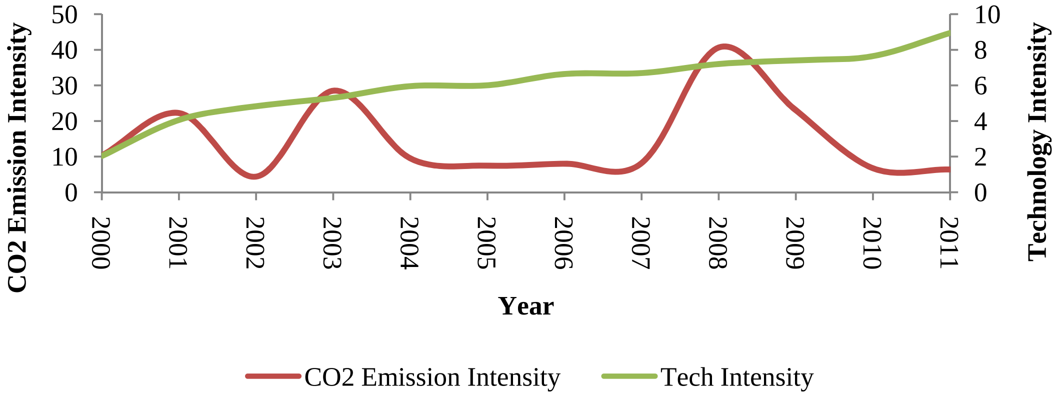
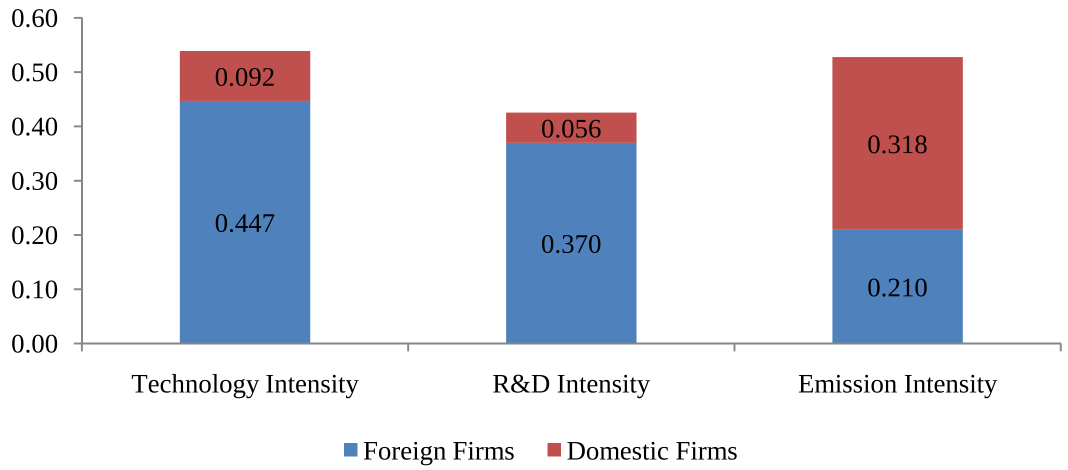


Figure-5: Emission, technology and R&D intensity of domestic and foreign firms



One of the indicators of firm heterogeneity is multinational affiliation of firms. In figure 5 we have plotted technology import, R&D and the emission intensity of firms. As a result of technology import and investment on research & development a firm might lead to reduce the emission. For a growing country such as India, we need to also look at the differences between the multinational affiliated and the domestic firms. From figure 5 we can see that foreign firms are higher technology intensive and higher R&D intensive however, the domestic firms are higher emitting. Emission intensity is not widely differenced, but domestic firms emit more than the foreign firms. Twelve years data of the sample states that the CO_2 emission is higher for the domestic firms (0.32) as compared to the foreign firms (0.21).

Firms use different sources of fossil fuel as primary sources of energy hence, emission from each of the emission are suppose to be different. Therefore, we have attempted to see the difference in emission from different fossil fuel use. In addition we would also like to compare technology intensity with emission with different fossil fuel consumption. Figure 6 gives the comparison of energy, technology, R&D and emission intensity classified by different sources of primary energy consumption. From the figure we can see that energy intensity is higher for firms using coal and oil however, firms using natural gas are energy efficient. In case of technology intensity we can observe that firms using coal as primary source of energy are importing higher technology as compared to firms using natural gas and oil. However, oil consuming firms are higher R&D intensive as compared to the other two classifications. Emission intensity is similar for firms using coal and oil where coal using firms are found higher emission intensive as compared to oil using firms but the firms using natural gas are least in emission intensity.

