The energy-efficient transformation of EU business enterprises: Adapting policies to contextual factors

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Abstract

Business contexts differ in their ability to foster the energy-efficient transformation (EET) of enterprises. Accordingly, energy efficiency policies have to be adapted to different situations. The present paper analyzes the relationships between the EET of European Union (EU) business end-users and three contextual factors, i.e. high energy prices, stringency of regulations, and society's alertness toward environment conservation. Enterprises from 9 EU Member States have been grouped according to country, industry and size. The final sample includes 256 enterprise classes, and the model controls for the innovation propensity and energy intensity of each enterprise class. Our results show that regulatory stringency is the most impactful contextual factor, while the environmental alertness of society does not have a significant effect. Concerns over energy costs have not been found to drive EET per se, but more energy-intensive enterprise classes are more likely to react to high energy prices. We discuss the implications of our results for the EU governments that are currently monitoring and refining the transposition of the 2012 Energy Efficiency Directive.

Highlights

- Regulatory stringency drives the energy-efficient transformation of EU enterprises
- Society's alertness toward environment does not have a comparable impact
- More energy-intensive enterprises are more likely to respond to energy prices
- Prescriptive elements of the EU Energy Efficiency Directive play a key role
- EU policymakers should assess the effects of supportive information measures

Keywords

Energy efficiency; European Union; business enterprises; energy price; alertness; regulatory stringency

1. Introduction

The European Union (EU) is committed to saving 20% of its primary energy consumption by 2020, compared to the business-as-usual projection, and has set an even more ambitious target for the longer term, i.e. a 27% saving by 2030 (European Council, 2014). Great emphasis is currently put on enhancing the energy efficiency of transport and buildings, in part because the EU business sector has already made substantial progress over the last 25 years (European Commission, 2014). However, the energy efficiency of EU business enterprises is not a solved issue. Industry, services and agriculture enterprises account for 42% of the EU's final energy consumption (Eurostat, 2016), but entire industries and countries lag behind the energy efficiency frontier (Odyssee-Mure, 2015a; International Energy Agency, 2016, pp. 24-29).

The Energy Efficiency Directive (EED, Directive 2012/27/EU) is the overarching act for EU business in this area (Section 2). EU policymakers are currently engaged in an adaptive process, as they have to set, monitor and refine their national energy efficiency plans. With the purpose of supporting their effort, this paper investigates the contextual factors that drive the energy-efficient transformation (EET) of EU business operations. Sections 2 and 3 will discuss and operationalize the definition of EET, but in general terms a business enterprise is engaged in EET when it undertakes innovations that reduce the energy consumed to produce the output.

This paper analyzes the role of the following three contextual conditions: high energy prices, stringency of regulations, environmental attentiveness and activism in society. A thorough analysis of the quantitative significance of the market, regulatory and social drivers that may have spurred business EET in Europe in recent years is missing, although we believe such an analysis could provide policymakers with helpful insights on the policy mechanisms that better cope with specific business environments.

On the one hand, a large amount of literature is devoted to the firm-specific characteristics that determine energy efficiency advances, such as size, managerial capabilities and innovation propensity (DeCanio and Watkins, 1998; Rennings and Rammer, 2009; Bloom et al., 2010; Sorrell et al., 2011;

Martin et al., 2012; Costa-Campi et al., 2015). However, despite their importance in managerial decision-making, firm-specific characteristics can be the target of policies only to a limited extent. Energy policies instead have the responsibility of making business environments more conducive to EET, by offering an appropriate support to the components of business environments that are found to foster EET and by remedying the failures of other components.

On the other hand, while many EET studies focus on firm-level determinants, relatively fewer works have analyzed contextual conditions, and these few have been addressing energy prices (Popp, 2001; Linn, 2008) and regulations (Horbach et al., 2012; Martin et al., 2012; Veugelers, 2012; Costa-Campi et al., 2015; Trianni et al., 2016). We include these factors in our model, but we also verify whether society's alertness toward environment conservation has any effect. Business enterprises could undertake EET not only to reduce their operational costs and to comply with regulatory pressures, but also to enhance their reputation with non-governmental organizations, the media and citizens at large, thanks to two positive EET externalities, namely emission abatement and enhanced security of supply. Unlike other environmental innovations (Berrone et al., 2013; Brunnermeier and Cohen, 2003; Khanna and Damon, 1999), business EET has not been examined as a means of coping with attentive and activist social stakeholders.

The model focuses on the relationship between EET and the three components of business context, i.e. energy price, regulations, and society's alertness, but it also controls for the influence of internal drivers, such as a firm's innovation propensity, energy intensity and size. The considered unit of analysis is the "enterprise class", i.e. the group of firms belonging to the same size class (SMEs with less than 250 employees v. larger enterprises), operating in the same industry (across 21 industries) and located in the same country (across 9 EU economies). The heterogeneity of this empirical test-bed increases the variation of contextual factors and augments the generalization potential of the analysis (Jeswani et al., 2009). The present paper measures EET, contextual conditions and control variables across very different countries, industries and size categories, in this way arguably ensuring a greater external validity to the findings. To this aim, 43,110 firms, surveyed in the sixth wave of the

Community Innovation Survey (2009), have been classified. The reasons for using this CIS wave are explained in the subsequent sections. The final sample includes 256 different classes of business enterprises. Coherently with our definition of EET, class-level EET is measured as the percentage of all the class enterprises that have reduced their own energy use thanks to process, product, organizational and marketing innovations. We analyze the relationship between EET and its determinants through a Generalized Linear Model (GLM) for grouped data, and check the robustness of results by modeling the contextual conditions in different ways. Finally, we use the model coefficients to simulate the response of a business sector to contextual factors, other things being equal. These simulations allow us to pinpoint the strengths and weaknesses of different business contexts, and to make recommendations on policy support mechanisms tailored to each specific business environment.

The rest of the paper is organized as follows. The recent literature on EET is presented, and EU energy efficiency policies for business end-users are reviewed (Section 2). The empirical methodology is then illustrated (Section 3), and this is followed by the presentation of the estimates, simulations, robustness analyses and a discussion of the empirical findings (Section 4). Finally, some implications for energy efficiency policies are discussed (Section 5).

