Energy efficiency and productivity:

A firm level analysis for developing countries

June 2019

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Abstract:

This work aims at exploring the relationship between energy efficiency and productivity for a sample of firms located in developing countries. This relationship, although important and relevant to policymaking, has not been studied in depth. Moreover, environmental impact has been extensively analyzed using data at the level of countries, states, and provinces, but relative few firm level analyses have been performed. Thanks to the availability of firm-level data for a large set of Developing countries from the national representative World bank Enterprise Survey (WBES) dataset, we provide a first comprehensive empirical analysis of the relationship between energy efficiency and firms' productivity for the main manufacturing industries, controlling for industry and firm heterogeneity. Our findings show - on average - a positive relationship, that holds also at industry level, with different magnitudes, for all sectors. Given the difficulty in determining a causal linkage, the empirical validation of whether cross industries and cross-firms differences in energy efficiency are correlated with differences in productivity is very relevant for policymaking.

Keywords: Energy use; firm productivity; Development countries

JEL codes: D24, L20, O50, Q40, Q56

1. Introduction

The promotion of a sustainable development is not possible without sustainable energy. Over the last three decades, energy intensity has fallen in all sectors: industrial production has become increasingly energy saving although it is still relatively energy intensive (World Bank, 2018). Improving energy efficiency is a growing policy priority for many countries around the world and, as pointed out by the International Energy Agency (IEA, 2014), is widely recognized as the most cost-effective and readily available means to address numerous energy-related issues, including energy security, the social and economic impacts of high energy prices, and concerns about climate change. Starting from the blueprint of the set of globally recognized principles and performance (e.g., IFC) also international investors are now increasingly assessing the environmental performance of business activities in developing countries.

Nevertheless still today, according to UN 2018: i) one person in five lacks access to electricity; ii) two in five rely on wood, coal, charcoal or animal waste for cooking and heating; and iii) in industrialized countries, inefficiency in energy consumption harms productivity and energy-related emissions worsen the global warming.The success of initiatives such as the United Nations' Sustainable Energy for All – that aims at ending energy poverty by 2030 – requires the adoption of conducts that are environmentally respectful in order to ensure universal access to modern energy services, as well to double both the global rate of improvement in energy efficiency and the share of renewable energy in the global energy mix.

Manufacturing and industrial activities are among the primary users of energy and thus also responsible for CO2 emissions (Abdelaziz et al., 2011). As a result, industrial firms have been subject to political and social pressure to re-examine their practices considering energy awareness and move towards greater energy efficiency (Okereke, 2007). At the firm level, energy efficiency can be also a key mean of enhancing productivity growth (Jorgenson 1984; Thollander et al. 2007).

A major drawback of the literature in this field is that most studies are either carried out in developed economies or at the aggregate level. On the empirical side, our paper is one of the few works that explores the effect of energy efficiency at firm level and the most complete in terms of geographical coverage since the analysis is carried out for many countries and years, using a panel data econometric model.

Relying on the detailed information available from the World Bank Enterprise Survey dataset, the present work explores the relationship between firms' energy efficiency and labor productivity for a large sample of countries (up to 122 countries), mainly developing economies. It aims at testing and extending at the global level a previous analysis on the same relationship carried out at regional level by Montalbano and Nenci (2018). Controlling for industry and firm heterogeneity (Duro et al., 2010; Mulder and de Groot, 2012; Grossi and Mussini, 2017) – through the identification of panel observations – our study investigates the existence of the so called "Porter Hypothesis" (Porter and van der Linde 1995), shedding light on the impact of different measures of energy efficiency. The Porter Hypothesis suggests that energy inefficiencies are often a waste of resources and that their reduction may lead to an improvement in the productivity with which resources are used. More stringent but properly designed environmental regulations can trigger innovation that, in turn, may partially or more than fully offset the regulatory costs.

The relationship under analysis has not been studied in depth so far and papers on the topic have mainly relied on country, regional and province level data with only few exceptions (*e.g.* Montalbano and Nenci, 2018 on LAC countries and Roy and Yasar, 2015 on Indonesia). The novelty of this paper comes from the focus on firm level data for a large sample of developing countries in different time periods as to obtain a panel subsample over different survey releases. To test whether energy efficiency affects firm performance, we apply a standard constant return to scale Cobb-Douglas production function with labor, capital, and knowledge expanded to export performance.

Our empirical outcomes confirm - on average - a positive causal relationship between energy efficiency and firm labour productivity for developing countries. This relationship holds also at industry level for all sectors. When analyzing regional heterogeneity, we found that South Asian countries show a negative (but statistically non-significant) relationship between energy efficiency and productivity while the other regional groups record, on average, a positive impact. These empirical results also appear relevant for policymaking. Incentive schemes aiming at fostering firms' productivity through energy regulatory policies should be fine-tuned on firms' characteristics such as size, industrial sector and country context.

The paper is organized as follows: Section 2 briefly reports the survey of literature; Section 3 introduces the methodology and provides some stylized facts on energy intensity by firm characteristics at region and industry level; Section 4 presents the empirical analysis and reports the outcomes; Section 5 concludes and provides policy implications.

2. Literature review (to be completed)

Energy efficiency has come back as a high-priority topic on policy and research agendas. This is mainly due to: first, the significant increases in both the level and volatility of energy prices due to the surge in the demand for energy at global levels; second, a causal link between global climate change and greenhouse gases emissions proved by scientists (Martin et al., 2012). As a consequence, the consumption of energy is currently largely shaped by governmental policies via regulations or voluntary agreements and markets are increasingly moving towards environmental responsibility (Okereke, 2007).

Over the last decades, the literature on the relationship between environment and productivity has increased considerably. A major drawback is that most studies in this field are either carried out in developed economies or at the aggregate level. In this work we focus specifically on the studies analyzing the impact of energy intensity and/or efficiency on firm productivity. The debate over this impact is directly ascribable to the so-called "Porter hypothesis" (PH). Porter (1991) and Porter and van der Linde (1995) stated that more stringent but properly designed environmental regulation might create incentives for firms to innovate, increase efficiency, and subsequently enhance their performance. The literature differentiates between "weak" and "strong" versions of the Porter Hypothesis: the "weak" version states that environmental regulation may lead to innovation; the "strong" version adds that the regulation can improve the competitiveness of firms (Jaffe and Palmer, 1997; Jorgenson 1984).

Up to now, scholars have not reached relatively consistent conclusions on the existence of strong PH. Some works concluded that environmental regulation policy has led to a reduction in productivity due to higher costs that firms may face (Gray and Shadbegian, 1995; Dechezleprêtre and Sato, 2014), whereas others highlighted the positive effects of this kind of regulation on productivity (Hamamoto, 2006; Yang et al., 2012; Jorge et al., 2015; Qiu et al., 2017).

Several studies have referred specifically to industrial productivity benefits associated with energy efficiency (see, among others, Boyd and Pang, 2000; Worrell et al., 2003; Eifert et al., 2005). The discrepancy between the results of different works is probably caused by the fact that there is no uniform standard on the measurement of environmental regulation intensity (Albrizio et al., 2017) nor performance (Zeng et al., 2010).

