Is there an environmental benefit to being an exporter? Evidence from firm-level data

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Abstract One concern over globalisation is its impact on the environment. We analyse the consequences of becoming an exporter on a firm’s energy consumption. We show theoretically and empirically with firm-level data that the increase in energy use when exporting is negatively correlated with energy intensity. This is because, although energy use rises with exporting due to greater production and transportation, it can be offset by adopting more energy-efficient technology. This second effect is strongest for high energy intensity firms. As such, analysis of average effects, as in other studies, conceals important connections between the trade and the environment.

Keywords Exporting · Energy · Heterogeneity · Matching · Quantiles

JEL Classification F18 · L23 · Q56 · C21
1 Introduction

With international trade now comprising half of world GDP [World Bank (2010)], the impact of international trade on the environment is a subject of growing concern by economists, environmentalists, and policy makers. The pollution haven hypothesis is now a cornerstone of the debate on globalisation and the environment. As formulated by Pethig (1976) and McGuire (1982) this hypothesis postulates that opening up to trade allows pollution-intensive industries to move to countries with weaker environmental regulations. This results in a race to the bottom in overall environmental standards and increased pollution levels. With this in mind, most of the attention has concentrated on foreign direct investment (FDI), plant location, and multinationals’ impact on the overall level of environmental standards and pollution. However, more recent theoretic work finds the effect is not as straightforward when environmental policy is endogenised (Copeland and Taylor 1994, 1995), pollution is local (Markusen et al. 1995), factor endowments are taken into consideration (Copeland and Taylor 1997; Antweiler et al. 2001), or when governments have other strategic considerations (Barrett 1994). The empirical evidence has been inconclusive on the pollution haven hypothesis. Studies using aggregate data, such as Dean and Lovely (2010), Javorcik and Wei (2004), Ederington et al. (2004) and Antweiler et al. (2001), generally fail to find support for increased FDI leading to increased pollution. An overview of an early literature by Jaffe et al. (1995) draws the same conclusion. In addition, recent firm-level studies including Albornoz et al. (2009), Cole et al. (2006, 2008), and Kaiser and Schulze (2003) have uncovered a positive effect of foreign ownership on the environmental performance of firms in the host country. This should not be taken to imply that there is no evidence for a shift in activities as a result of differences in environmental standards, since Levinson and Taylor (2008), Ederington et al. (2005), List et al. (2003) and Keller and Levinson (2002) find evidence of imports and FDI responding to environmental regulations. Rather, as discussed by Levinson (2009), these effects, at least for the US, are quantitatively small compared to other factors such as the effect of advances in technology.

This paper contributes to the debate by considering the impact of exporting status on energy use by firms. Since energy use is correlated with pollution, this is our measure of environmental performance.\(^1\) We begin with a theoretical model borrowing from the heterogeneous firms literature popularised by Melitz (2003).\(^2\) When a firm begins exporting, its output will tend to rise, increasing its demand for energy and the pollution it is responsible for. However, this greater scale increases the return from investment in energy-efficiency enhancing technologies which would reduce energy use. This latter effect is likely to be particularly large for big

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1 This is similar to the aggregate data studies by Eskeland and Harrison (2003) and Cole et al. (2008). The existing firm-level studies of Galdeano-Gómez (2010), Girma et al. (2008) and Kaiser and Schulze (2003) consider the impact of exporting status on, respectively, a firm’s environmental productivity performance, adoption of pollution abatement technology and environmental expenses as alternative measures of environmental performance. In contrast, we examine the impact of exporting on actual energy use.

2 For an overview of the empirical findings see Wagner (2007).
firms (i.e. more productive firms) and those that are energy intensive. The link between productivity and technology adoption is similar to the theoretical result found by Bustos (2011) following trade liberalization. Therefore the net effect of exporting on energy use is ambiguous and varies across different firms, with low energy intensity firms increasing energy use when exporting and high energy intensity firms reducing energy use when exporting.

We then test this using firm-level data on Irish manufacturing firms from 1991 to 2007. Looking at just the mean effect of exporting on a firm’s use of energy hides differences between low and high energy intensity firms, resulting in an overall neutral effect. Distinguishing between different energy intensities, we find that exporting status is associated with an increase in energy use for low energy intensity firms and with a decrease in energy use for high energy intensity firms. Thus, mean effects mask important variation in the data since such analysis restricts both low energy intensity firms (those for whom the increased output effect dominates) and high energy intensity firms (those most likely to adopt more energy efficient technologies) to have the same estimated coefficients. Our results therefore complement those of Bustos (2011) by considering how the effect of exporting differs depending on factor intensity.

We further establish that these differences arise after firms begin exporting, not before. By employing matching and difference-in-differences estimations we show that low energy intensity firms increase their energy use as a result of output expansion due to exporting. Likewise, high energy intensity firms decrease their energy use following the commencement of exporting, in line with our model’s prediction. In addition, we find that for low energy intensity firms that cease exporting, there is no difference between them and comparable non-exporters immediately following the cessation of exporting. For high energy intensity firms, there is a lasting reduction in energy usage even after exporting stops. If the scale effect disappears immediately but newly adopted technology remains when exporting stops, this is exactly the pattern one would expect to see. Thus, as highlighted by Levinson (2009), there is an important interplay between globalisation, technology adoption, and the environment.

Looking at the role of exporters is a relatively new terrain with only a few studies examining the issue. Galdeano-Gómez (2010) finds higher export orientation to be positively associated with an environmental performance component of a firm’s total productivity. Galdeano-Gómez (2010) also shows that a firm’s environmental performance measure positively affects a firm’s export performance. Kaiser and

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3 Unlike our model the general equilibrium model of Bustos (2011) only has one factor of production and therefore does not consider the impact of factor intensity.

4 When using a pooled sample, comparable to other studies, we find no significant effect of exporting on energy intensity. These results are available on request.

5 Here we rely on quantile regression technique as used before in some trade literature, such as Yasar et al. (2006) and Girma and Görg (2005).

6 Matching in combination with difference in differences has been widely used. Amongst the studies used to analyse an effect of exporting on productivity using matching and difference in differences are Girma et al. (2004) and Wagner (2002).
Schulze (2003) find that among Indonesian manufacturing plants those engaging in export activities are significantly more likely to report spending on environmental protection, with magnitudes at least on a par with spending by the non-exporting plants. Girma et al. (2008) analyse environmental performance of firms in a heterogeneous setting. Extending the Melitz (2003) model, they show that compared to non-exporters, more productive exporting firms will adopt newer and, therefore, more advanced and more environmentally-efficient technologies because they can afford them. Further, using the UK survey data Girma et al. (2008) empirically confirm their theoretical prediction by showing that exporters are more likely to report their innovations to be more environmentally- and energy-efficient. Our paper complements these by looking at energy use, rather than just the adoption of environmentally friendly technologies. Since exporting has a pollution-generating scale effect even for firms that do adopt new technologies, examining energy use is critical to understanding the link between exporting and the environment. In particular, it raises the possibility that targeting export promotion policies towards high energy intensity firms may be much more successful in persuading them to adopt greener technologies than when such policies are adopted at their low energy intensity counterparts.