Figure-6: CO_2 emission, energy, technology and R&D intensity between three fuel sources

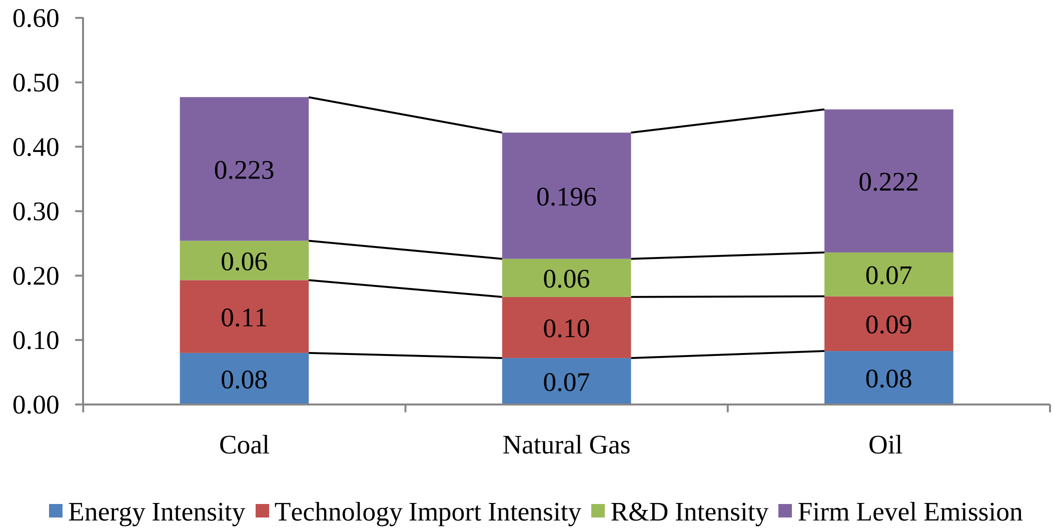
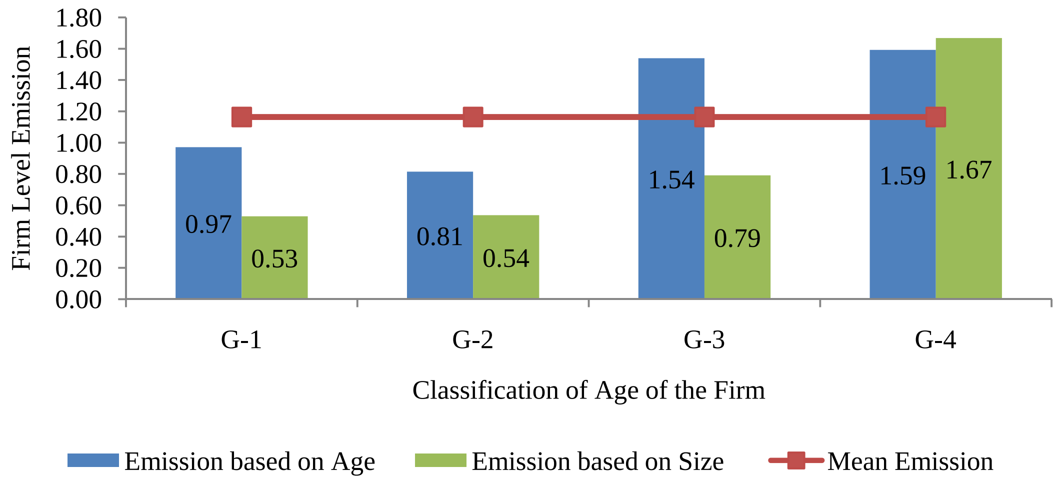