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3. Energy intensity and efficiency's measures: some stylized facts

The World Bank Enterprise Survey dataset[1] provides detailed information over 135,000 firms interviewed in 139 countries since 2005 under a common global methodology. In this study, due to missing observations for some key variables, we end up assessing our parametric analysis on 30,000 observations among which we have been able to identify a subsample of about 2,700 panel data records.

Following Montalbano and Nenci (2018), we measure firm energy efficiency as the inverse of energy intensities, using three different intensity definitions. The first measure of energy intensity is given by the ratio between the annual total expenditure in fuel and electricity and the value of total annual sales. The second measure is given by the ratio between fuel and electricity expenditure and the annual value added. Lastly, the third measure, the cost share, is the annual energy cost (fuel and electricity) over the total annual cost for variable inputs.

Identifying the total annual energy costs as $C_{EN} = C_F + C_E$, where C_F are the total annual fuel costs and C_E the total annual electricity costs, we compute energy intensities as:

$$EI_{1,it} = {C_{EN,it}}/{S_{it}} \qquad (1)$$

with S_{it} being the total annual sales for firm i at time t;

$$EI_{2,it} = {C_{EN,it}}/{VA_{it}} \qquad (2)$$

with VA_{it} being the total annual value added of firm i at time t and obtained as:

$$VA_{it} = S_{it,it} - \left(C_{RM,it} + C_{IG,it} + C_{F,it} + C_{E,it}\right) \qquad (3)$$

where $C_{RM,it}$ being the total annual costs for raw materials and $C_{IG,it}$ the total annual costs for intermediate goods for firm i in period t;

$$EI_{3,it} = {C_{EN,it}}/{C_{var.inputs,it}} \qquad (4)$$

with:

$$C_{var.inputs,it} = C_{RM,it} + C_{IG,it} + C_{F,it} + C_{E,it} + C_{L,it} \qquad (5)$$

where $C_{L,it}$ are the total annual labor costs.

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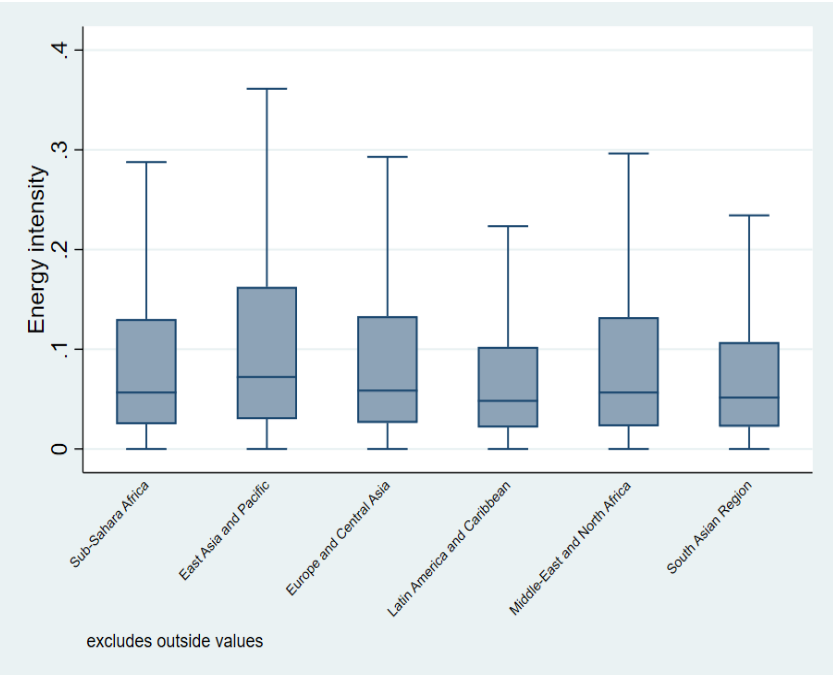
1 See it at http://www.enterprisesurveys.org

Using energy intensities as obtained in eqs. (1), (2) and (4), we then measure energy efficiency by computing their inverse. As a proxy for firm level productivity we use labor productivity, even though we acknowledge that it is not the only measure of productivity. In order to clean our dataset from potential outliers and keep consistency with the hypothesis of normal distribution required in the parametric analysis, we applied the minimum covariance determinant (MCD) estimator to identify and exclude from the analysis the outliers. All values are reported in 2009 US dollar.

Table A1 in Appendix provides by-country summary statistics on the total number of firms, the average value of the labor productivity and the value of firm energy intensity according to the three measures presented above. We find that the highest levels of labor productivity are recorded for Sweden (72,827), Israeli (61,233), Slovenian (58,843), Venezuelan (55,206) and Czech (49,768) firms while the least productive are firms from Guinea (6,707), Nigeria (6,596), Tajikistan (6,506), Guinea Bissau (5,610) and Gambia (5,046). Firms from Timor-Leste result having the highest share of energy cost over total annual sales and total value added and the second highest cost share (energy cost over total costs for variable inputs). High levels of energy intensities are found also for Pakistan firms (first in the energy costs to total costs for variable inputs ratio) and Malaysian (in the top three in all the energy intensity measures).

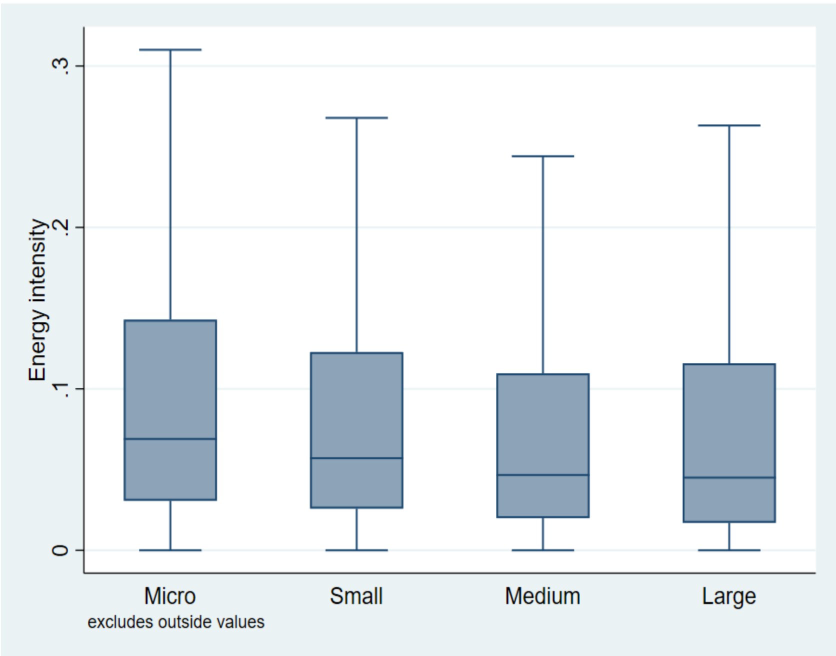
Figure 1: Energy intensity by country region



Note: Energy intensities computed as the ratio between total annual energy cost and total annual costs for variable inputs.
Source: Authors' elaborations from WBES

Figure 1 reports the box plots of energy intensities by region. It highlights evidence of a certain level of heterogeneity among firms across countries groups, with firms in East Asia and Pacific countries showing, on average, higher levels of energy intensity as measured by the ratio between energy costs and total costs for variable inputs. As reported also by *Table A2* in the appendix, such firms record, independently from the definition adopted, an energy intensity well above the average. From *Figure 1* it is clear that less energy intensive productions are performed, on average, by Latin American Countries' firms and by firms in South Asian economies even though this holds only for the energy intensity measure here reported: *Table A2* shows that when the energy efficiency is measured as the share between energy costs and total sales/value added, the least efficient firms are the Sub-Sahara Africans' ones. The evidence from *Figure 1* and *Table A2* suggests the existence of common characteristics deserving to be controlled for and that taking into consideration three different measures of energy intensity (and, therefore, three measures of energy efficiency) – as we do – gives robust ground to the parametric analysis we carry in this work.