The remainder of the paper is structured as follows. Section 2 outlines a simple theoretical model designed to illustrate the competing scale and technology adoption effects of exporting status with a particular eye for how these vary across energy intensities. Section 3 describes the data and provides some descriptive statistics. Section 4 presents our empirical methodology and findings for the exporter effects on environmental performance. Section 5 distinguishes between pre- and post-exporting dynamics of energy use, outlining both the empirical methodology and key findings. Section 6 gives a brief summary of some robustness checks. Section 7 concludes.

2 Theory

In this section, we present a simple theory of the decision to export and environmentally-friendly technology adoption. The purpose of this is to illustrate how technology adoption, and thus energy usage, can depend on both the firm’s productivity, the firm’s intensity of energy usage, and market size (in which access to foreign markets is a crucial component). Our basis begins with the well-known Melitz (2003) model of heterogeneous firms. Since our intent is to formulate some intuitive predictions regarding this relationship for use in our estimation rather than to provide a full and detailed model of technology adoption, the simple theory here omits issues such as the timing of technology adoption.

Since our data is at the firm level, we focus on a partial equilibrium analysis to focus our discussion. There exists a continuum of firms, indexed by $i$, which, as in Melitz (2003), are distinguished by a productivity parameter $b(i)$, which we assume is increasing in $i$. Unlike Melitz (2003), firms use two factors of production, labour ($l$) and energy ($e$). The price of labour is given by $w$ while the price of energy is $r$. Each firm’s production function is Cobb–Douglas in these two inputs, where the exponent
on energy \((\alpha(i))\) varies with \(i\).\(^7\) Note that we do not assume a particular relationship between the distributions of \(b(i)\) and \(\alpha(i)\). In addition, the firm chooses a level of technology \(t_j = t_H, t_L\), where \(t_H > t_L\). This technology choice augments the effectiveness of energy usage, i.e. higher technology for a given amount of energy increases the efficiency units of energy in production. Combining these elements yields the production function for firm \(i\): \(b(i)t^{1-\alpha(i)}(t_j)^{\alpha(i)}\). Taking the firms technology and factor prices as given, the cost minimising unit production cost function for firm \(i\) is:

\[
c(i, t_j) = t_j^{-\alpha(i)}b(i)^{-1}x_i^{\alpha(i)}(1 - x_i)^{\alpha(i)-1}r_i^\gamma \bar{w}(1-x_i). 
\]

This unit production cost is lower for a firm with high technology and/or a greater productivity parameter.

In addition to these production costs, the firm must purchase \(\tau\) units of energy in order to get exports to the overseas country.\(^8\) Note that since unit production costs are the same for both domestic and foreign destined output, this makes exports energy intensive relative to domestic output. Finally, the firm faces three types of fixed costs. First, should it choose to produce at all, it incurs \(F\).\(^9\) Second, it faces beachhead costs \(F_X\) if it chooses to serve the foreign market in addition to the home market.\(^10\) The firm’s final fixed cost is \(\gamma(t_H)\), which is the cost of its technology choice. We assume that \(F_X > F\) and \(\gamma(t_H) > \gamma(t_L)\).

The continuum of firms compete monopolistically competitively, with each facing a domestic inverse demand function of

\[
q(i) = p(i)^{-\sigma}P^{(\sigma-1)}I
\]

and

\[
q^*(i) = p^*(i)^{-\sigma}P^*^{(\sigma-1)}I^*
\]

where \(\sigma\) is the elasticity of substitution, \(p(i)\) (\(p^*(i)\)) is the domestic (foreign) price of firm \(i\), \(P\) (\(P^*\)) is the home (foreign) price index (a weighted average of firm prices), and \(I\) is the amount of income spent on the differentiated product industry. These latter two terms are endogenous in general equilibrium (see Melitz 2003), however individual firms treat them as given under monopolistic competition. Since our goal is to describe individual firm behaviour to motivate our regressions, we will also treat them as parameters. Under profit maximization, prices will be constant markups over unit costs. Thus the domestic and foreign prices for firm \(i\) with technology \(t_j\) will be:

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\(^7\) This is akin to the multi-factor model of Bernard et al. (2007). In practice, we would expect the largest differences in \(\alpha(i)\)’s to be found across sectors, with some industries more energy-intensive than others. This does not negate, however, the potential for firms within an industry to vary according to energy intensity as some firms, through design or happenstance, may utilize different production methods than others in the same industry.

\(^8\) This is akin to the iceberg transport costs common to these models.

\(^9\) In addition, it is common to assume a cost to learning one’s \(b(i)\) and \(\alpha(i)\). Since this does not affect relative payoffs from the different choices, we ignore it here.

\(^10\) In line with the heterogeneous firms literature, we assume that parameters are such that any exporting firm also chooses to serve the domestic market. Assuming positive transport costs and/or that \(F_X > F\) are sufficient for this.
\[ p(i, t) = \frac{\sigma}{\sigma - 1} c(i, t) \]  

(4)

and

\[ p^*(i) = \frac{\sigma}{\sigma - 1} (c(i, t) + r\tau) \]  

(5)

which yield quantities of

\[ q(i) = \left( \frac{\sigma}{\sigma - 1} c(i, t) \right)^{-\sigma} P^{(\sigma - 1)} I \]  

(6)

and

\[ q^*(i) = \left( \frac{\sigma}{\sigma - 1} (c(i, t) + r\tau) \right)^{-\sigma} P^{*\sigma - 1} I^* \]  

(7)

This leaves firms with five choices each associated with a particular profit. The profit for firm \( i \) if it only serves the domestic market with low technology is:

\[ \pi_D(i, t_L) = \Omega c(i, t_L)^{1-\sigma} P^{(\sigma - 1)} I - F - \gamma(t_L) \]  

(8)

where \( \Omega = (\sigma - 1)^{-\sigma - 1} C^{-\sigma} \).