2. Literature survey and policy overview

The present section reviews the pre-existing research on external and internal EET determinants, and introduces society's alertness as an additional factor. It then summarizes the EU policy framework for the energy efficiency of business end-users.

In the following, we assume that a firm undertakes an EET of its operations whenever it decreases its energy intensity, that is, given its output, it reduces the energy consumed, or given the energy consumed, it increases its output (International Energy Agency 2014). EET may be triggered by innovations of various nature, but it is an instance of process innovation.[1]

2.1. Contextual factors and internal drivers

Among the contextual factors that spur enterprises toward energy efficiency, energy prices and regulations have been studied extensively. According to the “induced-innovation” view (Newell et al., 1999; Rose and Joskow, 1990; Jaffe and Stavins, 1995), EET is the response of profit-maximizing firms to current and expected changes in energy price and regulations.

Popp (2001) finds a significant and negative response of the United States (US) industries’ consumption to energy price changes. Linn (2008) concludes that energy price increases lead to a small but significant reduction in the energy intensity of US manufacturing plants, but only for new entrants. Business enterprise that expect to reap cost savings or to face rising energy prices are more likely to conduct EET activities (Horbach et al., 2012; Trianni et al., 2016).

As far as energy and climate regulations are concerned, business surveys conducted in different countries return a mixed picture. Veugelers (2012) finds that voluntary agreements, public financial support and future regulations are powerful drivers of innovations that reduced energy consumption in Flemish firms, particularly if maintained over time and combined with taxes that increase energy prices. Horbach et al. (2012) do not find any correlation between the present and future regulations and energy-efficient process innovations of German firms. Martin et al. (2012) demonstrate that management practices play a more significant role than policies in energy efficiency of UK manufacturing plants. Costa-Campi et al. (2015) show that the energy-efficient innovations of Spanish firms are associated with public financing and unrelated to the importance attributed to regulatory requirements. Trianni et al. (2016) show that the ease of financing and regulatory restrictions are important factors for Italian manufacturing SMEs.

[1] Other studies addressed the invention and supply of energy-saving products and technologies (Newell et al., 1999; Popp, 2002; Verdolini and Galeotti, 2011; Rexhäuser and Löschel, 2015).

A third type of contextual factor, namely the degree to which business enterprises respond to the pressure of social stakeholders, is absent from the literature on business EET. Enterprises could in fact undertake EET efforts to enhance their reputation with social groups such as the media, NGOs, and citizens at large, and to behave as "good corporate citizens" who reduce emissions from the use of fuels and enhance their country's energy security.

Environmental management literature has long argued that enterprises enhance their own environmental performances in response to society's pressures and for discouraging adverse information campaigns (Buysse and Verbeke, 2003; Kassinis and Vafeas, 2006; Lyon and Maxwell, 2008). For instance, some firms introduce pollution control mainly to gain public recognition and legitimacy (Khanna and Damon 1999), while they attach less importance to the pressures of regulatory agencies (Brunnermeier and Cohen 2003; Kassinis and Vafeas, 2006). Horbach et al. (2012) and Veugelers (2012) find that EET innovations are associated with the customers' demand for environmental innovation, but the reasons for associating the "green-demand" pull with the EET of enterprises are not as clear.

To what degree external stakeholders are aware of the energy efficiency of internal business operations, and business enterprises undertake their own EET as a response to stakeholders is a research question that we will investigate in the remaining part of the paper.

Finally, several studies have examined the following EET internal drivers in detail (see the reviews by Gillingham et al., 2009, and Sorrell et al., 2011): the firm's size and economic performances (DeCanio and Watkins, 1998; Rennings and Rammer, 2009; Trianni and Cagno, 2012; Costa-Campi et al., 2015), its organizational and managerial capabilities (Bloom et al., 2010; Horbach et al., 2012; Martin et al., 2012; Cagno et al. 2015; Costa-Campi et al., 2015; Gerstlberger et al., 2016; Trianni et al., 2016), its commitment to environmental targets and innovation activities (Rennings and Rammer, 2009; Horbach et al., 2012; Costa-Campi et al., 2015; Cagno et al., 2015; Gerstlberger et al., 2016).

2.2. EU energy efficiency policies for business end-users

This sub-section summarizes the main EU policies for the EET of business end-users in recent years.

Wide consensus exists on the necessity of keeping energy efficiency among the policy priorities. The main motivations are climate change mitigation and enhanced security of supply (Doris et al., 2009; International Energy Agency, 2009, 2012; European Commission, 2014), even though the significance and causes of the so-called energy efficiency gap are still debated (Gillingham et al., 2009; Ley, 2010; Odyssee-Mure, 2015a).

The 2012 Energy Efficiency Directive (EED, 2012/27/EU) is the main instrument currently used to pursue the 2020 energy saving target, i.e. a 20% overall reduction in primary energy consumption, and it covers all /end-user sectors, with the exception of transport (Odyssee-Mure, 2015b). This directive repealed the 2006 Energy End-use Efficiency and Energy Services Directive (ESD, 2006/32/EC), which exerted a similar function during the timeframe analyzed in the research (2006-’08).[2]

Four main types of instruments influence the energy efficiency of a business process.[3]

– *Energy saving targets.* The EED sets a binding energy saving target for all EU countries. The Member States should achieve new energy savings that will be equivalent to a reduction of 1.5% in their annual energy sales over each year, from 2014 to 2020. Savings that have occurred in the industrial activities that are included in the Emissions Trading Scheme are not considered. The target was indicative and looser under the ESD (non-binding 1% target). EU countries can choose different strategies to meet the obligation, and have to report sub-targets and planned measures in their National Energy Efficiency Action Plans every three years.

[2] See Kanellakis et al. (2013) for a review of EU energy policies at the time of EED approval. Geller et al. (2006) review the earlier phases of the energy efficiency policy (from the mid - 1970s to the early 2000s) in Japan, the United States and Western Europe.

[3] Another pool of measures tackles the energy efficiency of products, i.e. Ecodesign Directive (2009/125/EC), Energy Labelling Directive (2010/30/EC), STAR programme (2001).