Figure 2: Energy intensity by firm size



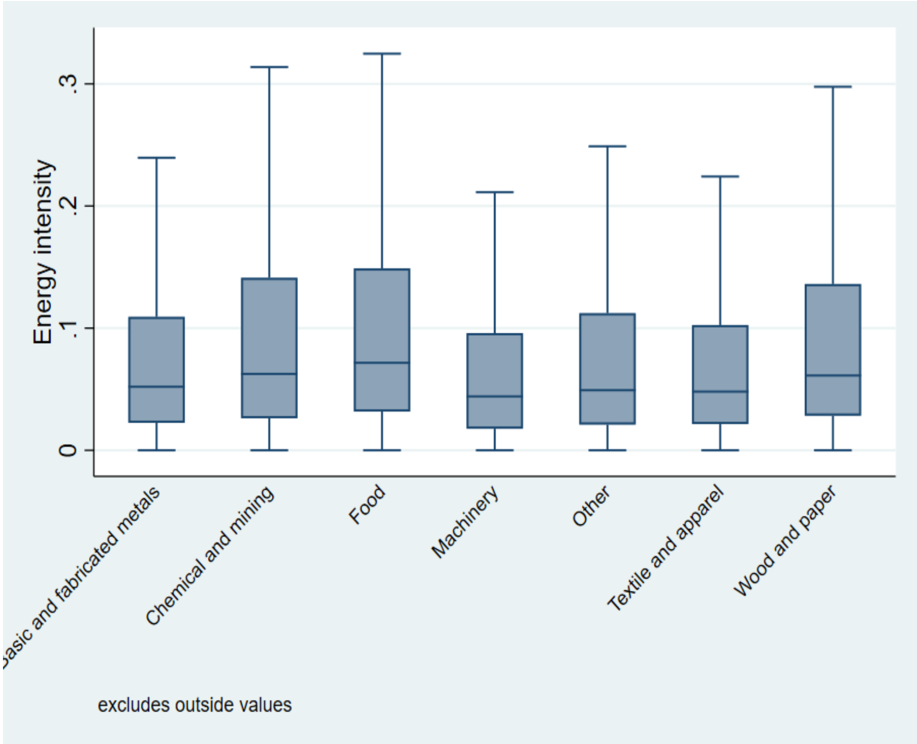
Notes: Energy intensities computed as the ratio between total annual energy cost and total annual costs for variable inputs.
Source: Authors' elaborations from WBES

Figure 2 reports the box plots of energy intensities by firm size (micro, small, medium and large)[2]. In line with the literature (Ref?), micro firms (with less than 10 permanent workers) show, on average, higher energy intensity compared with the other firms in the sample. They also present the highest variability of values around the median. On the contrary, medium firms (those with a

2 Firm size is defined based on the number of total permanent full-time workers employed at the end of the previous fiscal year.

number of permanent workers in the interval: 50-250) have both a lower average level of energy intensities and a lower degree of heterogeneity. *Table A3* in the appendix shows, however, that medium and large firms are the most energy intensive ones when the share of energy costs to value added is considered as proxy, contrarily to the other two measure of intensity.

Figure 3: Energy intensity by industry



Notes: Energy intensities computed as the ratio between total annual energy cost and total annual costs for variable inputs.
Source: Authors' elaborations from WBES.

Finally, in *Figure 3*, we present the box-plot distribution of energy intensities by industry. Analogously to the previous figures, the graph highlights the existence of heterogeneity between firms according to the manufacturing sector of activity: in line with the study on LAC countries performed by Montalbano and Nenci (2018), we find that firms producing food products and firms producing wood and paper products are the most energy intensive ones, while firms producing machinery products result being the most energy efficient in terms of cost shares. This latter result seems to be consistent with the hypothesis of the relative efficiency of the industrial sectors characterized by relatively higher energy consumption, probably due to higher technological standards. *Table A4* in the appendix confirm such evidence for all our three measures of energy intensity.

4. Empirical analysis and results

In order to investigate the relationship between energy efficiency and firm labor productivity, following Crespi *et al* (2016) and Montalbano and Nenci (2018), we estimate a Cobb-Douglas production function with capital, labor, export performance and energy efficiency:

$$\theta_{it} = \beta_0 + \beta_K K_{it} + \beta_{RM} RM_{it} + \beta_h h_{it} + \beta_X X_{it} + \beta_{TI} TI_{it} + \beta_{EE} EE_{it} + \eta_t + \epsilon_i \quad (6)$$

with the firm labor productivity θ_{it} determined by the capital intensity K_{it}, the raw materials and intermediate goods intensity RM_{it}, the share of skilled production worked (as declared by interviewed) h_{it} as proxy of human capital, the exporter status dummy X_{it} (equal to 1 if a firm sells abroad at least the 50 percent of its sales), the technological innovation dummy TI_{it} (following Farole and Winkler, 2014, it is equal to 1 when the firm uses technology licensed by a foreign owned company, owns international quality certifications and uses own website)[3] and the firm's energy efficiency EE_{it} – equal to the inverse of the energy intensity. We also control for time fixed effects.[4]

Table 1 reports the panel fixed-effects estimates of eq. (6) in the case in which energy efficiency, our main variable of interest, is defined as the inverse of the ratio of energy costs to total sales. Our results show that, controlling for firm heterogeneity, the labor productivity is always affected by the degree of energy efficiency. The coefficient relative to energy efficiency is, in all the specifications reported, statistically significant and positive, with a magnitude ranging between 1.16 and 1.43. Firm size does not significantly affect our dependent variable (most variance is captured by firm fixed effects) while capital and raw materials and intermediate goods intensities, as expected, are positively and statistically correlated with labor productivity. Coefficients for exporter status (dummy variable equal to 1 when the firm directly exports at least 10 percent of its sales), skilled production worker share and technological innovation are statistically equal to zero: intra-firm labor productivity dynamics is not explained by such variables.

3 As a proxy for technological innovation we have also taken into consideration the variable "spending on research and development" as well as the dichotomous variables "process innovation" and "product innovation". We preferred the proxy from Farole and Winkler because it does not dramatically cut the number of observations in our estimates.

[4] Country and industry fixed effects are included in Pooled OLS robustness estimates.