Figure-7: Emission based on groups of firm classified for age and size



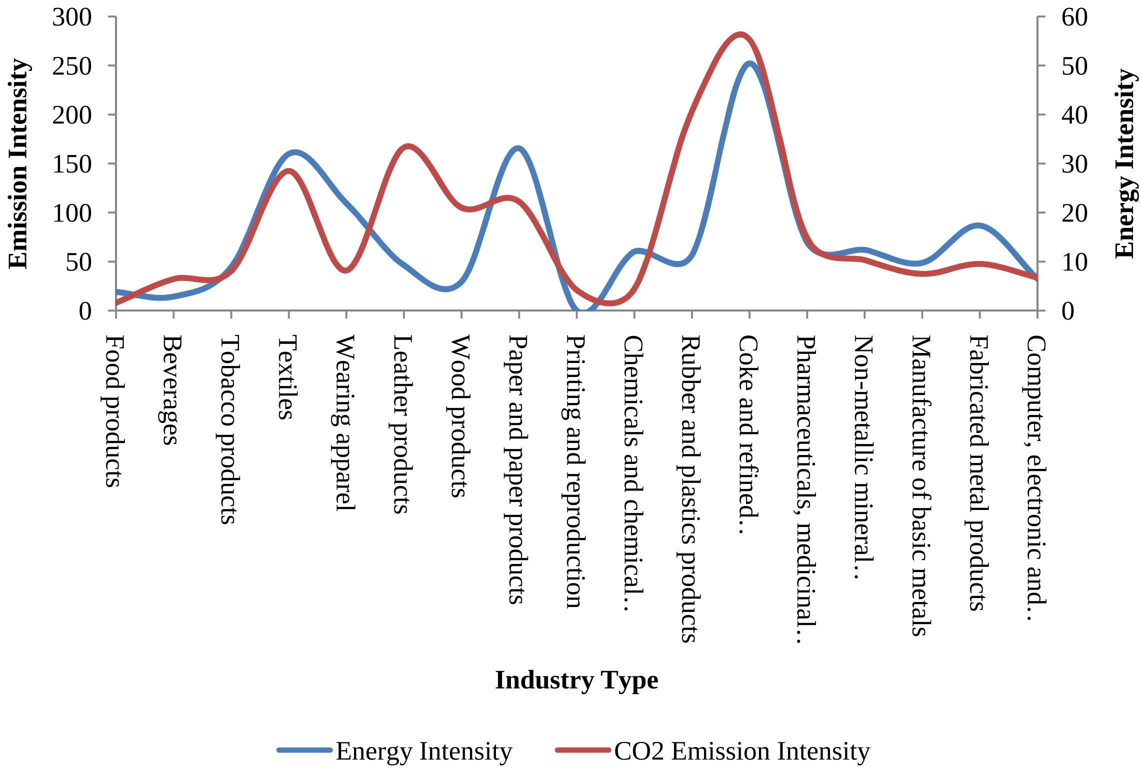
As literature suggests, the major indicators of firm heterogeneity are size and age of the firm. We have classified the sample based on age and size distribution of the firms and relate with firm level emission. Figure 7 presents group of firms classified based on size and age. In case of age of the firms we have created four classifications. The classification (G-1) represents firms age between 1-10 years old, G-2 represents 11-25, G-3 represents 26-50 and G-4 represents firms older than 51 years old. Similarly, for size of the firms, G-1 represents 10th percentile of the sample, G-2 represents 25th percentile, G-3 represents 50th percentile and G-4 represents higher than the 50th percentile. Emission intensity of G-2 firms are the least as compared to the other classifications. Older firms are emitting the highest. For size of the firms, bigger firms are emitting higher compared to the smaller firms. The cross-tabulation might not give the concluding result between firm size and age of the firm to emission intensity; hence the econometric analysis will help us in determining the relation for policy formulation.

Table-1: Comparison of energy intensity and CO_2 emission intensity across industries

NIC	Industry Type	Energy Intensity	CO_2 Emission Intensity
18	Printing and reproduction	0.116	4.195
11	Beverages	14.381	6.443
10	Food	19.059	1.586
16	Wood products	29.519	21.002
90	Computer and electronic	32.557	6.754
12	Tobacco	44.398	8.051
15	Leather	46.320	33.301
60	Manufacture of basic metals	48.742	7.490
22	Rubber and plastics	56.561	40.630
20	Chemicals	60.122	4.399
50	Non-metallic mineral products	61.970	10.320
40	Pharmaceuticals, medicinal chemical	69.943	14.709
80	Fabricated metal products	86.847	9.532
14	Wearing apparel	109.536	8.174
13	Textiles	159.866	28.508
17	Paper	165.525	22.240
30	Coke and refined petroleum	252.124	55.362
	Full Sample	104.702	22.977