- *Obligation schemes and alternative measures*. Under the EED, governments can designate energy retailers and distributors to help customers of any sector improve their energy efficiency, or to present certified savings achieved by energy service providers (Zygierewicz, 2016). Energy companies were assigned a similar role under the ESD, but without a proper mandate. Alternatively, or in combination with the obligation scheme, governments can issue and implement other policies to achieve the target, i.e. energy or carbon taxes, financial incentives, regulations, energy labeling, training, education and advice instruments, and voluntary agreements. So far, 16 EU countries have adopted an obligation scheme, along with financing incentives and taxes, thus ensuring the largest share of the overall savings (Zygierewicz, 2016, pp. 17-18). The actual additionality of measures is a source of criticisms of both ESD and EED (Zygierewicz, 2016, p. 16).
- *Energy audits and energy management systems (EMSs).* The EED promotes the use of high-quality and cost-effective energy audits and EMSs (Brems et al., 2016). Larger enterprises have to undergo an energy audit at least every 4 years, after applying for certified EMSs. Governments have to encourage SMEs to undertake energy audits, also through subsidies for audit-related costs borne by those SMEs that participate in voluntary agreements. The offer and promotion of energy audits was one of the possible choices available to energy companies under the ESD.
- *Metering, billing and information programs*. EU countries should take action to inform energy customers about their actual consumption. Billing should be offered free of charge, and individual meters that inform the user about the actual time of use should be offered in the case of new or renovated buildings. Governments should also promote information programs that spur small energy customers toward behavioral change, through instruments that range from fiscal incentives to exemplary projects.

Table 1 summarizes the policy overview in accordance with Tanaka (2011), who categorize energy efficiency policies for industry as *prescriptive*, *economic* or *supportive*.

<< Table 1 around here >>

3. Methodology

3.1. Dependent variable and sample

For the purpose of our research, we have built an indicator of the importance of EET across the EU business sector, *EET*. First, to this aim, we accessed the microdata of the 2009 Community Innovation Survey (CIS-VI) for 43,110 enterprises located in 9 countries, i.e. the Czech Republic, Germany, Estonia, Hungary, Ireland, Italy, Latvia, Portugal and Slovakia.[4] Differently from old and newer CIS versions, the 2009 CIS survey (CIS-VI) includes a whole section focusing on environmental benefits of innovation. Specifically, one question asks whether the respondent enterprise has obtained a *"reduced energy use per unit of output"* benefit from any product, process, organizational or marketing innovation introduced in the 2006-'08 period. We identified all the enterprises that undertook an innovation of any kind that resulted in the enhancement of its energy efficiency.[5] Second, the considered unit of analysis is the enterprise class. We grouped together EU enterprises that are located in the same country, operate in the same industry, and belong to the same class size (SMEs with less than 250 employees v. larger enterprises; a finer distinction was used in a robustness check). Our dependent variable, *EET*, is the number of enterprises in a class that have enhanced their energy efficiency over the total number of enterprises belonging to that class.

The use of grouped survey data helps alleviate concerns stemming from the possible inaccuracy of information self-reported by respondents (Sutton and Godfrey, 1995). Grouping of the CIS-VI micro-data is also necessary in order to be able to include energy intensity in the model. This key variable is not available at a firm level for CIS enterprises. We collected data on energy expenditures

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[4] The Community Innovation Surveys (CIS) are a series of harmonized surveys executed by national statistical offices throughout the European Union and in Norway and Iceland. Eurostat executed sample stratification with respect to the sector of a firm's activity and a firm's size. An overview of the survey type and other sampling and response characteristics is laid out in Eurostat (2008a: Table 2). Information on energy-efficient innovations has already been used in single-country studies (Rennings and Rammer, 2009; Veugelers, 2012; Horbach et al., 2012; Costa-Campi et al., 2015).

[5] The question of interest is "During the three years 2006 to 2008, did your enterprise introduce a product, process, organizational or marketing innovation with any of the following environmental benefits?" A list of "Environmental benefits from the production of goods or services within your enterprise" is then given. We only considered an enterprise to have undertaken an energy-efficient enhancement of its operations, when the respondent answered "Yes" to the item "Reduced energy use per unit of output".

per unit of value added at the class level from another source (EU Klems Database; see Section 3.2). Both CIS-VI and EU Klems use NACE Rev. 2 as an industry classification (Eurostat, 2008), but they overlap in a consistent way only after the grouping of a few neighboring industries (Table 2). We were able to obtain data on 21 industries, with some missing data across countries. The final sample includes 256 enterprise classes.

<< Table 2 around here >>

3.2. Explanatory and control variables

The independent variables of the model are summarized in Table 3. Information about the central explanatory variables was from data sources different from the CIS-VI dataset. Considering a multiplicity of data sources alleviates the possibility of a Common Method Bias (Chang et al., 2010). In order to reduce the endogeneity risks, the core explanatory variables were observed over the pre-sample period.

<< Table 3 around here >>

Energy price, *EPrice*, is proxied by the country's electricity price, which is taken from the Eurostat Energy Price Statistics.[6] The electricity prices are averaged over the pre-sample 6-semester period, to cope with endogeneity risks and because EET decisions are driven by expectations about future energy prices (Jaffe et al., 2004), which in turn depend on past prices. We also used an alternative price indicator that varies across countries and size classes to check the robustness of results (Section 4.2). The energy intensity of an enterprise class clearly moderates the class's EET response to a variation in energy prices, but no energy intensity data were available at a class level. However, we drew *EES*, the energy expenditure share, or energy expenditures per unit of value added, from the EU Klems Growth and Productivity Accounts Database (O'Mahony & Timmer, 2009, Timmer et al., 2007, http://www.euklems.net/), and added it to the model variables. The dependence of *EES* on

[6] Newell et al. (1999) use electricity prices relative to an input price index. Popp (2002), Linn (2008) and Verdolini and Galeotti (2011) use the Energy Information Agency (EIA), his own and International Energy Agency (IEA) indexes of energy prices, respectively.

energy intensity can be made explicit in a simple way by assuming that the electricity, gas and other energy product markets are mutually linked in each individual EU country. Moreover, energy intensity was assumed to be exogenous, with respect to the energy price, as any possible enhancement of energy efficiency, in response to an increase in energy prices, takes time to unfold. In this framework, *EES* can be expressed as the product of the energy price and energy intensity, a property that was used for simulation purposes (see the equation (2) in Section 3).[7]

We proxy the stringency of the environmental regulations on business (*RegString*) with the indicators that are published annually in the Global Competitiveness Reports of the World Economic Forum (2004, 2005, 2006). The score goes from 1 to 7 (with 7 being the maximum). This information is based on the opinion of experts in industry, and is generally correlated to objective information on governmental regulations (Nicoletti and Pryor, 2006; Blind, 2012).