Table 1: Panel FEs estimates. Energy efficiency measured as 1 / [annual ener.exp. / tot.ann.sales]

Dep. variable: Labor productivity (in Ln)	(1)	(2)	(3)	(4)
Capital intensity (in ln)	0.165***	0.128***	0.134***	0.109***
	(0.020)	(0.018)	(0.017)	(0.017)
Energy efficiency	1.431***	1.201***	1.198***	1.160***
	(0.201)	(0.172)	(0.173)	(0.223)
Firm size: Micro	0.146	0.246*	0.261*	0.273
	(0.151)	(0.145)	(0.147)	(0.167)
Firm size: Small	0.145	0.243*	0.257*	0.278*
	(0.135)	(0.133)	(0.135)	(0.154)
Firm size: Medium	0.060	0.128	0.138	0.115
	(0.119)	(0.118)	(0.120)	(0.135)
Raw materials and int. goods intensity (in ln)		0.169***	0.167***	0.223***
		(0.024)	(0.023)	(0.033)
Exporter status			0.067	0.117
			(0.074)	(0.079)
Skilled prod. workers share				-0.073
				(0.081)
Technological innovation				-0.150
				(0.128)
Constant	7.851***	6.660***	6.596***	6.871***
	(0.222)	(0.240)	(0.240)	(0.518)
Observations	33,223	32,589	32,553	29,699
nr of groups	31,558	30,984	30,953	28,365
R^2	0.18	0.34	0.34	0.38
Firm FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes

*Robust standard errors in parentheses. */**/*** indicate significance level at 10/5/1 percent respectively. Energy efficiency introduced in thousands.*

Table 2 reports the estimates of eq. (6) when our variable of interest is proxied by the inverse of the ratio of energy costs to firm value added. As in the previous table, the coefficients associated to energy efficiency are statistically significant and positive: more efficient firms record higher levels of labour productivity, and the beta coefficient of our main independent variable results having values ranging in the interval 1.98 – 2.185. Firm size is weakly significant (at 10 percent in the column 8) while capital intensity as well as raw materials and intermediate goods intensity positively affect labor productivity. The significance of energy efficiency coefficients is robust to the inclusion of various covariates. Exporter status, share of skilled production workers and technological innovation do not help explaining firm labor productivity.

Table 2: Panel FEs estimates. Energy efficiency measured as 1 / [annual ener.exp. /tot.ann.VA]

Dep. variable: Labor productivity (in Ln)	(5)	(6)	(7)	(8)
Capital intensity (in ln)	0.144***	0.112***	0.118***	0.100***
	(0.018)	(0.016)	(0.015)	(0.015)
Energy efficiency	1.984***	2.055***	2.045***	2.185***
	(0.296)	(0.262)	(0.263)	(0.290)
Firm size: Micro	0.100	0.195	0.212	0.302*
	(0.160)	(0.144)	(0.146)	(0.166)
Firm size: Small	0.095	0.185	0.201	0.286*
	(0.144)	(0.132)	(0.134)	(0.154)
Firm size: Medium	0.017	0.078	0.088	0.120
	(0.126)	(0.114)	(0.117)	(0.136)
Raw materials and int. goods intensity (in ln)		0.174***	0.172***	0.221***
		(0.025)	(0.025)	(0.035)
Exporter status			0.077	0.097
			(0.067)	(0.071)
Skilled prod. workers share				-0.055
				(0.075)
Technological innovation				-0.197
				(0.122)
Constant	8.052***	6.789***	6.725***	6.590***
	(0.219)	(0.241)	(0.240)	(0.440)
Observations	31,761	31,761	31,725	28,943
nr of groups	30,233	30,233	30,201	27,669
R^2	0.15	0.34	0.35	0.39
Firm FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes

*Robust standard errors in parentheses. */**/*** indicate significance level at 10/5/1 percent respectively. Energy efficiency introduced in thousands.*

Table 3 presents the estimation results when the inverse of the ratio of energy cost to total costs for variable inputs is adopted as energy efficiency measure. Since it is not built by using sales or value added, it represents the most exogenous energy efficiency proxy among the three. As expected, the firm capital intensity is positively and significantly associated with labor productivity as well as the intensity in the use of raw materials and intermediate goods. In spite of the inclusion of the latter among the covariates, the coefficients associated with energy efficiency are always significant, even though their magnitude is reduced from 2.437 (in column 9) to 1.273 (in column 10), a value coherent with those reported in *Table 1*. The value of the energy efficiency coefficient keeps its statistical significance also in the other two specifications despite a decrease in its magnitude. The exporter status is significant at 10 percent level only in column 12 while firm size and technological innovation do not matter for firms' productivity. Such results are not surprising as the fixed effect estimator used in our parametric analysis, by controlling for firm heterogeneity, focuses only on 'within effects' which might not be influenced 'sticky' characteristics such as size and technological innovation attitude. Even though the performance of innovation activities on firm-level productivity is not always positive and significant – as in the case of Kenyan firm as shown by Cirera (2015) – removing the firm fixed effects we would find that both size and technology innovation have positive and statistically significant coefficients, as reported in *Table A5-A7* in Appendix. In *Table 3*, as in the previous two, the coefficient associated to the share of skilled production workers is negative and not significative. This evidence might be surprising, also because, when adopting Pooled OLS estimates (*Tables A5-A7* in Appendix), such coefficient results to be negative and significative. No statistical significance is provided either by the inclusion of the share of 'unskilled' production workers (the complement to 1 of the skilled share).

Table 3: Panel FEs estimates. Energy efficiency measured as 1 / [annual ener.exp. /tot.ann.cost var.inputs]

Dep. variable: Labor productivity (in Ln)	(9)	(10)	(11)	(12)
Capital intensity (in ln)	0.151***	0.117***	0.122***	0.100***
	(0.021)	(0.019)	(0.018)	(0.019)
Energy efficiency	2.437***	1.273***	1.266***	0.740*
	(0.382)	(0.351)	(0.354)	(0.410)
Firm size: Micro	0.092	0.200	0.222	0.231
	(0.159)	(0.148)	(0.150)	(0.174)
Firm size: Small	0.091	0.200	0.221	0.231
	(0.143)	(0.134)	(0.137)	(0.159)
Firm size: Medium	0.020	0.114	0.128	0.114
	(0.123)	(0.116)	(0.118)	(0.136)
Raw materials and int. goods intensity (in ln)		0.159***	0.157***	0.209***
		(0.023)	(0.023)	(0.032)
Exporter status			0.101	0.140*
			(0.075)	(0.081)
Skilled prod. workers share				-0.090
				(0.086)
Technological innovation				-0.052
				(0.145)
Constant	7.991***	6.889***	6.818***	7.096***
	(0.237)	(0.250)	(0.252)	(0.536)
Observations	32,418	32,418	32,381	29,547
nr of groups	30,845	30,845	30,813	28,237
R^2	0.14	0.28	0.29	0.33
Firm FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes

*Robust standard errors in parentheses. */**/*** indicate significance level at 10/5/1 percent respectively. Energy efficiency introduced in thousands.*

Table 2 reports the results of panel estimates for the subsample of firms which appear at least twice in the World Bank Enterprise Survey. The results - which refer to a maximum of 2,717 observation and 1,354 firms – are almost identical to those presented in Table 1, with the exemption of coefficients' standard errors. These panel results give credit to our idea that firms with higher energy efficiency are those who perform better in terms of productivity. Anyway, the adoption of the share of workers with high school degree as well as the adoption of the share of workers with university degree as proxy of human capital gives us the expected results in term of sign and significance (columns 6-7, 13-14 and 20-21 in *Tables A5*, *A6* and *A7* respectively). However, the lack of panel observation for such information and the unavailability of a human capital proxy as in Montalbano and Nenci (2018)[5] has led us to adopt the share of 'skilled' production workers.[6]

Figure 4: plot of Energy efficiency coefficients by region. Energy efficiency measured as the inverse of the ratio between energy costs and total annual costs for variable inputs.