As of now we have analyzed the sample at aggregate level. However, as we know the sample consists of different types of firms at industrial classification. There are firms those use energy more and emit more. However, energy and emission intensity can be different based on the output level of such industrial classes. Hence, further the sample is classified in three digit industrial classification based on the NIC-2008 GoI classification. Indicators such as energy and emission intensity are further calculated for the set of these classifications. Table-1 summarizes the result. From the table we can observe that Coke and refined petroleum industries are energy intensive in the set of 17 classes of industries whereas industries related to printing and reproduction are found to be energy efficient in the same classification. Five energy intensive industries from the sample are (1) coke and refined petroleum, (2) paper and paper, (3) textiles, (4) wearing apparel and (5) fabricated metal products industries. In the similar classification five energy efficient industries are (1) printing and reproduction, (2) beverages, (3) food, (4) wood products and (5) computer and electronic industries. For the emission intensity we have also tries the similar classification and found that coke and refined petroleum industries are the emission intensive ones and food industries are the least emitting industries for the sample. The top five emission intensive industries in the sample are (1) coke and refined petroleum, (2) rubber and plastics, (3) leather, (4) textiles and (5) paper industries. The top five emission efficient industries are (1) food, (2) printing and reproduction, (3) chemicals, (4) beverages and (5) computer and electronic industries.

Figure-8: Comparison of energy intensity and CO_2 emission intensity across industries



A comparison of energy and emission intensity of the three digit classification of industries is presented in figure-8. From the top five industries in case of efficient and intensive firms for energy and emission intensity it is not clear whether industries those are higher energy intensive also higher in emission intensity. Hence, we have attempted the Spearmans' rank correlation analysis for three digit industrial classification for energy, emission intensity and technology intensity of the industries. The technology intensity is classified in two major classifications (1) technology import intensity and (2) research and development intensity. From the analysis of the rank correlation we conclude that energy and emission intensity are highly correlated at 1% of statistical significant. The relationship is found to be positive hence, energy intensive firms are found to be higher emitting. In addition we can also observe from table-2 that research and development intensity in negatively related and statistically significant to energy intensity of industries.

Table-2: Result of rank correlation

	Energy intensity	CO_2 emission intensity	Technology import intensity	R&D intensity
Energy intensity	1.000			
CO_2 emission Intensity	0.633***	1.000		
Technology import intensity	-0.377	0.082	1.000	
R&D intensity	-0.499**	-0.226	0.193	1.000

Above discussion has tried to link emission intensity with technology intensity and firm heterogeneity. We began from the macro point of view in relating industrial value added to CO_2 emission of industries. From the LEAP database we conform that CO_2 emission are the major emission from the industrial sector of the Indian manufacturing industries. However, this emission information is from the output generated of the firms as bad output. As data on CO_2 emission at firm level is not available we have constructed the emission at firm level from the IPCC reference case approach. Further, we also classified emission intensity to different firm characteristics, specifically MNE affiliation, firm size, age etc. Further, at three digit industrial classification we have computed the emission and energy intensity to find out the intensive and efficient industries in the sample. Also, this section tried to establish relationship of emission, energy intensity with technology intensity using rank correlation. However, the question of why firms differ in CO_2 emission has not established. The next section tries to attempt this question using an econometric approach at firm level.

5. The empirical results

The theoretical background of the estimated equation (1.4) is given earlier in section-3. However, before attempting equation 1.4 let us compute the correlation matrix for select variables. From the correlation coefficients (table-3) it is seen that energy intensity is statistically significant and positively related to emission intensity, where as size of the firm is negatively related and statistically significant to emission intensity. Capital intensity, age of the firm, technology import intensity and R&D intensity is also found to be positively related to firm level emission. Equation 1.4 is estimated first using pooled OLS and further using panel data econometrics that is fixed and random effects models. Based on the coefficients of Hausman statistics, the fixed effects estimates are selected over the random effects estimates. Methodologically, result of fixed effects is robust and efficient compared to the pooled OLS estimates. Hence, we have interpreted the results of the fixed effects model in table 3. Equation 1.4 is a semi log model and the definition of firm size is also natural log of net sales, hence the econometric specification turns out to be a double log model. Hence, the coefficients of the model are hence elasticities. The detailed results of the pooled OLS and random effects are presented in table A-1 and the result of the fixed effects model is described in table-4.