Next, we operationalized society's alertness toward environment conservation, i.e. the third contextual factor, through a measure of the public's attentiveness toward the environment (*PubAtt*). The construction of the *PubAtt* variable was carried out using a novel approach, i.e. a type of web-crawling method, which takes advantage of a publicly available Search Volume Index (SVI), created by means of the Google Trends facility (Gbadji et al., 2011; Ripberger, 2011). We focused on the search term "*environment*", translated by EuroVoc in local languages of all the sample countries.[8] *PubAtt* accounts for the percentage of Google web searches of the given term, compared with the total number of Google searches conducted in a country during the 2004-'06 period. In this way, we allowed some time for information internalization and execution. Consistently with the relative notion of attentiveness, the *PubAtt* measure was considered relative to the importance of the Google searches

[7] For exposition purposes, the consumption of different energy products f^v $(v = 1, ... F)$ is expressed in one energy unit, e.g. kWh. Under the assumption of integrated energy markets, the unitary prices p^v converged, on average and over an appropriate time window, to the same price *p* expressed in, e.g., Euro per kWh. *EES* is the ratio between expenditures for the consumption of all the different energy products, i.e. $\sum_1^F p \cdot f^v$, and the value added *VA*. As energy intensity *EI* is the ratio between the energy consumed, i.e. $\sum_1^F f^v$, and the value added *VA*, it is possible to conclude that *EES* = p · EI.

[8] EuroVoc is a multilingual, multidisciplinary thesaurus that covers the activities of the European Union, and which contains terms in 23 EU languages (see http://eurovoc.europa.eu/drupal/).

in the country and over the considered period. As a robustness check, we constructed two other proxies of society's alertness, and estimated alternative models (Section 4.2).

Our model follows the pre-existing research on internal EET determinants (see Section 2) and, along with the class's *EES*, controls for innovation propensity. *PrInn* is the percentages of class enterprises that introduced any kind of process innovation in the timeframe of interest. The degree to which process innovations diffuse within the enterprise class is expected to capture most of the unobserved innovation heterogeneity between countries, industries, and class sizes, i.e. unobserved variables, that is, market structure, sector appropriability, economies of scale in innovation and R&D intensity. Another important control variable is the size effect (*Size*). This is a dichotomous variable that equals 1, if the group is made up of firms with 250 or more employees (LEs) and 0, if the group is made up of firms with less than 250 employees (SMEs). Small enterprises will be distinguished from medium enterprises as a robustness check (Section 4.2). As a fixed size effect, it captures the remaining EET barriers associated with the size of the smaller firms (see Section 2).

We are not able to introduce 21 distinct industry fixed effects, due to the small size of the sample, but we were still able to_eliminate the main unobserved structural and behavioral factors that characterize each of the main business sectors, i.e. industry, construction, transportation, energy utilities and services. The model includes four binary variables (see Table 2), i.e. *DInd* (Nace Rev. 2 classes: B, C, E), *DConstr* (F), *DTransp* (H) and *DEnutil* (D) (services act as the baseline).

Summary statistics were computed for all of the variables included in the sample before they were standardized, and the results are shown in Table 4. It is possible to note the great heterogeneity of both EET and the innovation performances in the sample. Certain enterprise classes virtually do not carry out any innovation or EET, while in other classes, almost all the enterprises innovate or perform EET. Moreover, a comparison between the *PrInn* and *EET* mean values suggests that a large number of innovations may result in EET.

<< Table 4 around here >>

The correlation matrix is laid out in Table 5. While no unexpectedly high correlations can be observed, most of the correlation statistics are significant. A Variance Inflated Factor test was run in the subsequent econometric analysis in order to assess the risk of multicollinearity.

<< Table 5 around here >>

3.3. Model specification

We modeled $\boldsymbol{EET}$, the probability that the class enterprises enhance their energy efficiency through various kinds of innovation, using a Generalized Linear Model (GLM). GLM is considered to be the most appropriate estimation method for grouped data, when the dependent variable is a percentage, and extreme values (0 and 100 percent) are possible (Baum, 2008).[9] Our model is described in Equation 1.

$$\boldsymbol{EET_{ijk} = \alpha + \beta_1 \cdot EPrice_i + \beta_2 \cdot EES_{ij} + \beta_3 \cdot RegString_i + \beta_4 \cdot PubAtt_i + \beta_5 \cdot PrInn_{ijk} + \beta_6 \cdot Size_k + \beta_7 \cdot DInd_j + \beta_8 \cdot DConstr_j + \beta_9 \cdot DTransp_j + \beta_{10} \cdot DEnutil_j + u_{ijk},} \quad (1)$$

i stands for a country, j stands for an industry and k stands for a size class. β_1, β_3, and β_4 are the coefficients of core explanatory variables, and capture the dependence of *EET* on energy price (*EPrice*), stringency of regulations (*RegString*) and alertness of society (*PubAtt*). Likewise, β_2, β_5 and β_6 capture the effect of control variables, i.e. *EES, PrInn* and *Size*, on *EET*. Finally, the model constant varies across sectors, and is given by the sum of α and the coefficient of the sector-specific binary variable , i.e. β_7, β_8, β_9, or β_{10}.

Since a realistic variation of a non-normalized variable is its standard deviation (Table 4), a realistic variation of the normalized variables is equal to 1. As a consequence, coefficients from β_1 to β_6 are the estimates of the first-order effect of a "credible" change in independent variables on *EET*, other things being equal. In addition, β_2 captures a second-order effect of *EPrice*, because it brings the moderation role of energy intensity in the model. In fact, *EET* depends on *EPrice* also through

9 GLM is estimated by means of an option that allows the standard intragroup correlation errors to be considered, and this makes it possible to relax the typical requirement of independent observations. This option yields more realistic standard errors and does not influence the estimated coefficients.