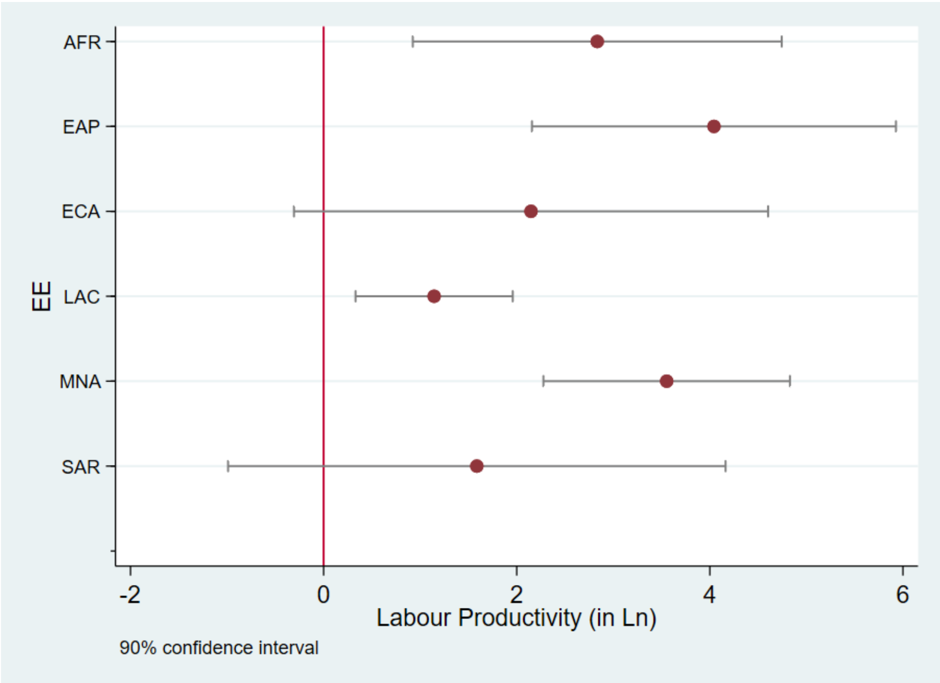


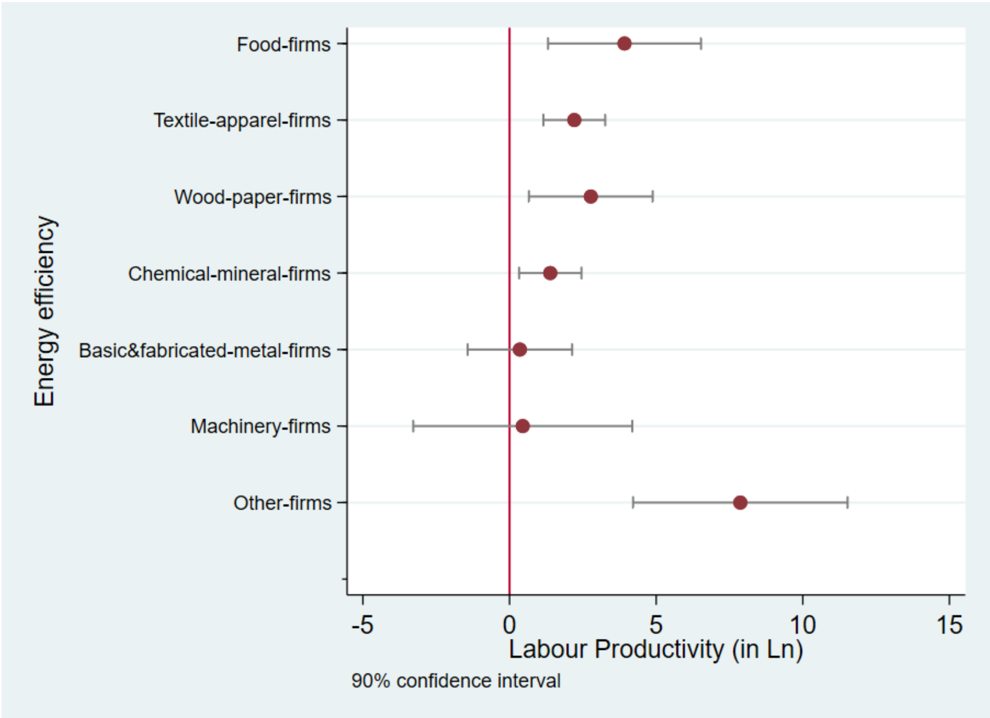
Figure 4 shows the plot of energy efficiency coefficient values by geographic area of the fixed effect panel estimates. Firms in the majority of the regions show a positive relationship between energy efficiency and labor productivity (with the only exception of Southern Asian and European and Central Asian firms which have a statistically non-significant, although positive, coefficient). This result is strongly significant for firms from East Asian and Pacific, Sub-Saharan African and Middle-East and North African countries. Firms in the former region record the highest impact on productivity (magnitude around 4).

[5] Obtained as the share of workers with a bachelor's degree. Available only in Latin American and Caribbean countries' WBES waves.

[6] Obtained as the ratio between the self-declared 'number full-time employees who were skilled production workers at end of last fiscal year' and total full-time employees.

Figure 5 reports the plot of energy efficiency coefficient values by macro-Isic sector of the fixed effect panel estimates. All the sectors show positive coefficients, statistically significative for food, wood and paper, textile and apparel and chemical and mineral firms (sorted from the highest to the lowes) ranging between 4 and 1.25. The highest coefficient is found for the residual sector labelled as 'other'.[7] Mild evidence is provided for basic and fabricated metal firms as well as machinery firms. This result might be the due to the fact that such industries have production processes heavy energy intensive.

Figure 5: plot of Energy efficiency coefficients by sector. Energy efficiency measured as the inverse of the ratio between energy costs and total annual costs for variable inputs.



[7] Mainly representing retail trade firms, wholesale trade and commission trade firms, hotels and restaurants, construction firms and firms with missing information.

5. Conclusive remarks

The debate on the validity of the so called ‘Porter Hypothesis’ has involved several studies over the last 20 years. Most of these have relied on country and regional studies with only few exemptions focusing on firm level data.

Using establishment-level data by the World Bank Enterprise Survey and controlling for firm heterogeneity we have been able to investigate the relationship between energy efficiency – measured as the inverse of the firm energy intensity – and labor productivity, finding a positive impact of the former on the latter. Moreover, we found that firms in all sectors but the machinery show a general positive impact of energy efficiency on labor productivity. When analyzing regional heterogeneity, we found that East Asian and Pacific countries’ firms show a very high relationship between energy efficiency and productivity while Latin American and Caribbean have, on average, a positive impact of a magnitude that is one-fourth of the former. With the exception of basic and fabricated metal firms and machinery firms, we found robust and positive effects of energy efficiency on labor productivity, with the highest coefficient recorded for food firms.