Compare this to the profits of a firm that only serves the domestic market but uses the high technology:

\[ \pi_D(i, t_H) = \Omega c(i, t_L)^{1-\sigma} P^{(\sigma - 1)} I - F - \gamma(t_L). \]  

(9)

The difference between these is that while a high technology firm has higher profits due to its lower production costs, it has a greater fixed cost as well. An exporter with low technology will earn:

\[ \pi_{EX}(i, t_L) = \Omega c(i, t_L)^{1-\sigma} P^{(\sigma - 1)} I + (c(i, t_L) + r\tau)^{1-\sigma} P^{*\sigma - 1} I^* - F - F_X - \gamma(t_L) \]  

(10)

which, compared to a comparable low technology non-exporter has greater revenues (even after netting out the added shipping costs) but also greater fixed costs due to \( F_X \). An exporter with high technology will earn:

\[ \pi_{EX}(i, t_H) = \Omega c(i, t_H)^{1-\sigma} P^{(\sigma - 1)} I + (c(i, t_H) + r\tau)^{1-\sigma} P^{*\sigma - 1} I^* - F - F_X - \gamma(t_H). \]  

(11)

which has lower production costs than a low technology exporter but greater fixed costs as well. If the maximum of these four is negative, a firm can simply decide not to enter at all and earn zero profits.

In order to most easily compare these four profit levels, consider Fig. 1 which illustrates the profit level as it varies across \( \alpha(i) \). Values for the various parameters are found in Table 7 in the “Appendix”. Three main results can be seen. First, there is a link between energy intensity (\( \alpha(i) \)) and technology adoption. For low levels of \( \alpha \), low technology choices dominate high technology choices for a given export status (i.e. domestic only or exporting). Since these firms use relatively little energy
in production, the increased productivity of energy use is outweighed by the added cost of installing this technology. For the highest values of $a$, the reverse is true.

Second, there is a link between energy intensity and exporting. Firms that have extreme values of $a$ benefit more from exporting. This is because under the Cobb–Douglas production technology, unit production costs are greatest when $a = 0.5$, all else equal. Thus firms with mid-range $a$ have the highest cost and generate the least profits overseas. Therefore these firms will not choose to export.

Third, and most important for the current study, there is a link between exporting status and technology adoption. This can be seen for firms with moderately high values of $a(i)$. When they do not export, the low technology is the profit maximizing choice. When exporting, however, the reverse is true. This is because the rate of return from installing the high technology is rising in output and firms that export produce more than firms that do not (all else equal). As such, for these firms, the more energy-efficient technology is only worth the added cost when they are serving a larger (international) market. For further insight, consider Fig. 2, which repeats this set of simulations but imposes a 25% reduction in trade costs $\tau$. Two key differences are seen by comparing the figures. First, more firms choose to export. Second, the set of exporters that choose to install the high technology grows. This is because with reduced trade costs, exporters increase overseas sales and therefore benefit more from the reduction in marginal costs which results from the high technology. Thus there is a positive correlation between exporting status and technology adoption.

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11 Similar figures are found if we alter the production function to be $b(i)x_i^{-a}(1 - x_i)^{a-1}l^{1-a}(t_f)^a$, a production function in which the cost function depends on $a$ only in the exponents on wages and energy prices. When these prices are equal, this alternative production function yields profits that are linear in $a$. However, the relative ranking of technology choices remains the same, i.e. high $a$ firms are more likely to use the high technology than low $a$ firms regardless of export status, and exporters are more likely to adopt the high technology than non-exporters for a given $a$. 

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Fig. 1 Profits across entry modes
technology adoption. Figure 3 reverts to the original trade cost, but increases productivity by 50%. Again, we see that more firms export (and under this productivity rise, all firms do so) and that more firms choose the high technology. Thus not only do we see the Melitz (2003) result that more productive firms are more apt to export, but we also find that more productive firms are more likely to adopt the energy-efficient technology.  

12 This provides a potential benefit to the environment from trade since highly productive exporters drive out low productivity domestic firms. If this results in a greater percentage of firms using a more environmentally friendly technology, this could lead to a positive correlation between international trade and the environment. We leave a thorough treatment of this issue to future research.
What then of total energy expenditures? Energy use for a firm $i$ with technology $j$ is:

$$re = (q + q^*)b(i)^{-1}t_j^{-\alpha_i}(1 - \alpha_i)r^\gamma \left( \frac{1 - \alpha_i}{\alpha_i w} \right)^{\gamma - 1} + r\tau q^*$$

which is increasing in domestic production, exports, and lower for a high technology firm for given production levels (and therefore given sales). As discussed above, when a firm begins to export, two changes occur. First, since domestic sales do not change, total energy use rises. Furthermore, since exports require additional transportation, there is actually an increase in the energy intensity of output. *Ceteris paribus*, this will increase energy use. It also increases energy expenditures relative to sales (our dependent variable in the data) since:

$$\hat{\text{c}_{pq+q^*}} = \left( \frac{\sigma}{(\sigma - 1)} \right)^{-1} (c(i,t)(q + q^*) + r\tau q^*)^{-2}r\tau c(i,t)(1 - \alpha_i)q > 0$$

Second, for high energy intensity firms, the firm will adopt a more efficient technology. For a given level of output, this reduces energy usage relative to sales:

$$\frac{d\hat{q}^*_c}{dq^*} = -\frac{\alpha_i(q + q^*)}{(pq + p^*q^*)} \alpha_i(1 - \alpha_i)^{-(1-\alpha_i)} \alpha_i^{\gamma - 1} b(i)^{-1} r^\gamma w(1-\alpha_i)^{-\gamma - 1} < 0$$

Given the discussion above, we expect that when a low energy intensity firm begins exporting, only this first effect will be present, i.e. there will be a positive correlation between exporting status and energy expenditures relative to sales. For high energy intensity firms, however, both effects are present. Thus, for these firms we expect either a smaller positive correlation or possibly even a negative correlation between exporting status and relative energy expenditures. This is the main prediction we will test. One item to keep in mind is the converse of this story. When a firm stops exporting, its scale declines as does its energy use. If technology is partially irreversible, or at least does not immediately depreciate, however, the effect of choosing the high technology will persist even after exporting ceases. Thus, we expect that low energy intensity firms that stop exporting see their energy intensity revert to that of comparable firms that never exported while high energy intensity firms that stop exporting will still use less energy than their counterparts because of the technology they adopted while exporting. This is a second prediction which will be tested.

### 3 Data, descriptive statistics

#### 3.1 Data

The panel of firm level data used in this study comes from the Irish Census of Industrial Production (CIP), an annual census of manufacturing, mining and utilities. The Census is conducted by the Central Statistics Office (CSO) at both enterprise and plant level. The CIP covers all enterprises or plants with three or

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more employees. The CIP data covers the period 1991–2007. Industries covered by the CIP are in classes 10–41 of the NACE Revision 1.1 (European Statistical Classification System). In this paper we concentrate solely on manufacturing (NACE classes 15–36).\textsuperscript{13} This leaves us with an unbalanced panel of 10,785 unique firms.\textsuperscript{14}

Our dependent variable is energy intensity, i.e. energy use divided by sales (total turnover), which is a measure of environmental performance. We use this because there are no data available on pollution at the firm level. This approach is similar to Eskeland and Harrison (2003) and Cole et al. (2008). As the questions on total fuel and power (energy) used were asked on the enterprise rather than plant level, we use the enterprise data set of the CIP. Most enterprises (more than 90%) in the Census are single-plant firms. Energy purchases include purchases of solid fuels, petroleum products, natural and derived gas, renewable energy sources, heat, and electricity. In addition, in our robustness checks, we add relative freight charges, i.e. firm expenditures on shipping, to energy intensity (relative energy use). This is to account for the likelihood that firms that ship overseas may be outsourcing their transportation, and hence a portion of their energy use. However, since the data do not breakdown these outsourced freight expenditures into those on energy and those on other costs, we do not use them in our main results.