EES, which is the product of the energy price and energy intensity variables (see Section 3.2). The response of *EET* to *EPrice* is a combination of its coefficient estimate and an indirect effect. As the variables are normalized, the overall *EET* change, in response to a credible variation in *EPrice*, other things being equal, can be expressed as:

$$\Delta EET = \beta_1 + \beta_2 \cdot \frac{\sigma^{EPrice}}{\sigma^{EES}} \cdot EI, \tag{2}$$

where β_1 and β_2 stand for the coefficients of *EPrice* and *EES*, respectively, and σ^{EPrice} and σ^{EES} are their standard deviations (Table 4); *EI* is the energy intensity, which can be computed from *EPrice* and *EES*.

Finally, the model constant might predict the *EET* value when all the independent variables simultaneously take a null value. Nevertheless, this situation lies outside the region of observed enterprise classes, and the model constant does not have any implications for our analysis.

4. Empirical results

The GLM estimates of the model are presented in Table 6. The baseline version of the model is presented in the second column for comparison purposes, while an augmented model, including sector fixed effects, is presented in the third column (equation (1)).

<< Table 6 around here >>

The estimates of the coefficients do not vary in sign, significance or magnitude with the introduction of sector fixed effects. For our discussion, we focus on the results of the complete model, i.e. the third column coefficients in Table 6.

The probability that business enterprises enhance the energy efficiency of their operations is positively associated to the energy price, ***EPrice***, but the relationship is not statistically significant. However, there is a positive and significant association, at the 10% significance level, between ***EET*** and the energy expenditure share, ***EES***. Considering the relationship between the energy expenditure share, energy intensity and energy prices (see Section 3), it can be argued that more energy intensive enterprise classes are more likely to undertake an EET in response to an increase in energy prices, other things being equal. Our results also show that enterprise classes operating in business contexts characterized by stringent environmental regulations are more likely to commit to EET, other things being equal, as the coefficient of ***RegString*** is positive and significant at the 1% significance level. On the other hand, our findings also reveal that society's attentiveness toward environment conservation, i.e. a contextual driver traditionally neglected in EET studies, ***PubAtt***, does not spur the business sector EET to any significant extent. Countries with stakeholders that demand environmental stewardship do not appear to differ significantly from less attentive societies.

When considering the estimates for the control variable coefficients, we confirm that a small size acts as a barrier to EET. When ***Size*** is equal to 1, i.e. when an enterprise class is populated by larger firms, it is more likely to perform innovation with an EET content at the 5% significance level. We have also controlled the general propensity to innovate through ***PrInn***, and have found a positive and significant association between this variable and EET, at the 1% significance level. This comes as no surprise, because the EET numerator counts all the class enterprises that enhance energy efficiency through various kinds of innovation, including process innovations. Finally, enterprise classes belonging to different sectors show a different probability of undertaking EET. Industry, construction and transportation enterprises are significantly more likely to improve the energy efficiency of their operations than service enterprises or energy utilities, other things being equal.

4.1. Simulations of the EET model

A central part of the analysis consists of simulations that illustrate how different the $\boldsymbol{EET}$ efforts undertaken by a class of enterprises may be, depending on the business context in which it operates. For this purpose, a credible variation, i.e. a difference that could be observed between the countries in the sample, is given to each contextual factor, i.e. electricity price, regulation stringency and public attentiveness, while all the other external and internal drivers are kept constant at their sample mean.

Owing to the fact that $\Delta\boldsymbol{EET}$ varies with the energy intensity of the enterprise class **(see the equation (2) in** Section 3.3), the response to ***EPrice*** can be simulated under different energy intensity scenarios. Specifically, in order to approximate the maximum and minimum ***EI*** values, ***EPrice*** is kept at its mean value, and we assigned its maximum and minimum observed values ($\mathrm{EI_{high}} = {}^{2.606}/_{0.066}$; $\mathrm{EI_{low}} = {}^{0.0001}/_{0.066}$; Table 4) to the ***EES*** variable. Table 7 reports the results of the EET simulations.

<< Table 7 around here >>

The simulations illustrated in Table 7 help us discuss the role of business contexts in driving EU enterprises to undertake EET. For example, let us consider two groups of SMEs (or larger enterprises) that are very similar in all respects. They are located in two EU countries that are very similar as far as energy prices and society's attitude toward the environment are concerned, yet differ to a reasonable degree in terms of stringency of regulations. The probability of EET for the enterprise group located in the country with a greater regulation stringency is 28.9% greater than the probability of EET of the other group (1% significance level). However, if the same class of enterprises is located in two national contexts that only differ in terms of energy price or society's alertness their EET does not differ significantly. Now let us consider two groups of enterprises that are very similar as far as energy intensity is concerned (for instance, owing to differences in plant obsolescence). They are located in two EU countries that differ degree in terms of energy prices. If the enterprise group is located in the country with the higher energy prices, EET probability is 7.2% greater than the EET probability of the other group.

4.2. Robustness checks

In order to check the robustness of the results in Tables 6 and 7, we first calculated the Variance Inflation Factors (VIF) of the independent variables used in the models, as a correlation between independent variables can lead to multicollinearity concerns. All the VIF tests yield relatively small VIF values, which implies that multicollinearity does not affect the analysis to any great extent.