Firm size and technological innovation do not impact productivity when controlling for firm characteristics. They do when considering all the observations in pool. Exporter firms tend, on average, to mildly impact the levels of productivity. In line with the literature on heterogeneous firms in international trade, POLS estimates show a positive and robust positive effect.

The idea that incentivizing energy efficient practices would result in more efficient productive processes and – then – on more productive outputs seems to find support in our analysis even though the heterogeneity that we have found in terms of both industry and geographic area suggests to be cautious when adopting *one size fits all* policies. Incentive schemes aiming at fostering the productivity of firms through energy regulatory policies should be fine-tuned on firms’ characteristics such as size, industrial sector and country context.

References

Abdelaziz, E. A., Saidur, R., and Mekhilef, S. (2011). A review on energy saving strategies in industrial sector.*Renewable and sustainable energy reviews*,*15*(1), 150-168.

Albrizio, S., Kozluk, T., Zipperer, V., 2017. Environmental policies and productivity growth: evidence across industries and firms. J. Environ. Econ. Manag. 81, 209-226.

Cirera, X., 2015. Catching up to the technological frontier? : understanding firm-level innovation and productivity in Kenya. *Washington, DC: World Bank Group.* http://documents.worldbank.org/curated/en/618871468039015224/Catching-up-to-the-technological-frontier-understanding-firm-level-innovation-and-productivity-in-Kenya

Dechezleprêtre, A., Sato, M., 2014. The Impacts of Environmental Regulations on Competitiveness. Grantham Research Institute on Climate Change and the Environment Policy Brief. London School of Economics and Political Science (LSE), London, UK.Denison, E. F. (1979). Accounting for slower growth: The United States in the 1970s.Brookings Institution, Washington, DC.

Gray, W.B., Shadbegian, R.J., 1995. Pollution Abatement Costs, Regulation, and Plant-level Productivity, NBER Working Paper, vol. 1995, p. 4994.

Hamamoto, M., 2006. Environmental regulation and the productivity of Japanese manufacturing industries. Resour. Energy Econ. 28, 299-312.

Jorge, M.L., Madueno, J.H.D., et al., 2015. Competitiveness and environmental performance in Spanish small and medium Enterprises: is there a direct link. J. Clean. Prod. 101, 26e37.

Jorgenson, D. W. (1984). The role of energy in productivity growth. The Energy Journal, 5(3), 11–26.

Martin, R., Muûls, M., De Preux, L. B., and Wagner, U. J. (2012). Anatomy of a paradox: Management practices, organizational structure and energy efficiency. *Journal of Environmental Economics and Management*, *63*(2), 208-223.

Okereke, C. (2007). An exploration of motivations, drivers and barriers to carbon management: The uk ftse 100. *European Management Journal*, *25*(6), 475-486

Qiu, L. D., Zhou, M., & Wei, X. (2017). Regulation, innovation, and firm selection: The porter hypothesis under monopolistic competition. *Journal of Environmental Economics and Management*.

World Bank, 2018. Atlas of Sustainable Development Goals 2018: From World Development Indicators. https://elibrary.worldbank.org/doi/pdf/10.1596/978-1-4648-1250-7

Yang, C.H., Tseng, Y.H., Chen, C.P., 2012. Environmental regulations, induced R&D, and productivity: evidence from Taiwan's manufacturing industries. Resour. Energy Econ. 34, 514e532.

Zeng S., Meng X., Yin H., Tam C.M. and Sun L. (2010) Impact of cleaner production on business performance, Journal of Cleaner Production, 18, 10-11, 975-983.

Appendix

Table A1: summary statistics on labor productivity and energy intensity, by country.