Our main variable of interest is a dummy variable “Exporter” which is equal to one if a firm exports in year \( t \) and is zero otherwise. We expect this to be greater for firms that have low energy intensity as compared to firms with high energy intensities (for whom the coefficient may well be negative). Again, as discussed in the theory section, it is important to control for exports as well as sales since the latter will not equal output (the true scale effect) in the presence of transportation costs. In our data, 57% of all firms export at some point during the sample.

Since the theory suggests that more productive firms produce more and are more likely to install energy-efficient technologies, we include labour productivity (measured as turnover per employee). To control for other aspects of a firm’s technology, we include the firm’s capital stock and skill level, with the idea that firms using a good deal of capital may require more energy while those with more white-collar workers may use less. In addition, we control for out-of-house R&D expenses which may be particularly important when focusing on technology changes. Earlier studies suggest that foreign ownership increases a firm’s environmental performance, as might be the case if the parent provides the subsidiary with better technology. With this in mind, we include an ownership variable equal to one if a firm is foreign owned. Since our dependent variable is

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\textsuperscript{13} The list of industries is given in Table 8 in the “Appendix”.

\textsuperscript{14} To prepare the data prior to analysis, we were required to clean the data. In a few instances, the CIP data reported negative or missing values of energy and/or export share and/or zero values of employment, earnings and/or turnover. When possible, these were replaced using values from adjacent years. When this was not possible, the observation was dropped. For instances of export shares bigger than 100 their values were replaced using values from previous and later years. Export share values that could not have been replaced were treated as follows. Firms which did not have an export share equal to 100 in any other years were dropped from the sample. If a firm had at least one occurrence of export share equal to 100 in other years the value of export share larger than 100 was set to 100.
energy use relative to sales, this should control for scale effects assuming constant
returns to scale. Nevertheless, as a safeguard against non-constant returns, we
include both the size (measured as total earnings) and size squared of a firm.

Finally, we include 3-digit industry classification dummies and year dummies. It
is important to recognise that year dummies control for variations in the price of
energy over time. Table 9 in the “Appendix” presents a list of variables used and
their definitions for the purpose of this analysis. Table 10 in the “Appendix”
provides summary statistics for the main variables used in the subsequent analysis.15

3.2 Descriptive statistics

Table 1 provides a brief overview of the distribution of exporters in manufacturing.
Exporters comprise 57% of firms. The average share of exports in sales for all
exporters is 45%. Amongst the exporters, 86% are domestic firms and 14% are
foreign owned. Almost all (97%) of the non-exporters are domestic firms.

Table 2 shows how the mean of energy intensity compares between exporters
and non-exporters alongside the means of other firm characteristics.

Similar to what has been found in previous research, exporting firms are larger,
more productive and capital-intensive, employ more people in general and more
skilled people in particular.16 Their energy use, however, is almost indistinguishable
from that of non-exporters. An important caveat to these comparisons is that they
use unconditional means and do not account for other important characteristics of a
firm, however, in unreported results pooling all firms there is no significant
difference between exporters and non-exporters. Nevertheless, as we show in the
next section the mean values in Table 2 mask important heterogeneity in the effect
of exporting on a firm’s energy use.

Table 1 Exporting status and ownership

|                | % Total | % Foreign-owned | % Domestic |
|----------------|---------|----------------|-----------|
| Exporter       | 57      | 14             | 86        |
| Non-exporter   | 43      | 3              | 97        |

Table 2 Exporters versus non-exporters

| Exporter | Energy per turnover | Productivity | Total earnings | Employment | % High-skilled | Capital |
|----------|---------------------|--------------|----------------|------------|----------------|---------|
| Yes      | 0.0153               | 185.41       | 2,017.08       | 72.29      | 26.88          | 24.49   |
| No       | 0.0151               | 106.12       | 495.72         | 20.89      | 22.66          | 14.37   |

Reported are mean values over the period of 1991–2007. All monetary values are in thousands of euros

15 Monetary values are deflated using Industrial Producer Price Indices with year 2000 as a base,
provided by the CSO. Energy variables are deflated using the CSO Wholesale Price Indices for Energy
Products with year 1995 as a base.

16 Although not reported here, exporters are also on average more R&D intensive.
4 Exporting and energy use

This section estimates the effect exporting has on energy use in manufacturing. As suggested in Sect. 2 it is important to concentrate on a firm’s energy intensity, which we hereby measure as a firm’s energy use relative to its total turnover.\textsuperscript{17}

To check whether the exporter effect varies along the distribution of relative energy consumption we employ quantile regressions as they allow us to study the impact of exporting at different points (conditional quantiles) of energy intensity distribution and not just the conditional mean. Quantile regression method as first introduced by Koenker and Bassett (1978) estimates conditional quantile functions: models in which quantiles of the dependent variable are conditioned on the observed covariates (Koenker and Hallock 2001). The advantage of using quantile regression is that it provides a more complete picture about the effect of the control variables \((X)\) on the dependent variables \((Y)\) as it allows us to study the impact of \(X\) along the full conditional distribution, or at different points (quantiles), of \(Y\). When the impact of a control variable varies across the range of the dependent variable, this can give a much better picture of the underlying data than when looking at just the conditional mean. Since we expect the dynamics of the relationship between exporting and energy intensity to vary with energy intensity, quantile regression is an optimal technique for our study. In particular, we expect the coefficient on exporting to be greater for low quantiles of energy intensity than for high quantiles.

The quantile regression model can be written as:

\[
\text{Quantile}_h(\text{Energy}_{it} | X_{it}) = X_{it}'\beta_h
\]

where \(\text{Quantile}_h(\text{Energy}_{it} | X_{it})\) denotes a conditional quantile of energy intensity and \(X_{it}\) represent control covariates.

Koenker and Bassett (1978) show that the \(\theta\)th regression quantile, where \(0 < \theta < 1\), can be computed by:

\[
\min_{\beta} \left[ \sum_{i:t:Energy > X_{it}'\beta_0} \theta|\text{Energy}_{it} - X_{it}'\beta_0| + \sum_{i:t:Energy < X_{it}'\beta_0} (1 - \theta)|\text{Energy}_{it} - X_{it}'\beta_0| \right]
\]

where \(\beta\) will be estimated differently at different quantiles \(\theta\), with \(\theta\) and \(1 - \theta\) used as weights and \(X\) are the set of variables as discussed in Sect. 3.