We then perform robustness checks in which different measures model the same underlying concepts. First, we estimate an alternative model specification that accounts for differences in electricity prices between business enterprises located in the same country but belonging to different consumption classes, because the electricity price varies across consumption levels within single EU countries. *EPricePerSize* is an electricity price indicator that differs between small, medium and large consumers in each EU country. We sourced it from the dataset on international industrial energy prices of the UK's Department for Business, Energy and Industrial Strategy, and averaged it over the 2003-2005 period. The correlation between the original proxy (*EPrice*) and the alternative one (*EPricePerSize*) is expectedly high (r = 0.779). The new indicator of electricity price introduced the need to split each small-medium enterprise class in two new classes. The CIS-VI microdata are still grouped by country, sector and size, but now they are assigned to 3 size classes, i.e. small (49 or fewer employees), medium (number of employees ranging from 50 to 249), and large enterprises (250 or more employees). New *EET* and *PrInn* variables are constructed accordingly, and the new sample counts 404 observations. The model now controls unobservable differences between small and medium enterprises, because *SizeS*, *SizeM* and *SizeL* binary variables capture size fixed effects for small, medium and large firms, respectively.[10] Estimates of the more nuanced electricity price models are presented in Table 8 (columns 1 and 2). The *EPricePerSize* coefficients are similar to the *EPrice* coefficients in the main analysis (Table 6), as to magnitude, sign and significance, nor the other parameters vary significantly.

Second, we perform a set of robustness checks regarding public attentiveness. We first estimated a model that describes society's alertness through the European Value Survey (EVS) measure of the environmental activism of communities (*EnvAct*),[11] instead of the more general concept of public attentiveness toward the environment (though the correlation between the two proxies is relatively high and significant, r = 0. 354). As suggested by previous studies, stakeholders exert greater pressures on companies toward the solution of environmental issues, if the number of community members who are aware of the issue and have propensity for collective action is larger (Delmas and

[10] We introduced firm size classification in line with the other related works (e.g. Trianni and Cagno, 2012). Firms with 49 or fewer employees are considered as small enterprises (*SizeS*), firms with 50 to 249 employees are considered as medium (*SizeM*), while firms with 250 and more employees are considered as large enterprises (*SizeL*).

[11] European Value Survey (EVS) 2008 is a wave of the EVS research project on human values in Europe.

Toffel, 2004). The results (see Table 8, columns 3 and 4) show that the *EnvAct* coefficient preserves the same sign and significance level as the core indicator (*PubAtt*, Table 6), while the other coefficients remain almost unchanged, corroborating the finding that environmental attentiveness and activism in society are not significant drivers of firms' EET.

<< Table 8 around here >>

Finally, we also construct a new proxy that is focused on the term *"energy"* instead of *"environment"*, again from Google Trends and in local languages (based on EuroVoc). The alternative indicator is significantly correlated to the original one (r = 0.407). Moreover, we combine the two proxies by means of factorization, and create an index that is likely to summarize the meanings that underlie the two words, and to capture most closely the targeted concept (i.e. attentiveness toward natural resources and the environment). The estimates obtained with either of the two proxies or the index yield results very similar (available upon request).

5. Discussion and policy implications

The research presented in this paper shows that different business contexts have a different potential for the energy efficiency transformation (EET) of enterprises. This result has been obtained through an analysis of a sample of EU enterprise classes, both SMEs and larger enterprises, belonging to 9 EU countries and 21 industries. The business contexts have been represented by three factors that vary to a great extent across the observed EU countries: stringency of regulations, energy price and society's alertness toward environment conservation.

A thorough discussion of the empirical findings is necessary to highlight the contribution of the paper to the existing research on energy efficiency in business enterprises.

The enterprise classes that are located in the EU countries with more stringent regulations have been shown to be significantly more likely to undertake EET. Simulations of a realistic difference in regulation stringency between EU countries, i.e. 0.684 on a 1-7 scale, have shown that more stringent regulatory environments benefit from a more sizeable diffusion of EET across enterprises. In this scenario, the enterprises that are located in the country with looser regulations are 29% less likely to improve the energy efficiency of their operations than the enterprises facing more severe regulations, other things being equal. Our results are in line with the view of enterprises presented in other studies. Veugelers (2012) finds that Flemish firms respond to energy regulations that are persistent over time, and persistence is a component of our construct, namely regulation stringency. Trianni et al. (2016) show that external regulations are a critical driver for Italian manufacturers, and are likely to trigger a behavioral change in smaller and less energy intensive enterprises. Other studies return a dimmer picture of the role of regulations (e.g. Horbach et al., 2012; Martin et al., 2012; Costa-Campi at al., 2015). Nevertheless, all these analyses are single-country, while we measure regulation stringency across very different countries. In other words, our model can exploit a greater variation in regulatory contexts. We believe that our paper contributes to the debate on the influence of regulations by showing that incremental changes in the stringency of regulations are unlikely to cause a more intensive EET of business enterprises. More radical reforms are necessary to this aim.

Second, the differences in EET due to a variation in energy prices are not significant, other things being equal. Our finding is at odds with a few contributions according to which EET activities are more likely in enterprises that face an energy price increase. A first possible explanation is a methodological limitation of our study, i.e. longitudinal data are necessary to appraise the role of energy prices (as, for instance, in Popp, 2001), while our data are cross-sectional. In spite of this problem, we believe that our results deserve consideration, for a few reasons. We use a cross-country sample, i.e. we are in the position to verify the effect of large differences in the economic environment. We also use an objective indicator for energy price, while other analyses proxy the presence of economic incentives through perceptual measures (Horbach et al., 2012; Trianni et al., 2016). Co-occurring differences in energy intensity could also explain the slight influence of energy prices, as we found that only enterprise groups that are highly energy intensive and undergo high energy expenditures are likely to respond to high energy prices through EET. The lack of sensitivity to energy price could also be related to the limited presence of new entrants, who have been found to be more responsive to economic incentives to EET (Linn 2008). Other explanations, which will be discussed in the remaining part of the section to highlight a policy proposal, are information asymmetries about energy costs or behavioral biases that affect the management of a firm. We conclude by now that our results suggest to be cautious about the effectiveness of economic incentives as EET mechanisms.

Finally, the paper has raised a question on another contextual factor, namely, society's alertness toward environment conservation, a case that has so far been somewhat neglected in EET research. Neither the main econometric analysis nor the additional robustness checks have found any evidence of a great influence of public attentiveness and activism on EET. Even enterprises that operate in countries with an aware and influential society appear unlikely to consider EET as a pure legitimization instrument, i.e. a strategy to build their own "energy-saver" reputation. We think that the last result is a small yet interesting contribution to the existing research on environmental innovation and legitimization (Khanna and Damon, 1999; Brunnermeier and Cohen, 2003; Kassinis and Vafeas, 2006). Section 2.1). The pressure of stakeholders is no guarantee of the diffusion of EET activities. Activists and the general public can spot the effects of replacing polluting or noxious technologies with cleaner systems, but they may fail to notice the consequences of resources-efficient innovations, e.g. EET.