country	*nr of firms*	*LP*	*ECTC*	*ECVA*	*ECCVI*	*country*	*nr of firms*	*LP*	*ECTC*	*ECVA*	*ECCVI*	*country*	*nr of firms*	*LP*	*ECTC*	*ECVA*	*ECCVI*
Afghanistan	62	11,352	0.086	0.213	0.164	*Georgia*	123	15,449	0.072	0.266	0.100	*Panama*	163	28,854	0.066	0.133	0.135
Albania	61	28,910	0.080	0.613	0.135	*Ghana*	453	10,078	0.049	0.125	0.086	*Papua New Guinea*	14	39,449	0.053	0.075	0.141
Angola	275	11,594	0.037	0.072	0.103	*Grenada*	15	22,660	0.094	0.217	0.127	*Paraguay*	227	22,046	0.061	0.157	0.098
Antigua and Barbuda	27	37,932	0.095	0.215	0.130	*Guatemala*	478	19,555	0.072	0.276	0.113	*Peru*	727	29,488	0.053	0.204	0.079
Argentina	721	42,329	0.030	0.126	0.044	*Guinea*	120	6,707	0.060	0.117	0.098	*Philippines*	1,117	22,197	0.083	0.356	0.133
Armenia	136	14,190	0.085	0.307	0.130	*GuineaBissau*	50	5,610	0.062	0.264	0.074	*Poland*	92	39,345	0.054	0.169	0.105
Azerbaijan	143	13,718	0.073	0.378	0.095	*Guyana*	49	27,616	0.105	0.284	0.150	*Romania*	176	25,708	0.066	0.223	0.102
Bahamas	20	40,354	0.061	0.156	0.069	*Honduras*	296	18,874	0.079	0.448	0.128	*Russia*	729	30,321	0.058	0.190	0.085
Bangladesh	1,054	11,583	0.046	0.140	0.075	*Hungary*	71	43,341	0.082	0.621	0.100	*Rwanda*	56	15,097	0.056	0.194	0.077
Barbados	29	43,911	0.061	0.124	0.080	*India*	4,520	24,201	0.059	0.197	0.083	*Senegal*	375	15,894	0.074	0.196	0.107
Belarus	107	21,260	0.051	0.111	0.082	*Indonesia*	1,574	9,640	0.057	0.161	0.091	*Serbia*	162	33,209	0.059	0.278	0.090
Belize	66	37,389	0.042	0.082	0.063	*Iraq*	431	26,225	0.066	0.127	0.137	*Slovak Republic*	55	41,820	0.143	0.353	0.193
Bhutan	67	14,971	0.069	0.293	0.107	*Israel*	35	61,233	0.045	0.074	0.080	*Slovenia*	59	58,843	0.041	0.092	0.053
Bolivia	256	15,287	0.051	0.233	0.090	*Jamaica*	73	28,800	0.040	0.087	0.055	*Solomon Islands*	34	35,702	0.068	0.180	0.139
Bosnia and Herzegovina	132	34,136	0.063	0.234	0.089	*Jordan*	232	33,051	0.068	0.175	0.130	*South Africa*	515	35,693	0.039	0.072	0.058
Botswana	154	23,383	0.041	0.110	0.067	*Kazakhstan*	174	22,224	0.061	0.211	0.081	*South Sudan*	41	17,109	0.090	0.381	0.194
Brazil	839	27,028	0.049	0.148	0.093	*Kenya*	577	22,463	0.048	0.111	0.100	*Sri Lanka*	279	11,218	0.064	0.139	0.109
Bulgaria	549	21,460	0.055	0.284	0.087	*Kosovo*	102	27,316	0.085	0.337	0.112	*St Kitts and Nevis*	19	28,785	0.054	0.116	0.063
BurkinaFaso	39	13,959	0.093	0.174	0.222	*Kyrgyz Republic*	93	10,661	0.081	0.311	0.121	*St Lucia*	55	34,376	0.103	0.276	0.124
Burundi	143	8,828	0.044	0.096	0.072	*LaoPDR*	489	12,018	0.096	0.389	0.156	*St Vincent and Grenadine*	42	32,751	0.110	0.225	0.164
Cambodia	110	10,786	0.135	0.584	0.211	*Latvia*	69	34,861	0.048	0.142	0.065	*Sudan*	12	14,155	0.018	0.024	0.209
Cameroon	67	17,438	0.050	0.090	0.109	*Lebanon*	123	39,504	0.076	0.175	0.125	*Suriname*	67	34,249	0.113	0.264	0.139
Chile	896	37,291	0.048	0.346	0.070	*Lithuania*	90	32,168	0.064	0.257	0.095	*Sweden*	2	72,827	0.042	0.069	0.043
China	1,185	34,635	0.062	0.143	0.108	*Madagascar*	253	6,822	0.088	0.292	0.150	*Tajikistan*	133	6,506	0.088	0.385	0.130
Colombia	1,059	25,574	0.035	0.084	0.056	*Malawi*	80	11,016	0.131	0.601	0.212	*Tanzania*	350	14,001	0.057	0.122	0.097
Costarica	179	31,713	0.058	0.140	0.081	*Malaysia*	397	13,993	0.143	0.642	0.225	*Thailand*	515	16,859	0.059	0.112	0.099
Croatia	259	45,709	0.045	0.154	0.063	*Mali*	303	7,244	0.062	0.136	0.089	*Timor-Leste*	43	11,608	0.229	2.236	0.248
Czech Republic	78	49,768	0.061	0.265	0.100	*Mauritania*	86	20,092	0.078	0.356	0.115	*Trinidad and Tobag*	87	32,911	0.051	0.105	0.069
Côte d'Ivoire	126	12,151	0.073	0.471	0.149	*Mauritius*	115	17,204	0.070	0.150	0.122	*Tunisia*	231	28,369	0.049	0.149	0.075
Democratic Rep. of Congo	362	9,825	0.056	0.108	0.122	*Mexico*	1,719	27,317	0.050	0.118	0.080	*Turkey*	475	41,665	0.062	0.224	0.111
Djibouti	3	25,667	0.120	0.182	0.182	*Moldova*	145	18,051	0.068	0.165	0.112	*Uganda*	369	9,345	0.060	0.163	0.107
Dominica	21	35,661	0.049	0.113	0.062	*Mongolia*	189	12,130	0.078	0.204	0.115	*Ukraine*	302	14,088	0.115	0.310	0.184
Dominican Republic	87	25,926	0.072	0.198	0.103	*Montenegro*	35	34,352	0.085	0.277	0.117	*Uruguay*	319	31,238	0.058	0.153	0.081
Ecuador	325	30,859	0.045	0.130	0.070	*Morocco*	95	24,718	0.068	0.201	0.114	*Uzbekistan*	193	16,528	0.075	0.333	0.118
Egypt	2,119	18,480	0.059	0.183	0.094	*Mozambique*	330	7,913	0.061	0.127	0.086	*Venezuela*	18	55,206	0.037	0.250	0.038
El Salvador	450	18,823	0.061	0.172	0.095	*Myanmar*	214	31,438	0.076	0.175	0.128	*Vietnam*	913	19,159	0.080	0.327	0.122
Estonia	95	44,952	0.050	0.121	0.073	*Namibia*	98	32,397	0.047	0.111	0.093	*West Bank And Gaza*	86	26,331	0.073	0.168	0.124
Eswatini	64	19,119	0.046	0.073	0.080	*Nepal*	316	13,013	0.061	0.306	0.081	*Yemen*	146	13,180	0.085	0.287	0.135
Ethiopia	355	14,043	0.033	0.129	0.064	*Nicaragua*	351	12,791	0.087	0.586	0.140	*Zambia*	492	14,910	0.056	0.131	0.105
Fyr Macedonia	166	25,420	0.076	0.183	0.122	*Nigeria*	1,313	6,596	0.052	0.117	0.095	*Zimbabwe*	292	27,953	0.049	0.096	0.084
Gambia	31	5,046	0.081	0.234	0.115	*Pakistan*	177	15,143	0.139	0.403	0.279	***Total***	**39,352**	**22,025**	**0.061**	**0.203**	**0.099**

Note. LP: Labour productivity; ECTC: Energy costs to total costs; ECVA: energy costs to value added; ECCVI: energy costs to total costs on variable inputs.

region	nr of firms	energy costs to total costs	energy costs to value added	energy costs to total variable inputs
Sub-Sahara Africa	8,490	0.0527	0.1364	0.0959
East Asia and Pacific	7,559	0.0722	0.2580	0.1204
Europe and Central Asia	6,252	0.0599	0.2207	0.0970
Latin America and Caribbean	11,171	0.0499	0.1790	0.0809
Middle-East and North Africa	4,037	0.0594	0.1716	0.1022
South Asian Region	7,083	0.0568	0.1894	0.0864
Total	**44,592**	**0.0575**	**0.1911**	**0.0955**

Table A2: summary statistics on energy intensity, by region.

Note: with respect to values reported in Figure 1, referred to energy costs to total variable inputs, statistics reported in this table do not exclude outside values.

Table A3: summary statistics on energy intensity, by firm size.

firm size	nr of firms	energy costs to total costs	energy costs to value added	energy costs to total variable inputs
Micro	9,774	0.0677	0.1990	0.1065
Small	16,947	0.0606	0.1929	0.0969
Medium	9,251	0.0570	0.2276	0.0935
Large	3,284	0.0566	0.2004	0.0948
Total	**39,256**	**0.0612**	**0.2032**	**0.0983**

Note: with respect to values reported in Figure 2, referred to energy costs to total variable inputs, statistics reported in this table do not exclude outside values.

Table A4: summary statistics on energy intensity, by industry.

industry	nr of firms	energy costs to total costs	energy costs to value added	energy costs to total variable inputs
Basic and fabricated metals	4,229	0.0562	0.1726	0.0890
Chemical and minerals	8,093	0.0691	0.2379	0.1097
Food	7,716	0.0720	0.2572	0.1168
Machinery	1,925	0.0486	0.1269	0.0795
Textile and apparel	7,959	0.0524	0.1366	0.0839
Wood and paper	1,810	0.0681	0.2514	0.1024
Other	7,620	0.0553	0.2064	0.0916
Total	**39,352**	**0.0612**	**0.2032**	**0.0983**

Note: with respect to values reported in Figure 3, referred to energy costs to total variable inputs, statistics reported in this table do not exclude outside values.