The results of estimations in (16) are presented in Table 3.\textsuperscript{18} Indeed, as predicted by the theory, there is a heterogeneity in the effect of exporting on energy use. The results in Table 3 show that as one moves from low energy intensity towards high energy intensity, the coefficient on exporting declines.

Looking to our other controls, labour productivity is significantly negative in all cases. As the theory indicates, more productive firms are more apt to invest in energy-efficiency enhancing technologies, therefore this too is in line with our

\textsuperscript{17} The same results are obtained when using energy relative to total costs or absolute energy usage as alternative measures of a firm’s energy intensity.

\textsuperscript{18} Results for 0.10th quantile are not reported to save space but the exporter effect is positive in line with theoretical predictions.
Also in line with our priors, we find that firms with more capital and less skill use more energy relative to sales. Firms that spend more on out-of-house R&D also use more energy. Looking at the size variables, we find that increased size seems to reduce energy intensity for small firms, but that the effect is reduced for large ones. Finally, we find heterogeneity across quantiles for the ownership variable. Unlike the exporter variable, this is negative for low energy intensity firms, suggesting that in the lower quantiles foreign ownership reduces energy intensity. For higher quantiles, however, the reverse is true and the effect grows as one moves towards the most energy intensive firms.

### 5 Pre- and post-exporter dynamics

As a next step of the analysis we would like to see whether the exporter effect observed above can be attributed to pre- or post-exporter differences in energy intensity. It is reasonable to expect that similar to the observations that most productive firms self-select into exporting, firms may adopt newer, more energy-

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**Table 3** Quantile estimations of exporter effects on energy intensity

| Quantile | Exporter | Ownership | Labour productivity | Size | Size² | Capital | Skill | R&D | Constant | Observations | Pseudo R² |
|----------|----------|-----------|---------------------|------|-------|---------|-------|-----|----------|-------------|----------|
| 0.20     | 0.05087*** | −0.01649*** | −0.04861*** | −0.00198 | 0.00019 | 0.00839*** | −0.02631*** | 0.00816*** | −0.38265*** | 74,257      | 0.11     |
| 0.50     | 0.04550*** | 0.02697*** | −0.05459*** | −0.01521*** | 0.01084*** | 0.02185*** | −0.02718*** | 0.01412*** | −0.03708*** | 74,257      | 0.17     |
| 0.70     | 0.01804*** | 0.06698*** | −0.05292*** | −0.02233*** | 0.00127*** | 0.02153*** | −0.02882*** | 0.01270*** | 0.31409***  | 74,257      | 0.19     |
| 0.80     | −0.00099  | 0.10622*** | −0.05894*** | −0.03102*** | 0.01584*** | 0.02839*** | −0.03281*** | 0.01245*** | 0.59334***  | 74,257      | 0.20     |
| 0.90     | −0.02722*** | 0.11670*** | −0.06852*** | −0.05687*** | 0.02867*** | 0.04570*** | −0.02361*** | 0.00346*** | 1.22525***  | 74,257      | 0.22     |
| 0.95     | −0.06952*** | 0.11870*** | −0.07333*** | −0.07305*** | 0.03615*** | 0.05957*** | −0.01671 | 0.00468*** | 2.33197***  | 74,257      | 0.24     |

Standard errors in parentheses *** p < 0.01, ** p < 0.05, * p < 0.1
Dependent variable: total fuel and power purchase per turnover, all coefficients are standardised
The model includes year and 3-digit industry dummies, which are not reported

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19 Statistical significance of this result generally disappears when removing outliers from the data set.
efficient technologies before becoming exporters. Alternatively, as Sect. 2 suggests, upon becoming exporters more energy-intensive firms may find it more profitable to adopt a higher level of technology. In order to disentangle these two effects, we employ a matching and difference-in-differences technique as suggested by Heckman et al. (1997) and Blundell and Dias (2000) to establish a causal effect of becoming an exporter on a firm’s energy consumption. Propensity score matching and difference-in-differences techniques allow us to deal with selection bias and any differences in time-invariant unobserved characteristics of firms that matching alone was unable to control for.

5.1 Empirical strategy

According to Blundell and Dias (2000), matching is a way of re-creating the conditions of a natural experiment where none is realistically available. Matching uses non-experimental data by assuming that selection into treatment, in our case exporting, is completely determined by observed variables and, conditional on these observed variables, the assignment to treatment is random. This is known as conditional independence assumption (CIA) and can be written as:

\[(Y_1, Y_0) \perp \triangledown D | X\]  

where \(\perp \triangledown\) denotes independence, \(D\) the treatment (=1) or control (=0) group, \((Y_1, Y_0)\) are the outcomes and \(X\) the observed covariates.

Conditioning on a large number of covariates \(X\), however, can present a serious dimensionality problem. The solution to this was proposed by Rosenbaum and Rubin (1983) who suggested to use propensity score which measures the probability of receiving a treatment given the observed variables. Propensity scoring therefore allows us to match the treated and the control on one number rather than across a whole range of covariates. Here we select a number of variables that predict the probability of becoming an exporter and calculate propensity scores based on those observable variables.

We do this by running probit estimations predicting the probability of becoming an exporter to see what characteristics make a firm more likely to start exporting (based on Wooldridge 2002, p. 482):

\[P(Y_{it} = 1|X_{it-1}) = G(X_{it-1}\beta)\]  

where \(Y\) equals 1 for an exporting firm and 0 otherwise and \(X\) is a set of 1 year lagged covariates used to predict a probability of becoming an exporter at a year \(t\). We additionally control for industry (at NACE 3-digit) and year effects.\(^{20}\) The probit estimations are also used to calculate propensity scores for matching.

We then match firms from the treatment group (exporters) with firms from the control group (non-exporters) based on their respective propensity scores. As it is impossible to match the scores exactly, the Nearest Neighbor Matching (NNM)

\(^{20}\) We cannot include firm-level fixed effects in a probit estimation as it leads to inconsistent estimates, see Wooldridge (2002, p. 484).
method with one neighbour and with replacement is used. Nearest Neighbor Matching chooses a firm from the control group of non-exporters that is closest in terms of propensity score to a firm in the treatment group of exporters.

Common support is also imposed to ensure there are no regions where the support of \( X \) does not overlap for the \( D = 1 \) and \( D = 0 \) (Smith and Todd 2005), in other words we exclude those firms for whom a match could not be found or whose propensity scores are too far apart from each other.