Table-3: Correlation matrix

	Capital Intensity	Labour Intensity	Energy Intensity	Size of the firm	Age of the firm	Technology Import Intensity	R&D Intensity	Firm Level Emission
Capital Intensity	1.000							
Labour Intensity	0.846	1.000						
Energy Intensity	0.004	-0.016	1.000					
Size of the firm	0.345	0.298	-0.235	1.000				
Age of the firm	0.104	0.138	0.020	0.172	1.000			
Technology Import Intensity	0.590	0.479	0.039	0.387	0.219	1.000		
R&D Intensity	0.092	0.155	0.107	0.127	0.040	0.109	1.000	
Firm Level Emission	0.024	-0.015	0.582	-0.232	0.077	0.117	0.007	1.000

Two parameters are considered for technology intensity namely; technology import intensity and R&D intensity. We can observe from the result of the fixed effects estimates that technology import intensity is statistically significant at 1% and carries a negative sign with emission intensity implying firms importing higher technologies are emitting less. Hence, higher the import of technologies of firms, lower the emission intensity of the firms. Because we have constructed emission from the input use of firms in terms of energy choice the result indicates only one explanation of the relationship that is technology intensive firms mostly use cleaner source of energy such as natural gas. From the cross tabulation it is also clear that natural gas using firms are emitting less. Hence, higher technology intensive firms might be using natural gas in the energy mix instead of other two inputs.

From the result it is clear that research and development intensity is statistically significant and negatively related to emission intensity. This means firms investing more in research and development are emitting less. This result is also similar to the earlier discussions on the selection of energy choice of firm. Relationship of technology import and research & development intensity with emission intensity clearly states that they are negatively related and firms depending more on technology import and investing more in R&D are emission efficient. The result of technology intensity can also be discussed as firms import technology for up-gradation of plant and machinery or develop the output process by using such technologies. In addition through higher R&D intensity firms learn from the technology imported and hence both the parameter help firm in achieving higher emission efficient. Therefore, the role of technology intensity for firms is an important indicator in reducing emission. Linking these results with eco-innovation studies such as Konar and Cohen (2001) we can assume that technology import and the R&D investments are eco-innovation strategies of the firms in reducing emission intensity.

Table-4: Determinants of CO_2 emission

Independent Variables	Coefficient	Standard Error	t value
Capital Intensity	-0.003	0.001	-2.200**
Labour Intensity	-0.005	0.003	-2.520***
Energy Intensity	1.293	0.164	4.870***
Size of the firm	0.043	0.154	2.280***
Square of Size of the firm	-0.132	0.048	-2.730***
Age of the firm	0.013	0.004	3.280***
Square of age of the firm	0.004	0.003	-2.010***
Technology Import Intensity	-0.539	0.274	-1.970**
R&D Intensity	-0.016	0.104	-2.160**
MNE	-0.042	0.168	-0.250
Constant	-1.305	0.141	-9.290
R^2 (overall)	0.289		
R^2 (within)	0.288		
R^2 (between)	0.294		
(u_i=0) F(2324, 621)	8.290***		
F(7,621)	20.65***		
Number of observations	2275		

Since the sample consists of very small as well as very large firms, we have tried to establish non-linear relationship between firm size and CO_2 emission intensity. The result indicates a positive and negative coefficient for size and size square variable. This implies that very large and very small firms are emitting less and the medium sized firms are emitting more. Similar exercise is also carried out for the age of the firms. We also found a nonlinear relationship for emission and age of firm indicating an inverted ‘U’ shape relationship as the coefficients are statistically significant at 1% and carries positive and negative sign. That in turn indicates that both older and the younger firms are emitting less whereas, medium aged firms are emitting more. These results are akin to the literature on environmental Kuznets curve for both developed and developing countries. That is as both size and age of the firm increases, CO_2 emission also increases. However, with increasing innovation, technologies awareness and building capabilities of firms, emission level starts declining beyond a threshold point. In other words it may be easier for both older & younger firm as well as bigger and smaller sized firms to either adapt to or shift to cleaner energy sources compared to the medium sized and aged firms to adapt or shift from the existing energy sources.