Table A5: POLS estimates. Energy efficiency measured as 1 / [annual ener.exp. / tot.ann.sales]

Labor productivity (in Ln)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Capital intensity (in ln)	0.198***	0.199***	0.196***	0.197***	0.196***	0.192***	0.173***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)	(0.007)
Raw mat and intermediate goods intensity (in ln)	0.126***	0.126***	0.130***	0.129***	0.131***	0.155***	0.186***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.009)	(0.013)
Energy efficiency	1.561***	1.557***	1.542***	1.575***	1.547***	1.733***	1.714***
	(0.068)	(0.068)	(0.069)	(0.071)	(0.070)	(0.117)	(0.118)
firmsize==Small	0.177***	0.166***	0.161***	0.159***	0.162***	0.117***	0.092***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.018)	(0.019)
firmsize==Medium	0.378***	0.341***	0.329***	0.328***	0.330***	0.281***	0.253***
	(0.015)	(0.015)	(0.015)	(0.016)	(0.016)	(0.022)	(0.023)
firmsize==Large	0.428***	0.357***	0.334***	0.337***	0.341***	0.270***	0.270***
	(0.022)	(0.023)	(0.023)	(0.024)	(0.024)	(0.032)	(0.033)
Exporter status		0.148***	0.143***	0.150***	0.150***	0.143***	0.153***
		(0.014)	(0.014)	(0.014)	(0.014)	(0.020)	(0.021)
Technological innovation			0.142***	0.130***	0.132***	0.128***	0.147***
			(0.024)	(0.024)	(0.024)	(0.031)	(0.031)
Skilled prod. workers share				-0.122***			
				(0.020)			
Unskilled prod. workers share					0.011		
					(0.022)		
% of wks with univ.degree						0.003*	
						(0.002)	
% of wks with high sch.degree							0.001**
							(0.000)
Constant	6.628	6.370	7.150***	7.233***	8.105***	5.883***	6.785***
		(1,079.106)	(0.159)	(0.089)	(0.157)	(0.112)	(0.105)
Observations	32,589	32,553	31,121	29,699	30,257	16,186	13,444
R^2	0.55	0.55	0.56	0.56	0.55	0.55	0.59
Industry FE	yes	yes	yes	yes	yes	yes	yes
Country FE	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes

*Robust standard errors in parentheses. */**/*** indicate significance level at 10/5/1 percent respectively. Energy efficiency introduced in thousands.*

Table A6: POLS estimates. Energy efficiency measured as 1 / [annual ener.exp. /tot.ann.VA]

Labor productivity (in Ln)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Capital intensity (in ln)	0.197***	0.198***	0.195***	0.196***	0.195***	0.194***	0.176***
	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.007)	(0.007)
Raw mat and intermediate goods intensity (in ln)	0.132***	0.131***	0.136***	0.135***	0.137***	0.164***	0.199***
	(0.005)	(0.005)	(0.005)	(0.006)	(0.006)	(0.009)	(0.014)
Energy efficiency	2.137***	2.130***	2.124***	2.137***	2.125***	2.680***	2.854***
	(0.099)	(0.098)	(0.099)	(0.101)	(0.100)	(0.190)	(0.165)
firmsize==Small	0.172***	0.161***	0.155***	0.152***	0.156***	0.118***	0.096***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.017)	(0.019)
firmsize==Medium	0.373***	0.335***	0.323***	0.319***	0.322***	0.282***	0.260***
	(0.014)	(0.015)	(0.015)	(0.016)	(0.015)	(0.021)	(0.023)
firmsize==Large	0.429***	0.359***	0.335***	0.336***	0.341***	0.278***	0.273***
	(0.021)	(0.022)	(0.023)	(0.023)	(0.023)	(0.031)	(0.032)
Exporter status		0.147***	0.143***	0.149***	0.149***	0.151***	0.150***
		(0.013)	(0.014)	(0.014)	(0.014)	(0.019)	(0.020)
Technological innovation			0.139***	0.129***	0.131***	0.112***	0.124***
			(0.023)	(0.023)	(0.023)	(0.031)	(0.031)
Skilled prod. workers share				-0.123***			
				(0.020)			
Unskilled prod. workers share					0.014		
					(0.022)		
% of wks with univ.degree						0.003*	
						(0.002)	
% of wks with high sch.degree							0.001**
							(0.000)
Constant	7.848***	7.847***	7.844***	7.918***	8.006***	6.212***	6.609***
	(0.195)	(0.139)	(0.144)	(0.151)	(0.139)	(0.099)	(0.211)
Observations	31,761	31,725	30,339	28,943	29,505	15,760	13,148
R^2	0.56	0.56	0.57	0.57	0.57	0.56	0.60
Industry FE	yes	yes	yes	yes	yes	yes	yes
Country FE	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes

*Robust standard errors in parentheses. */**/*** indicate significance level at 10/5/1 percent respectively. Energy efficiency introduced in thousands.*

Table A7: POLS estimates. Energy efficiency measured as 1 / [annual ener.exp. /tot.ann.cost var.inputs]

Labor productivity (in Ln)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
Capital intensity (in ln)	0.192***	0.194***	0.190***	0.192***	0.191***	0.182***	0.162***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)	(0.007)
Raw mat and intermediate goods intensity (in ln)	0.120***	0.120***	0.124***	0.123***	0.125***	0.148***	0.180***
	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.008)	(0.013)
Energy efficiency	2.539***	2.532***	2.447***	2.487***	2.450***	2.524***	2.426***
	(0.103)	(0.103)	(0.104)	(0.108)	(0.105)	(0.176)	(0.190)
firmsize==Small	0.182***	0.171***	0.166***	0.165***	0.168***	0.123***	0.100***
	(0.012)	(0.012)	(0.012)	(0.013)	(0.013)	(0.018)	(0.020)
firmsize==Medium	0.399***	0.360***	0.349***	0.348***	0.349***	0.301***	0.278***
	(0.015)	(0.015)	(0.016)	(0.016)	(0.016)	(0.023)	(0.024)
firmsize==Large	0.463***	0.390***	0.365***	0.371***	0.376***	0.309***	0.303***
	(0.022)	(0.023)	(0.024)	(0.024)	(0.024)	(0.032)	(0.033)
Exporter status		0.153***	0.148***	0.153***	0.152***	0.151***	0.172***
		(0.014)	(0.014)	(0.015)	(0.014)	(0.020)	(0.022)
Technological innovation			0.152***	0.142***	0.142***	0.146***	0.161***
			(0.025)	(0.025)	(0.025)	(0.032)	(0.033)
Skilled prod. workers share				-0.117***			
				(0.021)			
Unskilled prod. workers share					0.000		
					(0.022)		
% of wks with univ.degree						0.004**	
						(0.002)	
% of wks with high sch.degree							0.001**
							(0.000)
Constant	8.124***	6.762	8.238***	8.547***	8.060***	6.128***	6.934***
	(0.125)		(0.143)	(0.263)	(0.155)	(0.115)	(0.106)
Observations	32,418	32,381	30,962	29,547	30,103	16,119	13,399
R^2	0.53	0.53	0.54	0.54	0.54	0.53	0.56
Industry FE	yes	yes	yes	yes	yes	yes	yes
Country FE	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes

*Robust standard errors in parentheses. */**/*** indicate significance level at 10/5/1 percent respectively. Energy efficiency introduced in thousands.*