When performing matching a careful balance needs to be established between the CIA and the common support. Selecting a large number of covariates might introduce a bias due to the weakness of the common support, while adhering to a minimal number of explanatory variable will ensure the common support is not a problem but the plausibility of the CIA becomes questionable. In Sect. 5.2 we try and strike a balance between both common support and the CIA to ensure a good quality of matching.

The conditional independence assumption, however, is quite strong and it is possible some unobserved, time-invariant characteristics may influence the selection into treatment (e.g. geographic location, among other things). We therefore use a difference-in-differences estimator to remove such temporally-invariant components of bias (Heckman et al. 1997).

Therefore (based on Angrist and Pischke 2009),

\[
E(Y_{1t} - Y_{0t}|X, D = \text{exporters}) - E(Y_{1t} - Y_{0t}|X, D = \text{non - exporters}) = \delta
\]

(19)
is the causal effect of interest, or difference-in-differences estimator where \( Y \) is the outcome of a firm’s energy intensity among exporters and non-exporters. \( Y_{0t} \) represents energy intensity 1 year before a firm switches to exporting. \( Y_{1t} \) represents the outcomes of energy intensity after the switch to exporting. We utilise three specifications for this latter variable: at the first year a firm exports, at the second year of exporting and at the third year of exporting.

To establish how exporting matters for energy intensity we need to single out firms that change their exporting status from non-exporter to exporter to be able to see the causal effect of that change on their energy use. We therefore leave out all firms that always export during the sample since we do not have any pre-export information on their energy use. We also need those firms that switch to exporting to stay exporters for some time if we are to examine effects of a long-term decision to export that “phase in” over time. We thus require that firms to stay exporters for at least 3 years to be classified as such. To eliminate firms that switch more than once in our sample we require firms not to export for at least 3 years before they switch to exporting. Therefore, we focus on those firms that do not export 3 years prior to switching to exporting and then export for at least 3 years (years \( t \) to \( t + 2 \)). We contrast these firms with those that have never exported (our control group).

The procedure is then to first match firms on a number of characteristics that make them likely to become exporter in a year \( t \), select firms that have the most similar characteristics in a year \( t - 1 \) from exporter and non-exporter groups and

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21 See Caliendo and Kopeinig (2005) for further details on the quality of matching.
then examine how the energy intensity of firms that become exporters diverges from those that stay non-exporters.  

5.2 Results

To establish a pre-exporter effect on energy intensity we run a probit estimation that measures the probability that a firm exports in year $t$ based on its characteristics in $t - 1$, as in (18). Table 4, column (1) presents these results. We find no evidence that more energy-efficient firms self-select into becoming exporters. We do find that firms with more capital are more likely to become exporters. Additionally, given the range of values for size, the probability of exporting is decreasing as size increases.

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22 A caveat should be mentioned here that although matching with difference in difference allows us to control for both observable firm level characteristics and time-invariant unobservables, it is possible that subject to data limitations some time-varying firm characteristics might be omitted.

23 The choice of variables used is a combination of their significance and quality of matching. Tables 11, 12 and 13 in the “Appendix” assess the quality of matching by reporting $t$-tests that indicate that there are no statistically significant differences in the means of variables used to calculate the propensity scores.
Similar to McCann (2009) and International Study Group on Exports and Productivity (2008) who also use Irish firm-level data, we do not find that more productive firms self-select into exporting. This is in contrast to studies such as Bernard and Jensen (1999) who find that more productive firms self-select into exporting. As such, this may represent an unusual feature of the Irish data.

To establish what happens after a firm begins exporting, we compare the subsequent energy intensity of matched exporters and non-exporters as defined in (19) in the upper part of Table 5. The pattern afterwards is mixed and shows no significant differences in relative energy consumption of exporters compared to non-exporters.

However, as shown in Sect. 2, the patterns of energy expenditures of exporters may vary depending on an energy intensity of a firm. To test this, we divide the sample into two groups, based on their energy intensity. This division is based on unconditional quantiles of energy intensity. We cannot directly apply
any insights from the quantile regressions since they give conditional quantile functions that do not directly translate into unconditional quantiles. We therefore try out several divisions, starting with the one at the median. After splitting the sample, we find that there is a clear difference in the pattern of energy consumption of exporters based on their initial energy intensity. This difference is most plainly seen when we contrast two groups: firms up to (and including) the median quantile of energy intensity, which we refer to as low energy intensity firms, and firms from the 0.6th quantile of energy intensity onward, whom we refer to as high energy intensity firms. We then go on to repeat the same matching and difference-in-differences estimations for these low and high energy intensity firms. The results for the propensity to export are found in columns 2 and 3 of Table 4 while the changes in subsequent energy intensity are in the lower two panels of Table 5.24

While there are not any big variations between the two groups in their pre-exporting patterns, their post-exporting behaviour is clearly different, as shown in Table 5. Low energy intensity firms that start exporting increase their energy intensity relative to comparable non-exporters and this difference persists across time. This would be expected if their energy use rises due to increased production. On average, we observe an increase in energy intensity of about 20% compared to the pre-exporting year.

For high energy intensity firms that start to export we observe a decrease in energy intensity compared to comparable non-exporters, which is statistically significant in the first and the second year of exporting and of slightly higher magnitude than the increase in energy consumption of low energy intensity firms. This difference, however, becomes insignificant in the third year after exporting. This would be consistent with a setting in which high energy intensity exporting firms experience a scale effect increasing energy use but also choose to adopt greener technology, resulting in a net negative effect. If this technology either depreciates or becomes cheaper over time, in which case even non-exporters adopt it, this difference would gradually disappear. This is consistent with the observed dynamics of energy intensity of high energy intensity non-exporters.

An additional way of testing whether the observed outcome differences can indeed be attributed to, respectively, output and technology effects, we invert the focus and examine what happens when firms stop exporting as compared to firms that have never exported. Our theoretical predictions would suggest that scale effect would cease immediately when a firm stops exporting. Technology adoption, however, would have a longer lasting effect since once the fixed cost of adoption is paid a firm would continue to utilise it. By replicating the estimations used to derive the results of the last two rows of Table 5 for firms that stop rather than start exporting, as shown in Table 6, this is exactly what we find.

24 It is important to note here that these results are not derived from matching firms on the extreme ends of the distribution. Rather, results for the low energy intensity are derived from firms at slightly above the 0.20 percentile of energy intensity, while results for the high energy intensity firms are for those firms clustered at around the 0.90 percentile.
As expected, the scale effect observed above for the low energy intensity firms disappears as soon as a firm stops exporting. In contrast, the technology effect is still observed for high energy intensity firms that stop exporting for at least 2 years after exporting ceases.25

6 Robustness checks

In order to test the veracity of our primary conclusions, we performed a number of robustness checks on both the interpretations and techniques used. Some of these findings are summarised below.