Further, capital intensity has a negative relation with emission intensity of the firm, and is highly significant at 1%. This means firms with the larger capital are emitting less compared to firms with the smaller capital. If we compared the results of age and size of firm to emission we can see that older and bigger firms are emitting less and here capital intensive firms are also emitting less. Hence, we can now assume that older and bigger firms might be higher capital intensive firms. Hence, being capital intensive, older and larger they emit less as compared to the less capital intensive firms. According to Narayanan (1998), accumulation of technological capabilities through learning by doing is facilitated by the skilled manpower employed in a firm. The calculation of the labour intensity is quite similar to Narayanan (1998), hence labour intensity can also refer as a proxy for skill manpower. The result of the labour intensity is statistically significant at 1% and negatively related to emission intensity. Therefore, labour intensive firms are emitting less as compared to the less labour intensive sample firms. Rennings and Zwick (2001) found that employment is not a major reason for eco-innovation of firms, contrary we found that higher labour intensive firms are less emitting.

MNE affiliation of firms is not found to be statically significant but looking at the descriptive statistics on the relationship of MNE, R&D and technology import intensity we can find that foreign firms are investing more in technology import and R&D compared to domestic firms. Even in case of the emission we can see that there is difference between the domestic and foreign firms. Therefore, we assume that the presence of foreign affiliation might be captured either in the technology import or in the research and development expenses of firms in the model. Further, energy intensity of firm is found to be positively related and statistically significant with the emission intensity. This implies energy intensive firms are also emission intensive. This result is akin to the rank correlation coefficient between energy and emission intensity. As the construction of CO_2 emission is from the fossil fuel consumption this result is accepted.

6. Summary and policy implications

The increasing concern on climate change, green house gases, and emissions are matter of concern not only for developed countries but also for the developing as well as the underdeveloped countries. In addition, concerns have been also reinvigorated by the global and local environmental problems caused by the ever-increasing use of fossil fuels, and so it is clearly an enormous challenge to fuel economic growth in an environmentally sustainable way. India being one of the largest and rapidly growing developing countries the issue of emission needs special focus. Analysis on the emission from the industries of Indian economy should not be at the aggregate level/ at national level. Specific interest must be given for the sub-sectors as well. In this connection, this work is an attempt to compute CO_2 emission of sample firms in Indian manufacturing 2000-2011 by adopting the IPCC reference approach. The results indicate that there are differences in firm-level emission intensity and they, in turn, are systematically related to identifiable firm heterogeneity. This study found size, age, energy intensity and technology intensity as the major determinants of CO_2 emission intensity of Indian manufacturing firms. In addition capital and labour intensity of the firms are also related to the firms' emission intensity.

Indian manufacturing industries play a significant role in the country's economic growth. However, in global competitiveness in this sector has to upgrade the technologies and should achieve for energy as well as emission efficiency. In addition, specific policy measures should be formulated to encourage medium sized and aged firms to upgrade technology and invest in technology import and research & development pertaining to eco-innovation to reduce CO_2 emission. In addition reducing fossil fuel consumption and adopting cleaner and green energy firms will be able to become both energy and emission efficient. Summarizing the findings; R&D, technology sourcing, fuel switching, should be given due attention for green growth. The contribution of this paper lies in estimating CO_2 emission at the firm level and analyzing the factors that explain inter-firm variation in CO_2 emission.

Table A-1: Estimates of Pooled OLS and Random effect models

Variables	Coef	RSE	t value	Coef	SE	z value
	Pooled OLS			Random Effect		
Capital Intensity	0.002	0.001	2.320	0.003	0.001	2.700
Labour Intensity	-0.002	0.001	-1.710	-0.002	0.001	-2.630
Energy Intensity	5.096	0.863	5.900	3.409	0.120	6.430
Size of the firm	1.219	0.113	5.830	0.881	0.074	5.870
Square of Size of the firm	-0.174	0.038	-4.550	-0.085	0.023	-3.640
Age of the firm	0.011	0.004	2.890	0.013	0.004	3.280
Square of age of the firm	0.003	0.002	-1.790	0.002	0.001	-2.010
Technology Import Intensity	-0.896	0.378	-2.370	-0.848	0.103	-8.240
R&D Intensity	-0.071	0.123	-1.580	-0.023	0.034	-0.680
MNE	-0.038	0.180	-0.210	-0.042	0.168	-0.250
Constant	-2.850	0.238	-11.960	-2.473	0.198	-12.460
F(10, 2942)	101.130			--		
R^2 (overall)	0.429			0.338		
R^2 (within)	--			0.423		
R^2 (between)	--			0.411		
Root MSE	1.076			--		
Wald chi^2	--			1516		
Number of observations	2275					

Note: Coef: Coefficient, RSE: Robust Standard Error, SE: Standard Error

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