Although we are aware that further efforts are necessary to both measure regulatory pressures more precisely and to increase the understanding on the possible contingencies that may moderate the impact of contextual factors on EET, we also believe that the present analysis introduces some interesting implications for policies. In fact, Section 2 synthesized the recent and current EU energy efficiency policies that have a possible influence on business EET, and have classified them following Tanaka (2011) (Table 1). The discussion of the empirical results has provided us with a few insights into the actual potential of current policy measures. In light of this, it is possible to formulate a few recommendations for the EU governments that are committed to appraising and updating their action plans.

First, our estimates show that regulatory stringency is the single most influential driver of EET. We recommend to strengthen the *prescriptive* elements of the EED. Provisions such as the assignment of binding targets to an obligated party and mandatory audits for larger enterprises are likely to have a greater impact on EET than *economic* and *supportive* measures. The relative weakness of *prescriptive* elements in the as now repealed ESD (Section 2), combined with the weaker perception of regulatory stringency for certain EU countries, could help explain the slower than expected progress toward business EET in certain countries and industries. Furthermore, the EED establishes that independent parties should monitor, control and verify the operation of obligation schemes and the implementation of audits in larger enterprises. Finally, EU policymakers should acknowledge that *prescriptive* provisions may not be sufficient to spur the diffusion of EET efforts. It is their stringency that influences enterprises. In other words, the persistence and credibility of regulations covered by the National Energy Efficiency Action Plans are critical elements for the success of EED.

Next, we have found that the majority of EU business enterprises do not appear to undertake EET in response to high energy prices, even though a reaction is more likely in the presence of highly energy-intensive operations. A few reflections can be made on the basis of this finding.

Energy and/or climate taxes are *economic* measures (like prices) that are often used as an alternative to obligation schemes to fuel virtuous conduct among the end-users. The present analysis suggests that they could prove to be ineffective. We have not investigated the reasons why prospect cost savings fail to incentivize EET in the business sector, but a few hypotheses and suggestions can be made with the aim of putting forward policy proposals.

- If information problems are at the origin of the energy efficiency gap, appropriate EED *supportive* measures could spur EET. Instruments such as energy audits or new billing and metering systems inform business enterprises about their energy consumption and expenses. An alternative *supportive* approach pertains to the EED measures that can relax the cognitive biases of end-users, such as programs aimed at spurring the behavior changes of smaller customers.

- National policymakers should monitor the effect of the *supportive* instruments on the different classes of enterprises, including less energy-intensive ones. Governments of EU countries that suffer from higher energy prices should analyze the evolution of energy consumption, on a recurring basis and micro level.
- Our findings do not offer insights on the validity of alternative *economic* EED measures, such as subsidies toward audit-related costs for SMEs, or fiscal incentives that promote the participation of SMEs in information programs. Since they provide enterprises with benefits that are not conditional to energy savings, it is unclear whether they are affected by the unresponsiveness of users. Also in this case, however, National Plans should contemplate the introduction of monitoring and assessment rounds. More particularly, the impact of subsidies and fiscal measures has to be evaluated on a recurring basis to decide on their additionality, and to verify the actual responsiveness of enterprises.

A few final reflections can be made concerning voluntary agreements. The effectiveness of this policy measure is put at risk by the weakness of linkages between society's alertness and EET. Voluntary environmental agreements can be typified as *prescriptive* or simply *supportive*, on the basis of different details in agreements, such as the stringency of obligations, the accountability of monitoring, and the degree of government sponsorship (Prakash and Potoski, 2012). On the one hand, the compelling components of agreements should not be dismissed. On the other hand, EU countries that can capitalize on the environmentalism of citizens should assess the design details in order to make the energy efficiency of participating enterprises more apparent.

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Tables

Table 1 EU policy measures for business EET: a typology.

	Description	Prescriptive [a]	Economic	Supportive
Energy saving target	Overall performance obligation	X		
Obligation scheme	Designated parties	X		
	Energy services; Trade of certified savings		X	
Alternative measures	Energy or carbon taxes; Financial incentives		X	
	Regulations	X		
	Training, education and advise			X
	Voluntary agreements	X		X
Audits and EMSs	Large enterprises	X		X
	SMEs		X	X
Metering and billing information	Information on actual consumption; Information on actual time of use			X
Information programs	Support to behavioural change of small customers		X	X

[a] Binding provisions under the EED, Indicative provisions or discretionary instruments under the ESD.

Table 2 Criteria for grouping data.

Country	*Industry (NACE Rev. 2 classification)*		*Size class*
• Czech Republic	• B	Mining and Quarrying	• Small and Medium enterprises (<250 employees)
• Germany	• C10-C12	Manufacture of food products, beverages and tobacco products	• Large enterprises (>= 250 employees)
• Estonia	• C13-C15	Manufacture of textile, wearing apparel, and leather and related products	
• Hungary	• C16-C18	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials, paper and paper products; Printing and reproduction of recorded media	
• Ireland	• C19-C23	Manufacture of coke and refined petroleum products; Manufacture of basic pharmaceutical products and pharmaceutical preparations; Manufacture of rubber and plastic products; Manufacture of other non-metallic mineral products;	
• Italy	• C24-C25	Manufacture of basic metals and fabricated metal products, except machinery and equipment	
• Latvia	• C26-C30	Manufacture of computer, electronic and optical products; Manufacture of electrical equipment and machinery and equipment; Manufacture of motor vehicles, trailers and semi-trailers; Manufacture of other transport equipment;	
• Portugal	• C31-C33	Manufacture of furniture; Other manufacturing; Repair and installation of machinery and equipment;	
• Slovakia	• D	Electricity, gas, steam and air conditioning supply	
	• E	Water supply; Sewerage, waste management and remediation activities	
	• F	Construction	
	• G	Wholesale and retail trade and repair of motor vehicles and motorcycles	
	• H49-H51	Land transport and transport via pipelines; Water and air transport	
	• H52-H53	Warehousing and support activities for transportation; Postal and courier activities;	
	• I, J	Accommodation and food service activities; Information and communication	
	• K	Financial and insurance activities	
	• L	Real estate activities	
	• M69-M70	Legal and accounting activities; Activities of head offices; Management consultancy activities	
	• M71-M73	Architectural and engineering activities; technical testing and analysis; Scientific research and development; Advertising and market research	
	• M74-M75	Other professional, scientific and technical activities; Veterinary activities	
	• N	Administrative and support service activities	

Table 3 Description of variables.