- Outsourcing of transportation
  Upon becoming an exporter a firm might be more likely to outsource transportation of its goods due to the added difficulty of reaching overseas markets. In this case, the firm’s direct energy purchases would understate their actual energy usage (and thus the pollution for which they are responsible). The CIP data set provides additional information on a firm’s spending on freight

25 A caveat should be mentioned with regard to the results for firms that stop exporting. Due to CSO data collection issues, the results for the high energy intensity firms stopping exporting might be affected, although, if anything, we expect a bias towards zero outcomes.
charges which we used to check the importance of transportation outsourcing. Both low and high energy intensity firms outsource transportation significantly more after starting to export. The difference between the two groups, however, is small and not high enough to suggest that it affects one group significantly more than the other. As a next step we added outsourced freight charges to the expenses on energy to account for any potential outsourcing influence. Using this alternative measure of environmental performance, we find that the results are qualitatively unchanged for the low energy intensity firms with a higher magnitude of the output effects but the negative dynamics of exporters’ energy use becomes insignificant for the high energy intensity firms. Thus, although we do not find the reductions for high energy intensity firms we find that, unlike low energy intensity firms, they do not increase expenditures on energy and shipping when they begin exporting. Since the theory only implies that the rise in total expenditures should fall as energy intensity rises, not that it be negative, this is again consistent with our model.

- Increased import of inputs
Another alternative explanation of the technology effect might be the increasing reliance of exporters on imported inputs which would lead to a lower energy use. It is possible that firms develop international ties after starting to export and begin importing more of their inputs and this might bring their relative energy use down significantly. This increase in import intensity would then have to be much stronger for high energy intensity firms than for low energy intensity ones for it to substitute for a technology effect. The former group might be more prone to import inputs given that energy constitutes a large share of their costs. However, we find this not to be the case. First, the import intensity of low energy intensity firms is on a higher level than that of high energy intensity firms. Moreover, the observed growth of inputs importing is of the same magnitude for both low and high energy intensity firms when averaged over 3 years exporting time and the dynamics of the changes year on year is very similar. Second, and more important, we observe import intensity to rise quite notably in a second year of exporting while the significant changes in relative energy use are already observed in the first year for both types of firms. This suggests that technology effects cannot be attributed to an increased import of inputs.

- Kernel matching
To test the robustness of Nearest Neighbor Matching with one neighbour we double check the results with kernel matching since Caliendo and Kopeinig (2005) suggest using it where the number of comparable control observations is large, as is the case in our sample. Qualitatively, the kernel matching results are unchanged with the magnitudes of the effects somewhat smaller overall.

- Alternative exporter definitions
An alternative definition of exporters is also tried out where export starters are defined as firms that do not export for 2 years and then export for two

26 Note that here firms are divided into lower and upper quantiles of the sum of energy and freight costs relative to turnover rather than energy costs alone.
consecutive years. Such an abridged definition might introduce volatility since some firms change their exporting status more than once and one might expect that it is longer term exporting plans that would have a stronger and more pronounced effect. The main results, however, stay unchanged.

– Absolute energy use
In the above analysis, we use energy use relative to sales as our dependent variable. As an alternative, we repeated our estimation using absolute, rather than relative, energy use. When doing so, we found comparable results: i.e. exporting increases energy use for firms that use small amounts of energy, reduces it for firms using large quantities of energy, and that these changes are largely driven by changes while exporting. The only distinction is that we observe a self-selection effect of more energy-efficient firms into exporting among big energy users.

– Outlying observations
To make sure extreme control variable values are not driving the results, we have removed the top and bottom 0.1% of observations and all negative values of capital, some of which are so by construction of this variable. Our main findings are mainly unaffected, although matching estimation outcomes lose some of their statistical significance though retaining the observed signs.

– Capital intensity
To account for capital intensity of a firm which may more likely be a determinant of energy intensity than total capital, we re-ran all estimations using the capital/labour ratio instead of total capital. Quantile estimations produce very similar outcomes. Matching findings lose their significance although retaining their signs. Since capital intensity might be strongly correlated with the industry a firm is in, when we repeat the matching estimations taking out controls at NACE 3-digit level, matching results return to the previous levels of significance.

7 Conclusions
One of the greatest concerns over globalisation and trade openness is the impact on the environment. This paper contributes to this debate by examining the relationship between a firm’s decision to export and its energy use. Our theoretical model predicts a positive correlation between exporting and energy expenditures for low energy intensity firms and a smaller or even a negative correlation for high energy intensity firms. This is because for low energy intensity firms exporting creates only a scale effect through which increased production increases energy use. For high energy intensity firms, this is at least partially offset by the adoption of greener technology made profitable because of the increased market size. We confirm this empirically using a panel firm-level data set on Irish manufacturing firms for 1991–2007. This suggests that studies using aggregated data or firm level data with a focus entirely on mean effects may miss important links between globalisation, energy use, and the environment.
Although neither our model nor our estimates speak directly to policy implications, our results suggest that the energy use implications of trade liberalization are likely to be complex. If trade barriers are lowered in energy intensive industries, our estimates suggest that the associated change in energy consumption is likely to be lower than when barriers are removed in a less energy-intensive industry. Similarly, the mix of energy-intensities within an industry would affect the net change in usage because of differing technology adoption rates within a sector. Furthermore, although if energy use rises on net pollution too will rise (as shown by correlation between the two in Eskeland and Harrison 2003; Cole et al. 2008), trade liberalisation can induce improved pollution abatement, expansion in renewable energy, and other changes which would mitigate the environmental impact. Although such analysis is beyond the scope of this paper, we hope that our estimates provide a useful framework for the continuing debate.

Appendix

See Tables 7, 8, 9, 10, 11, 12, and 13.

Table 7  Baseline values for simulations

| Variable | Interpretation                      | Baseline value |
|----------|-------------------------------------|----------------|
| $F$      | Fixed cost of a domestic plant      | 0              |
| $F_x$    | Fixed cost of exporting             | 10             |
| $P$      | Domestic price index                | 2              |
| $I$      | Domestic income                     | 15             |
| $P^*$    | Foreign price index                 | 4              |
| $I^*$    | Foreign income                      | 30             |
| $\sigma$| Elasticity of substitution          | 3.8            |
| $\tau$  | Energy use for exporting            | 1              |
| $b(i)$  | Productivity parameter              | 1              |
| $r$      | Cost of fuel                        | 1              |
| $w$      | Wage rate                           | 1              |
| $t_H$   | High technology parameter           | 1.08           |
| $t_L$   | Low technology parameter            | 1              |
| $\gamma(t_H)$ | High technology cost | 2.1            |
| $\gamma(t_L)$ | Low technology cost    | 0              |
### Table 8  List of NACE 2-digit industries in the census of industrial production (CIP)

| NACE code | Description                                                                 |
|-----------|-----------------------------------------------------------------------------|
| 15        | Manufacture of food products and beverages                                  |
| 16        | Manufacture of tobacco products                                             |
| 17        | Manufacture of textiles                                                     |
| 18        | Manufacture of wearing apparel; dressing and dyeing of fur                  |
| 19        | Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, |
|           | harness and footwear                                                        |
| 20        | Manufacture of wood and of products of wood and cork, except furniture;     |
|           | manufacture of articles of straw and plaiting materials                    |
| 21        | Manufacture of pulp, paper and paper products                              |
| 22        | Publishing, printing and reproduction of recorded media                     |
| 23        | Manufacture of coke, refined petroleum products and nuclear fuel            |
| 24        | Manufacture of chemicals and chemical products                             |
| 25        | Manufacture of rubber and plastic products                                 |
| 26        | Manufacture of other non-metallic mineral products                          |
| 27        | Manufacture of basic metals                                                 |
| 28        | Manufacture of fabricated metal products, except machinery and equipment    |
| 29        | Manufacture of machinery and equipment n.e.c.                              |
| 30        | Manufacture of office machinery and computers                              |
| 31        | Manufacture of electrical machinery and apparatus n.e.c.                    |
| 32        | Manufacture of radio, television and communication equipment and apparatus  |
| 33        | Manufacture of medical, precision and optical instruments, watches and     |
|           | clocks                                                                     |
| 34        | Manufacture of motor vehicles, trailers and semi-trailers                  |
| 35        | Manufacture of other transport equipment                                    |
| 36        | Manufacture of furniture; manufacturing n.e.c.                              |

### Table 9  Definition of variables

| Variable               | Description                                                                                                                                                                                                 |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Relative energy use    | Total fuel and power purchase as declared by firms in the CIP, scaled down by total turnover.                                                                                                             |
| Exporter               | Dummy variable equal to 1 if a firm exports in any given year and 0 otherwise. For matching estimations exporters are defined as firms that switch to and stay exporting: firms that do not export 3 years prior to switching to exporting and then export for at least 3 years. |
| Ownership              | Dummy variable equal to 1 if a firm is foreign-owned and 0 if it is a domestic firm.                                                                                                                       |
| Labour productivity    | Total turnover divided by the number of employees.                                                                                                                                                         |
| Size                   | Total earnings (in constant thousand of euros).                                                                                                                                                            |
| Skill                  | % of managerial/technical and clerical personnel in total employment.                                                                                                                                     |
| R&D                    | Research and development services supplied to the enterprise.                                                                                                                                               |
| Freight costs          | Freight charges for transport of the firm’s products.                                                                                                                                                      |
| Capital                | Firm’s capital additions built over the whole period minus sales of capitals assets, assuming 10% yearly depreciation rate overall.                                                                      |
$t$-tests for Sect. 5.2 comparing sample means of the treated and control groups to assess the quality of propensity score matching performed. Both tables indicate that there is no statistically significant difference in the means of variables used to calculate the propensity score.

Table 10  Summary statistics, manufacturing

| Variable                  | Mean   | SD     | Min    | Max     |
|---------------------------|--------|--------|--------|---------|
| Total energy use          | 120.72 | 853.57 | 0      | 66,043.99 |
| Energy per turnover       | 0.015  | 0.021  | 0      | 1.356   |
| Export share              | 25.86  | 36.48  | 0      | 100     |
| Total turnover            | 18,240.99 | 203,343.73 | 0 | 12,670,647 |
| Size                       | 1,370.54 | 5,144.87 | 0      | 257,530.28 |
| Total employed            | 50.42  | 143.66 | 0      | 4,554   |
| Labour productivity       | 151.71 | 373.58 | 0      | 16,062.42 |
| % High-skilled            | 25.09  | 18.87  | 0      | 100     |
| Capital                   | 2,726.69 | 38,761.71 | $-93,586.49$ | 4,326,626.5 |
| R&D                       | 384.16 | 12,639.16 | 0      | 1,386,157 |
| Energy and freight charges| 330.84 | 2,087.33 | 0      | 195,178.77 |
| Energy and freight per turnover | 0.033  | 0.037  | 0      | 1.935   |

All monetary values are in thousands of euros

Table 11 All manufacturing firms, $t$-test

|                        | Treated | Control | $t$-test |
|------------------------|---------|---------|----------|
| Energy intensity$_{t-1}$ | 0.01553 | 0.01611 | $-0.52$  |
| Labour productivity$_{t-1}$ | 101.73 | 101.42 | 0.03     |
| Size$_{t-1}$            | 611.55  | 710.87  | $-0.94$  |
| $\text{Size}^2_{t-1}$   | 1.9e+06 | 3.2e+06 | $-1.01$  |
| Capital$_{t-1}$         | 672.92  | 865.16  | $-0.80$  |
| Ownership$_{t-1}$       | 0.01867 | 0.02133 | $-0.26$  |
| Skill$_{t-1}$           | 25.215  | 24.827  | 0.30     |

Table 12 Low energy intensity firms, $t$-test

|                        | Treated | Control | $t$-test |
|------------------------|---------|---------|----------|
| Energy intensity$_{t-1}$ | 0.00521 | 0.00558 | $-0.81$  |
| Labour productivity$_{t-1}$ | 113.06 | 123.32 | $-0.57$  |
| Size$_{t-1}$            | 694.89  | 541.81  | 1.04     |
| $\text{Size}^2_{t-1}$   | 1.2e+06 | 8.4e+05 | 0.64     |
| Capital$_{t-1}$         | 404.76  | 514.23  | $-0.65$  |
| Ownership$_{t-1}$       | 0.05    | 0.08333 | $-0.73$  |
| Skill$_{t-1}$           | 30.646  | 33.572  | $-0.65$  |

$t$-tests for Sect. 5.2 comparing sample means of the treated and control groups to assess the quality of propensity score matching performed. Both tables indicate that there is no statistically significant difference in the means of variables used to calculate the propensity score.
Table 13 High energy intensity firms, t-test

|                                | Treated | Control | t-test |
|--------------------------------|---------|---------|--------|
| Energy intensity_{t-1}         | 0.03249 | 0.03235 | 0.03   |
| Size_{t-1}                     | 444.58  | 414.22  | 0.34   |
| Size_{t-1}^2                   | 4.4e+05 | 3.8e+05 | 0.34   |
| Capital_{t-1}                  | 506.4   | 416.7   | 0.40   |
| Labour productivity_{t-1}      | 73.171  | 82.007  | −0.72  |
| Skill_{t-1}                    | 18.27   | 17.32   | 0.46   |
| R&D_{t-1}                      | 2.1859  | 0.56206 | 1.43   |

High energy intensity firms—firms from 0.6th quantile of energy intensity upwards

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