Variable	Description	Data Source
EET	Percentage of the class enterprises that introduced EET in 2006-2008	CIS-VI Dataset
EPrice	Electricity price of the country, averaged over the 2003-2005 period; [EUR/kWh]; standardised (mean=0, st.d.=1)	Eurostat Energy statistics
EES	Energy expenditure share, observed in 2005; standardised (mean=0, st.d.=1)	EU Klems Dataset
RegString	Stringency of environmental regulations of the country, averaged over the 2003-2005 period; scale [1-7]; standardised (mean=0, st.d.=1)	Global Competitiveness Reports
PubAtt	Public attentiveness toward energy in the country, in 2004-2006 period; standardised (mean=0, st.d.=1)	Google Trends
PrInn	Percentage of the class enterprises that introduced process innovation in 2006-2008	CIS-VI Dataset
Size	Dichotomous variable which equals 1 if the class enterprises are LEs (firms with 250 employees or more)	CIS-VI Dataset

Table 4 Descriptive statistics.

Variable[a]	Obs	Mean	Std. Dev.	Min	Max
EET	256	0.303	0.182	0.019	0.846
EPrice	256	0.066	0.013	0.040	0.084
EES	256	0.216	0.406	0.000	2.606
RegString	256	5.066	0.684	4.15	6.7
PubAtt	256	20.576	15.935	0	55.025
PrInn	256	0.440	0.188	0.085	1
Size	256	0.396	0.490	0	1

[a] Variables before standardization.

Table 5 Correlation matrix.

Variable[a]	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1 EET	1						
2 EPrice	0.198 (0.001)	1					
3 EES	0.116 (0.062)	-0.058 (0.354)	1				
4 RegString	0.351 (0.000)	0.304 (0.000)	-0.055 (0.376)	1			
5 PubAtt	0.132 (0.030)	0.206 (0.000)	0.009 (0.876)	-0.132 (0.030)	1		
6 PrInn	0.435 (0.000)	0.138 (0.024)	0.048 (0.439)	0.060 (0.323)	0.228 (0.000)	1	
7 Size	0.686 (0.000)	0.130 (0.033)	0.048 (0.444)	0.133 (0.030)	0.129 (0.035)	0.601 (0.000)	1

[a] Variables before standardization.

Table 6 GLM estimates of the core model.

Independent Variables	*Baseline model* [a]	*Complete model* [a]
EPrice	+0.012 +(0.059)	+0.005 +(0.055)
EES	+0.069 ** +(0.033)	+0.057 * +(0.033)
RegString	+0.278 *** +(0.067)	+0.289 *** +(0.067)
PubAtt	+0.032 +(0.055)	+0.049 +(0.059)
PrInn	+1.663 *** +(0.292)	+1.402 *** +(0.369)
Size	+0.161 ** +(0.071)	+0.221 ** +(0.086)
DInd		+0.424 *** +(0.050)
DConst		+0.333 ** +(0.151)
DTransp		+0.236 *** +(0.051)
DEnutil		+0.132 +(0.129)
Constant	−2.766 *** +(0.412)	−3.000 *** +(0.406)
Number of observations	+256	+256

[a] Robust standard errors are shown in parenthesis; * p<0.1, ** p<0.05, *** p<0.01.

Table 7 Simulations of EET responses to contextual factors. [a]

Business context	***Enterprise class***	***ΔEET*** [b]
	Energy intensity	
Higher energy price	Maximum value	0.077 (0.076)
	Minimum value	0.005 (0.055)
	Difference	0.072 * (0.042)
Greater regulation stringency	Mean value	0.289 *** (0.067)
Greater society's alertness	Mean value	0.049 (0.059)

[a] Simulations are based on Complete model estimates of Table 6.
[b] Robust standard errors are shown in parenthesis; * p<0.1, ** p<0.05, *** p<0.01.

Table 8 GLM estimates of alternative models.

	Baseline price per size class model [a,b]	*Complete price per size class model* [a,b]	*Baseline environmental activism model* [b]	*Complete environmental activism model* [b]
EPrice			0.032 (0.094)	0.020 (0.092)
EPricePerSize	0.043 (0.108)	0.053 (0.116)		
EES	0.117 ** (0.055)	0.081 (0.052)	0.093 * (0.047)	0.077 (0.048)
RegString	0.441 *** (0.114)	0.478 *** (0.118)	0.389 *** (0.102)	0.428 *** (0.105)
PubAtt	0.050 (0.087)	0.065 (0.090)		
EnvAct			0.020 (0.118)	0.028 (0.121)
PrInn	2.450 *** (0.406)	2.284 *** (0.455)	2.727 *** (0.407)	2.437 *** (0.486)
Size			0.265 ** (0.107)	0.341 ** (0.135)
SizeM	0.253 * (0.147)	0.290 * (0.157)		
SizeL	0.456 *** (0.161)	0.511 *** (0.170)		
DInd		0.839 *** (0.098)		0.763 *** (0.104)
DConst		0.394 (0.285)		0.585 ** (0.233)
DTransp		0.706 *** (0.260)		0.473 *** (0.106)
DEnutil		0.532 *** (0.114)		0.242 (0.284)
Constant	-4.498 *** (0.692)	-5.197 *** (0.680)	-4.196 *** (0.698)	-4.790 *** (0.696)
Number of observations	404	404	256	256

[a] Business enterprises are grouped over 3 size classes (corresponding to small, medium and large enterprises); small enterprise (*SizeS*) are used as a baseline.
[b] Robust standard errors are shown in parenthesis; * p<0.1, ** p<0.05, *** p<0.01.